Science on the Edge: The Story of the Coast and Geodetic Survey from 1867-1970

by

John Cloud

The Wake of the Civil War

The Coast Survey/Coast and Geodetic Survey was a profoundly civilian institution, but it was mobilized and transformed by every war its personnel participated in. The first of these, which set the pattern for all the rest, was the Civil War.

It is clear from analysis of the changes in Coast Survey work and movement of personnel that, for the Survey, participation in the oncoming war began in about 1857 or 1858. It is also clear that the structure and approaches of the post-war Survey can be seen long before the end of the war in 1865, in the new instruments, approaches to work, printing techniques and modes of map distribution, and other changes to the Survey and its staff during the war.

The major work and major stories of the Survey in the Civil War are addressed in great detail elsewhere.[1] The purpose of this chapter is different; rather than re-telling the stories of how the Survey fought specific battles scientifically, it addresses how the Survey and its personnel came out of the war changed by the experiences and the challenges mastered to survive and win the battles.

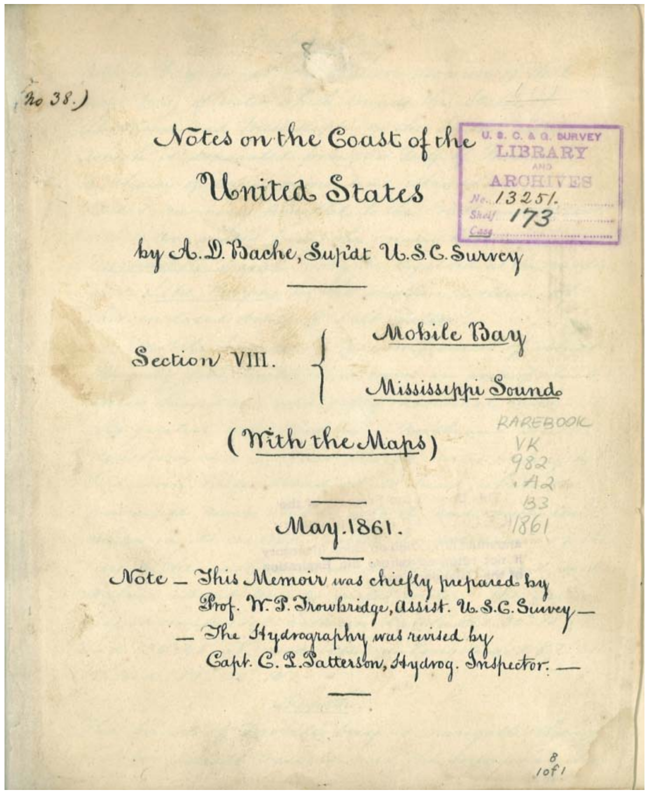
Anticipation of the War

By 1858, Superintendent Bache had positioned the Survey for the coming war. Survey personnel were to be re-assigned and moved to the areas where the war most likely would be fought. Bache anticipated that the war would not be fought on the Pacific coast, and he ordered almost all field operations along that coast to end. As a result, there is a decade or so, roughly 1858 to 1868, in which no field surveys were completed to the point of registered t-sheets, as is evident in the analysis of t-sheet frequencies made by staff from the San Francisco Estuary Institute.[2]

The initial emphasis of the immediate pre-war period was the coastal waters, harbors, passages, and hazards to navigation offshore from the southern slave-holding

[1] See Theberge The Coast Survey 1807-1867.
[2] Grossinger, Robin, et al., 2009. Historical Wetlands of the Southern California Coast: An Atlas of US Coast Survey T-sheets, 1851-1889.The names listed on the graph are those of the Survey assistants who "signed off" on the t-sheets registered that year. There were no t-sheets registered between 1859 and 1869.

states. As Survey personnel traveled to and around the Atlantic and Gulf coasts, they familiarized themselves with both the traditional issues of concern in coast-wise navigation, and also newer, more strategic matters related to the possible defense or invasion of the same harbors and passages.


(No 38.)

Notes on the Coast of the
United States
by A. D. Bache, Supdt U.S.C. Survey

Section VIII. { Mobile Bay
Mississippi Sound

(With the Maps)

May. 1861.

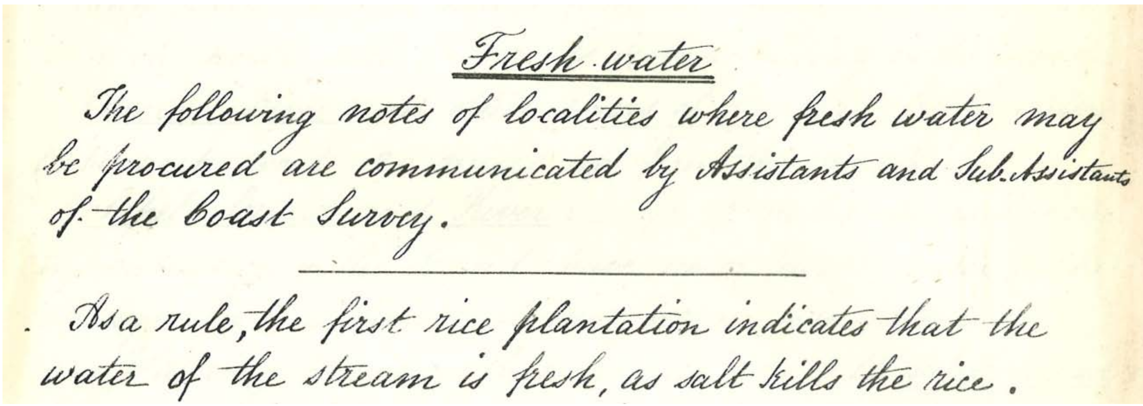
Note — This Memoir was chiefly prepared by
Prof. W. P. Trowbridge, Assist. U.S.C. Survey —
— The Hydrography was revised by
Capt. C. P. Patterson, Hydrog. Inspector. —

Title Page of one of the 12 volumes of the Notes on the Coast

"Notes on the Coast"

These new insights were later codified in the series of memoirs called the "Notes on the Coast", which were soft-cover books with attached folded maps, in 12 volumes, from Delaware Bay to the Mississippi Sound, created for the use of the Union blockading squadrons. The Notes on the Coast combined aspects of the Blunt family's American Coast Pilots, with sailing directions and detailed descriptions of likely conditions and possible actions to be taken to arrive and depart from specific bays and harbors, along with much more specifically military-oriented information about the strategic significance of different coastal features and harbors, relationships to railroad lines, and the like. The Notes were written in clear cursive writing, not type-set, and were lithographed at the Coast Survey's office, which allowed them to bypass the spy-ridden Government Printing Office. Each volume contained 8-12 or more folded maps, combining regionally scaled sailing direction charts, diagrams to wind patterns and tidal patterns, and harbor and nautical charts for the area in question. The charts were all lithographs, derived by photographic transfer from copies of original engraved charts.

Each of the 12 volumes was produced as, essentially, a ‘paperback’ without hard board covers, making them easy to protect and conceal under a coat. In vivid, succinct language, they attempted to convey the essence of southern coastal geography to Yankee blockaders who were likely encountering the south for the first time.


Fresh water

The following notes of localities where fresh water may be procured are communicated by Assistants and Sub-Assistants of the Coast Survey.

As a rule, the first rice plantation indicates that the water of the stream is fresh, as salt kills the rice.

The Notes on the Coast were uniquely new, but would also set the pattern for major transformations in Coast Survey work for decades after the war.[3] On every subsequent military mobilization, the civilian Survey would transform itself and all of its activities to fight the next war scientifically.

And Then the War Came

The Civil War was fought on battle fields and harbors, but also in houses and taverns and public squares. It was a political as well as a military campaign unlike any ever seen in American history, but also closely related to struggles over slavery and secession that went back at least a century before the outbreak of war. On the eve of conflict, the Coast Survey published two of the most important battle maps for the coming war. They were battle maps in the same sense that Harriet Beecher Stowe’s novel “Uncle Tom’s Cabin; or, Life Among the Lowly” was a call to arms.

[3] The text only (without accompanying maps) from the 12 volumes of the Notes on the Coast may be accessed at: http://www.nauticalcharts.noaa.gov/nsd/hcp_notesoncoast.html

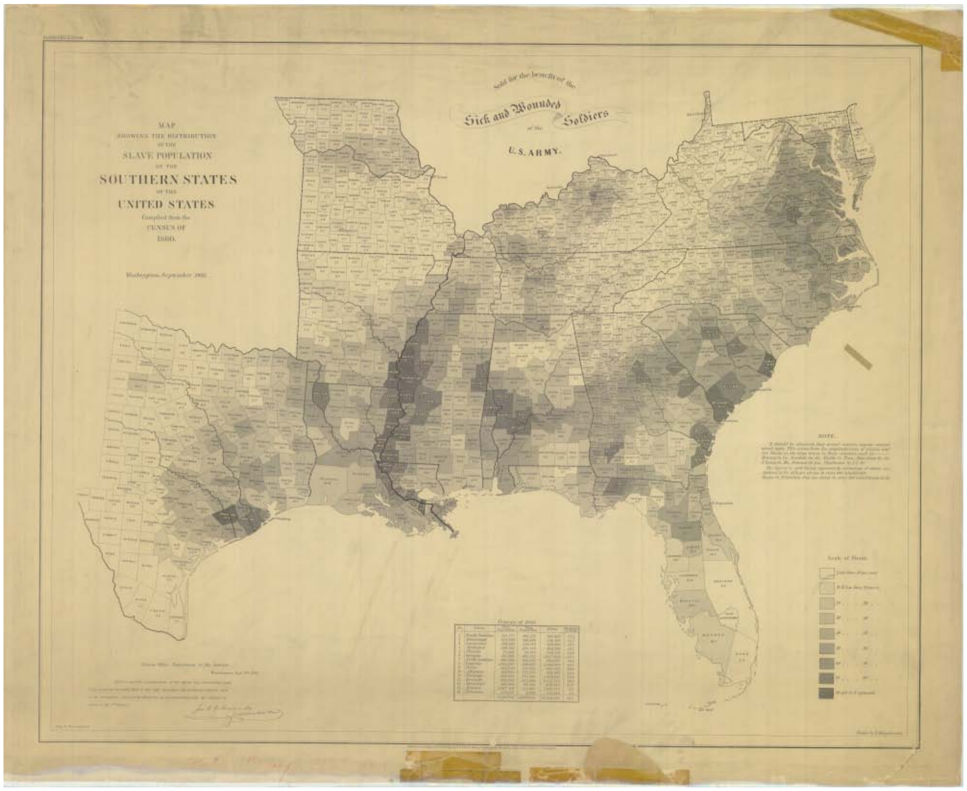


Fig. 1: Map of the Distribution of the Slave Populations of the Southern States
Of the United States compiled from the Census of 1860 (Sept. 1861)
Drawn by Edwin Hergesheimer

The first map, one of two based on data from the just completed Census of 1860, revealed the spatial concentration of slave populations in the slave-holding states.[4] The maps were utterly different from anything the Coast Survey had ever before produced, but were also a prelude to Survey graphics and projects that would extend into the next century and continue in NOAA today, as explicit concerns about society and social policies in Survey practices. The maps were associated with the US Sanitary Commission (of which A.D. Bache was Vice-President) and "Sold for the benefit of sick and wounded soldiers of the US Army".

The maps are also landmarks in the emerging cartographic practices for mapping statistical data, and an important prelude to the Statistical Atlas of the 1870 Census.[5] This enterprise was not designed for the war, and in fact had long preceded it. Superintendent Bache had taken over the Survey in 1843, following Ferdinand Hassler's sudden death. Bache accelerated production of Hassler's first maps of New York Bay and Harbor, but he also developed an entirely new plan for mapping. Many years later, in the 1860

[4] The second map, closely related, showed the slave populations of the state of Virginia, differentiating the counties that were in the process of withdrawing from the Confederate state to form a free state, called Kanawha on the map, later changed to West Virginia.
[5] See Walker, F., 1874

annual report, Bache looked back at an experimental process that had lasted over a decade. As he noted:

> "In 1845 and the years immediately following, the subject of style of drawing and engraving the maps and charts of the Survey were discussed in great detail… Besides, large numbers of maps had been printed, and the criticisms upon them by navigators and others had enlightened us on many doubtful points. The labor, too, of engraving the first class charts in the style adopted had, under the most favorable circumstances, proved greater than was expected. *But above and before all other reasons, photography was to be introduced as a regular part of office detail, and great changes were necessarily consequent.* I determined therefore to have a thorough revision of the whole system; to re-establish approved rules and usages, and carefully to study new ones; to avail ourselves, in short, of the experience acquired in the field and office for a new step in improvement. Assistant H.L. Whiting, whose experience in field topography is greater than that of any other assistant, and whose success in all matters of relating to representations of ground in the field and office is very great, was ordered to the office to study the whole subject."[6] (emphasis added)

The systematic re-evaluation of the entire cartographic process included many elements, but one in particular bears attention. As Bache noted,: "[t]he subject of the scale of shade, by which ground is represented by hachures, was carefully gone over.'[7] Translated into modern terms, the discussion was concerned with systems to convey the form and steepness of slope of hills and terrain, using sets of engraved or incised lines that darkened or lightened in ways to convey the changing slopes graphically. There were a number of major European systems already in use, but these were found insufficiently appropriate, at the extremes of slopes, both very shallow and very steep, to express the changes in terrain as well as Bache and company wanted the maps to do. Under Whiting's direction, Edwin Hergesheimer, one of the most skilled of the draughtsmen in the Survey, who eventually became head of the Drawing Division, executed a series of graphics trials, using the complex terrain around Ipswich, near Cape Ann, Massachusetts, as a test case. Eventually they developed a hybrid scale of shade, which worked for the Survey. "This scale is at once practicable in execution and graphic in effect, and adheres with sufficient closeness to that of the existing maps, avoiding some practical difficulties which experience had developed in representing the lowest and highest slopes".[8]

Thus in 1860, on the eve of war, the Survey had completed a review and improvement of the entire system of cartography as practiced since Bache's arrival. One of the first major applications of the new systems became the adaptation of the new system of hachures to display topographic relief to the new task of political and moral

[6] Bache, 1860 Annual report, pp. 19-20.
[7] Bache, ibid., p. 20
[8] bache, ibid., p. 20

relief, in the display on the slavery populations in the southern states. The system developed to show classes of angles of slope from shallow to steep was adapted to display population proportions in 10% increments. A comparison between the new standardized schematic for "Orographical Design" and the Scale of Shade for the slavery maps, makes the adaptation clear.

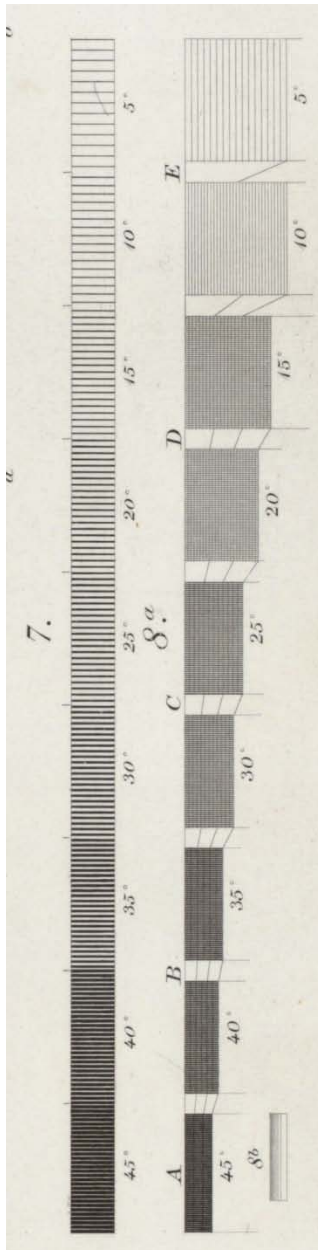


Fig. 2: Elementary Rules for Orographical Design
By J. Enthoffer, Chief Engraver, US Coast Survey[9]

[9] See Enthoffer, 1860

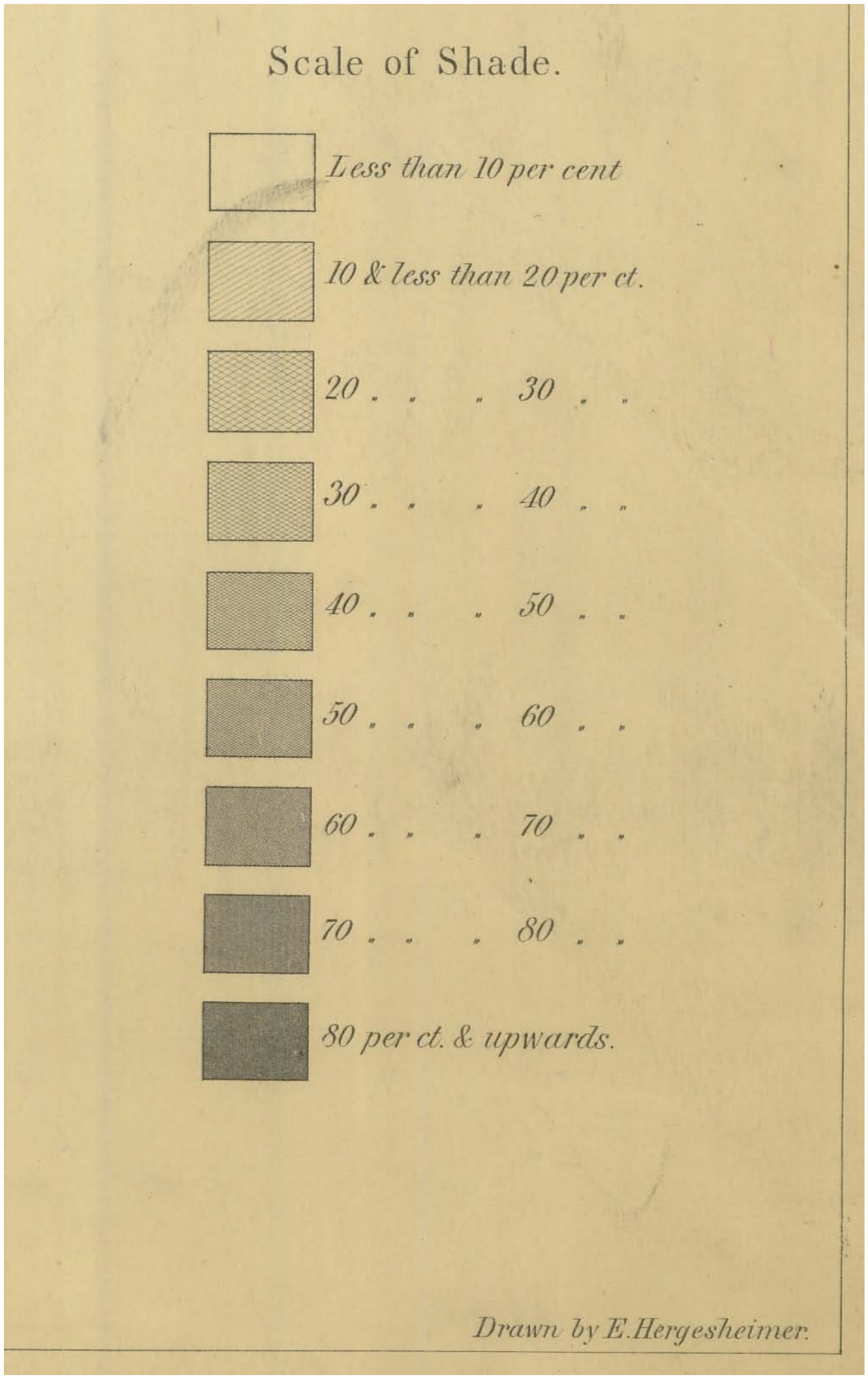


Fig. 3: Scale of Shade, from
Map of the Distribution of the Slave Populations of the Southern States
of the United States compiled from the Census of 1860 (Sept. 1861)
Drawn by Edwin Hergesheimer

The War in the South

As has been noted in Albert Theberge's history of the Coast Survey, a not insignificant aspect of the service of the Coast Survey in the Civil War was that an entire generation of Union Army and Navy officers and personnel had not only been trained in geodesy and surveying from service with the Coast Survey, they had also done this in many of the most critical areas where the later war was fought.[10]

Survey crews accompanied all the major nautical campaigns of the war in the southern states, as fully described in the Theberge history. This had the effect of familiarizing the Survey with river hydrography and riverine surveying. Before the Civil War, the Survey traditionally surveyed the hydrography and associated topography of coastal estuaries and rivers only to the head of tide (which, in the case of the somewhat anomalous Hudson River, was over a hundred miles inland, above Albany, the capitol). During the war, the Coast Survey ascended strategic rivers far inland, fighting their way upriver, on the Mississippi, the Ohio, and, above Chesapeake Bay, the York, Potomac, Rappahannock, James and other Virginia rivers. These rivers were far above the head of tide, with hydrography far different from that of estuaries.

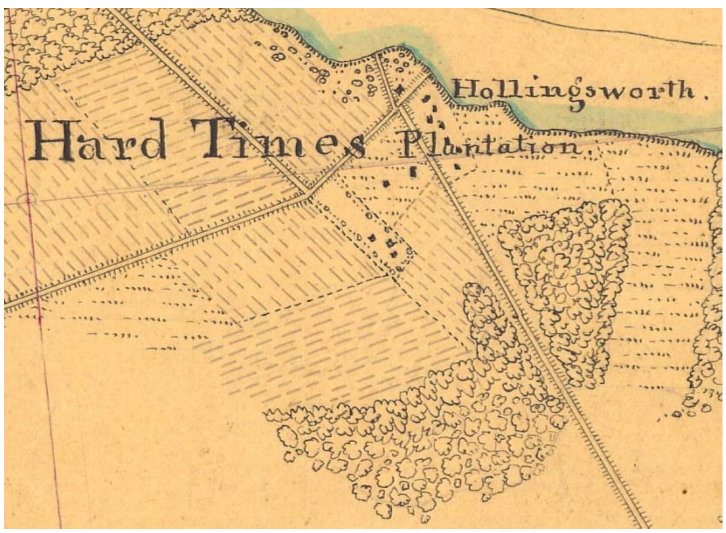


Fig. 4: A small portion of T-1920
Bruinsburg Mississippi to Turners Point Louisiana,
By Ferdinand Gerdes, accompanying Admiral Porter, 1864

The more terrestrial battles of the war in the south had much to do with massing and transporting huge armies and their supplies, with sieges and attacks, with rapid movements and with railroads. In response, the Coast Survey developed unique series of territorial maps derived from a variety of sources. These were unlike any maps the Survey had ever produced in several respects.

[10] See Theberge, Jr., The Coast Survey 1807-1867, p. 491

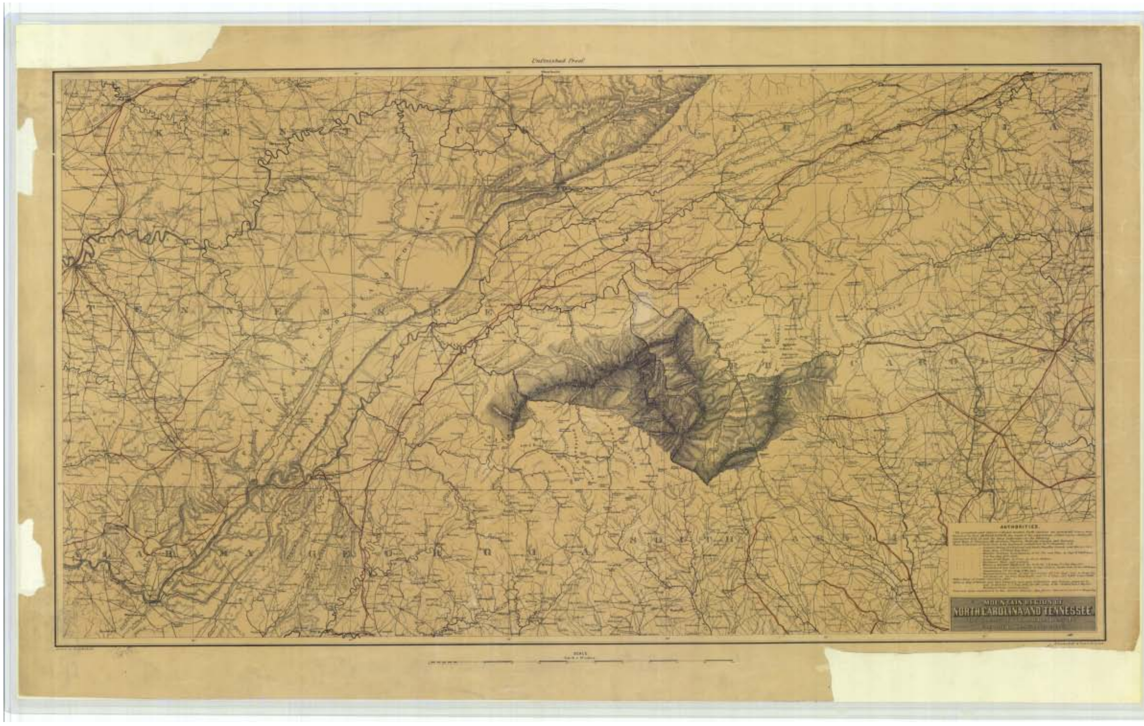


Fig. 5: Mountain Region of North Carolina and Tennessee (1863)

First, they were derived from many sources, including new Survey work, but also incorporating the maps of many other people and institutions (always carefully referencing the sources). For example, the map displayed here particularly singles out cartographically and by reference the central terrain unit with topography derived from Arnold Guyot, the first American academic geographer and geologist, who worked closely with the Survey. Second, the individual maps appear to have been developed from a very large cartographic base (as we would call it now) of contiguous material from the Atlantic coast inland as far east as Mississippi and Missouri. As the war was prosecuted, and campaigns moved about, different sections of the cartographic base were produced and printed as needed. Third, the maps were multi-colored chromo-lithographs, using standardized conventions and colors for terrain, roads, railroads, hydrology, and other critical features. Fourth, the maps were produced and distributed in ways never before used by the Survey. In 1861, the Survey created an entirely new division, the Lithographing Division, "which was organized two years ago as a measure of necessity to meet the largely increase demands for charts".[11] Bache hired W.L. Nicholson, a very experience chromo-lithographer and map distributor, to form the new department within the traditional cartographic shop of the Survey.

The War in the Cities

The maps the Survey produced and distributed included those designed primarily for military use, and also maps produced for general public use, to allow citizens to follow the progress of the war as the campaigns fought on. These latter maps featured

[11] Bache, A.D., 1863. Annual Report, p. 60

concentric bull's eye rings around Richmond, Virginia and Washington, DC to assist citizens calculating distances.

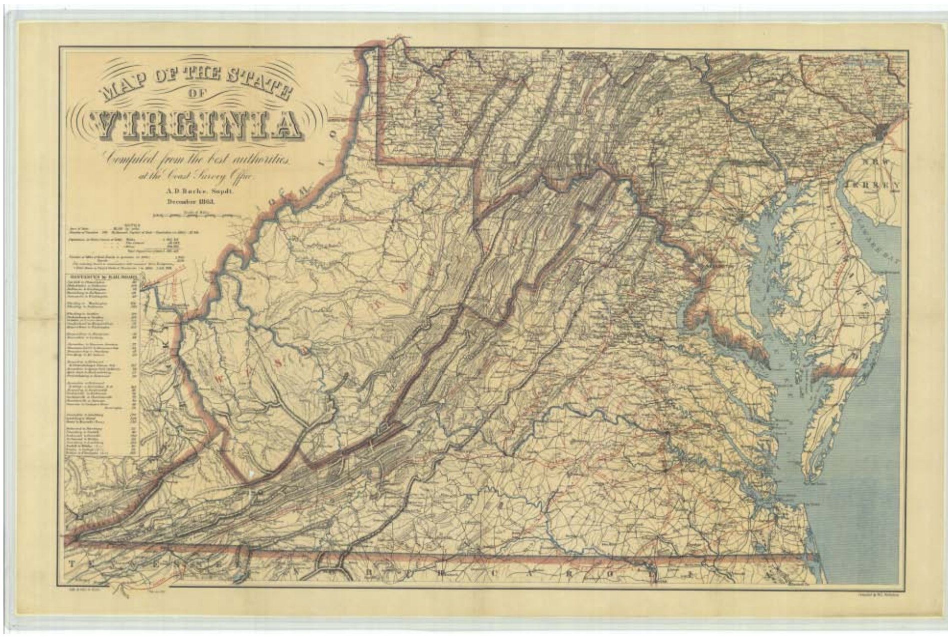


Fig. 6: Map of the State of Virginia, 1863

The utility and iconic status of these Coast Survey maps for the Union war effort is captured in Francis Carpenter's painting of 1864, which hangs in the Senate wing of the US Capitol, of Abraham Lincoln preparing to read the Emancipation Proclamation to his cabinet for the first time. Both maps in the painting were produced by the Coast Survey.

Fig. 7: First Reading of the Emancipation Proclamation
by F.B. Carpenter, 1864

The War in the North

While most attention has been focused on Survey personnel and their work in the areas where the war was actively fought, the Survey was also very active in hydrographic and topographic surveying in the northern parts of Chesapeake Bay, in Delaware Bay, and in various critical harbors during the duration of the war. In part, especially during the period that Philadelphia was threatened by Confederate attack, the surveying was a part of major preparations for defense against attack.

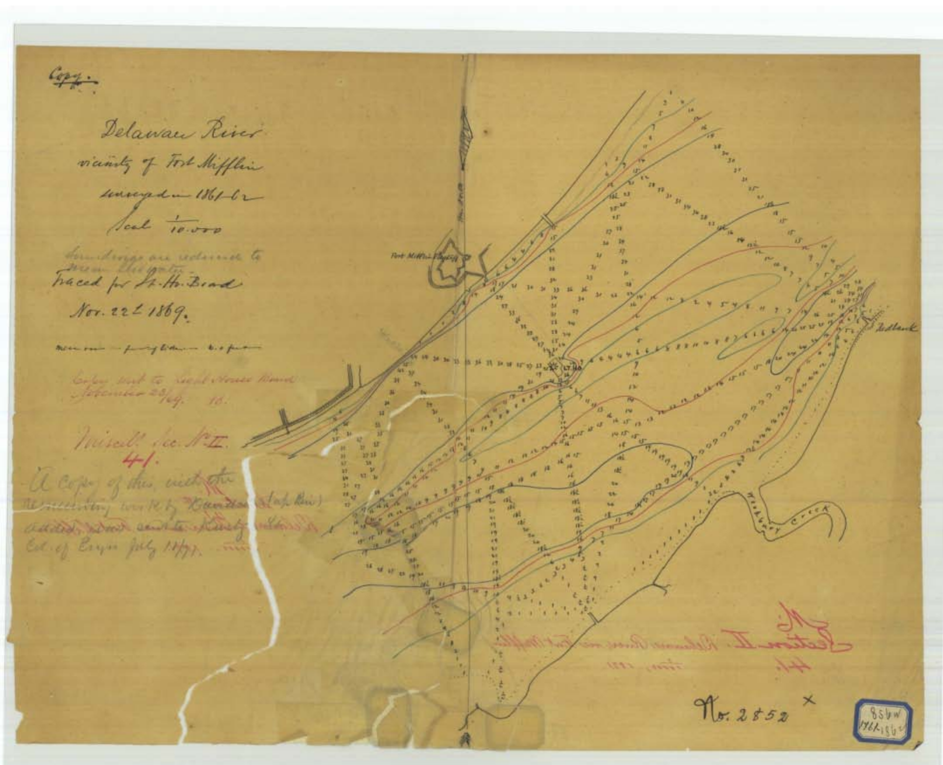


Fig. 8: Delaware River, Surveys in the Vicinity of Fort Mifflin, 1861-62

Elsewhere, Survey work was dedicated to accommodating increased demands on northern ports and supply systems for war materials and passage of goods and people. There was also complex civil unrest in the north. In July of 1863, the New York City draft riots began, the largest and most deadly civil disorder in American history. Several months previous to that, Ferdinand Gerdes, in between assignments with Admiral Porter, headed a Survey team which extended the Survey topographic surveys of Manhattan begun in the 1840s, with updated color codings on a special copy of the Manhattan t-sheet, to code different patterns of urban development underway on the island. It is unclear what Gerdes assignment, "to show the current state of improvements in the City" might have to the social relations in the north at the time, but it is, again, an example of Survey personnel working on projects and themes unlike those they had done before the war.

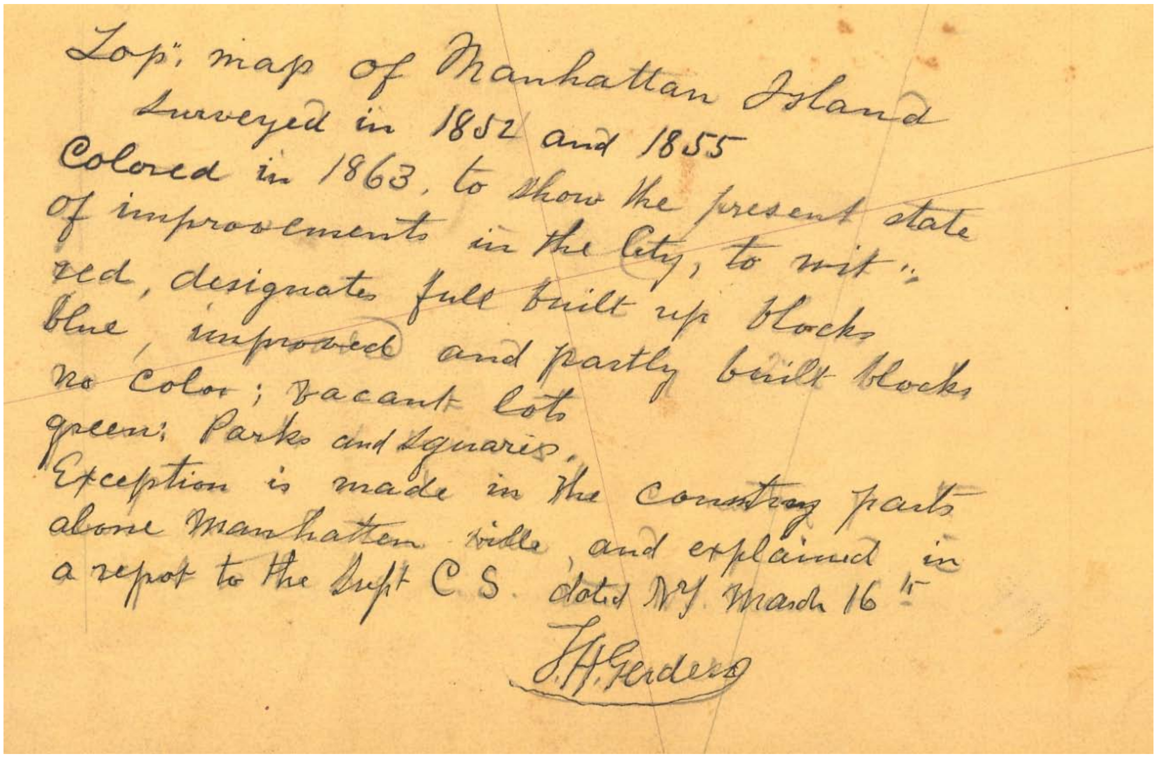

Top: map of Manhattan Island
Surveyed in 1852 and 1855
Colored in 1863, to show the present state
of improvements in the City, to wit:
red, designates full built up blocks
blue, improved and partly built blocks
no Color; vacant lots
green: Parks and Squares.
Exception is made in the country parts
above Manhattan ville, and explained in
a report to the Supt C.S. dated N.Y. March 16th
F.H. Gerdes

Fig. 9: T-475B, Island of Manhattan (1863)
Annotation by Ferdinand Gerdes

At the same time, there were also projects that extended pre-war work. These included the progressive extension of very precise determination of longitude through the Survey's telegraphic methods. Telegraphic longitude observation points generally correlated with railroads, as telegraph lines were laid in conjunction with and alongside railroad lines. And, since railroads correlated closely with Union and Confederate armies and territories held, telegraphic progress westward was closely associated with the fortunes and progress of the Union armies. By 1865 and the end of the war, the telegraphic longitude lines had reached the Mississippi River, at St. Louis in the north, and New Orleans in the south.

The eastern extension of the telegraphic longitude lines was another story completely. American telegraph lines were connected at the Maine border to Canadian telegraph lines extending to ports on the eastern coast of Newfoundland. From there eastward was the Atlantic Ocean and then the British Isles. The major ultimate goal of American telegraphic longitude was to connect the American system to the British system and the Prime Meridian at Greenwich, via a functioning Trans-Atlantic Cable. This made the Survey's progress intimately associated with the problems of the many attempts at a functioning cable system. A major associate of the Survey in this effort was Benjamin Apthorpe Gould, then a mathematician and astrophysicist at Harvard

University, who had already had a long and complex association with the Survey.[12] Gould worked first at the Irish end of the cable, and later at a station in Newfoundland. In 1867, after progressive activities over several years (and several failed cables) he was able to find the mean of values for the longitude differences between the Newfoundland station and Greenwich that was sufficiently accurate for the Survey's geodetic work. That longitude difference was then "passed" telegraphically to the American station in Calais, Maine, and from there as far west as the Mississippi River. Gould's report on the exercise was a landmark in American science, and also a major flowering of the international nature of scientific progress that would continue to characterize the work of the Survey.[13]

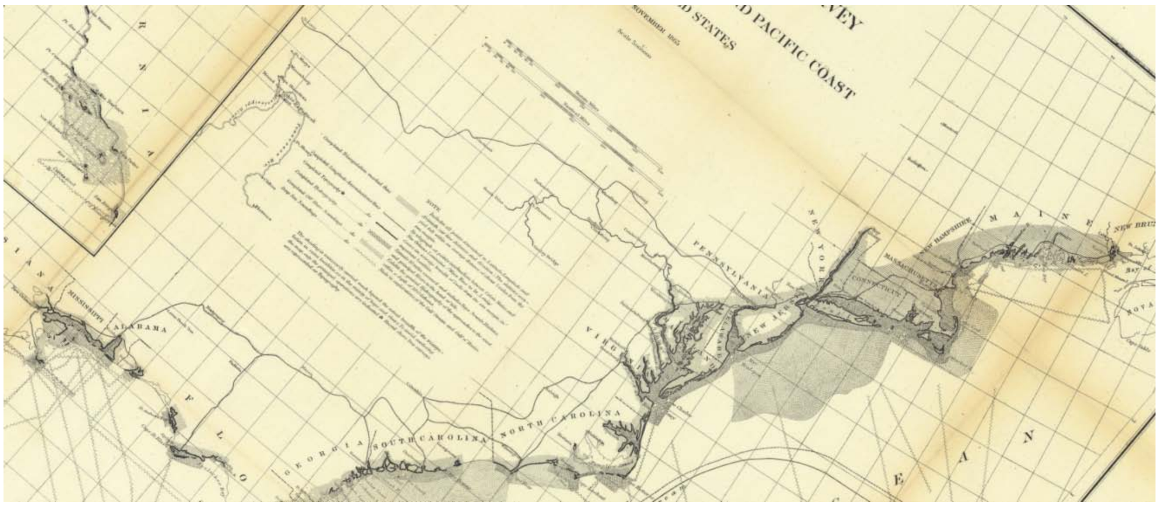


Fig. 10: Portion of Sketch 25, General Survey Progress through November, 1865, Annual Report of the Superintendent for 1865.
Note telegraphic lines of longitude west to St. Louis and New Orleans

By 1865, the longitude by wire network had been extended as far south as New Orleans, and west as far as Saint Louis. Although the extension of telegraph lines was often closely correlated with extensions of railroads, the Western Union telegraph line to California was completed in 1861, while the transcontinental railroad was completed in 1869. Because of the drawdown of personnel on the West Coast, the Survey's long-anticipated longitude tie across the continent to the Pacific coast network would have to wait until the return of George Davidson to the Pacific Coast. In early 1869, the observations were made and for the first time, the Atlantic, Pacific, and Gulf coasts were all tied together in a common longitude network.

The American Coast Pilot

[12] See Theberge's "The Dudley Observatory Affair" in The Coast Survey, 1807-1867 at: http://www.lib.noaa.gov/noaainfo/heritage/coastsurveyvol1/BACHE3.html#DUDLEY
[13] See Gould, "On the longitude between America and Europe from signals through the Atlantic Cable," Appendix No. 6, Annual Report for 867

The most essential publication for sailing in American waters in the 19th century was The American Coast Pilot, which had been established by Edmund Blunt in 1796 in Massachusetts. In the 1830s, when actual field activities began for the Survey under Ferdinand Hassler, Edmund Blunt the Younger became Hassler's assistant. There was forged a long and productive relationship between the Blunt family and their publishing, and the Coast Survey. The American Coast Pilot in its early editions described sailing directions for the Atlantic and Gulf coasts. In 1858, George Davidson wrote an article for a San Francisco newspaper detailing sailing directions on the Pacific coast. Davidson then expanded this into "Directory of the Pacific Coast of the United States", first published as Appendix 44 in the annual report of 1858. During the Civil War, while in the east, Davidson revised the Directory and published it again as Appendix 39 in the 1862 annual report, and then as a separate publication. Further, the 12 memoirs of the Notes on the Coast published by the Coast Survey were major extensions and enlargements of the Coast Pilots, with particular reference to the unique needs and requirements of the Union blockading force, and the invading Union armies and navies. Therefore, in a sense, the Survey had already melded with the Blunt enterprise in various ways. This was solidified in a most solemn way when Edmund Blunt the Younger died in 1867, from injuries suffered at work for the Survey. Eventually, in that year 1867, the Coast Survey secured the sum of $20,000 to pay the Blunt family for the rights and properties of the American Coast Pilot. From that date, to the present, the Survey and its successor agencies have continued publication of the series, now re-named the United States Coast Pilot. The Coast Pilots have been continuously in print from the late 18th century to the 21st. [14]

The Fall of the Leader

Alexander Dallas Bache declined in his health as the war progressed. While overseeing construction of fortifications to defend Philadelphia against possible attack in May, 1864, Bache suffered some sort of debilitating stroke or other disorder. The exact nature of his ailment was not known then, nor has been surmised since. The effects were mental as well as physical, which meant that Bache was no longer a real participant in understanding his condition or possible treatments.

At this critical point, when Bache was so abruptly incapacitated, much of the center of mass of the Coast Survey shifted to Joseph Henry, Bache's closest friend and confidant, the Secretary of the Smithsonian Institution. Most of what we know of Bache's condition and the Survey's perilous course comes from Henry's correspondence to others, and especially his confidential letters to Nancy Clarke Fowler Bache, A. D. Bache's wife and now caregiver. The clearest description of Bache's mysterious malady comes from Henry's letter to John H. Lefroy, a British artillery officer, who had been the director of the Canadian magnetic observatory from 1842 to 1853 and was thus a fellow scientist to Henry in magnetic research: "There are conditions of those we love and have respected worse than death; my friend Professor Bache with whom I have been on terms

[14] See Theberge, http://www.nauticalcharts.noaa.gov/nsd/cp-history.html

of the greatest intimacy was suddenly stricken down about two years ago in the midst of his responsible duties as head of the coast survey and is now in the last stage of animal existence, does not recognize his friends and is gradually fading away in body as well as in mind. He was overworked during the war, was seized with paralysis and softening of the brain."[15]

That Bache was incapacitated was immediately apparent. However, for the next two years, until Bache's death in February, 1867, both Henry and the leadership of the Survey took pains to shield outsiders about the nature and extent of Bache's maladies. There were three major reasons for this, all inter-connected. First, prosaically, as long as Bache was the nominal leader of the Survey, he, or more specifically his wife Nancy, would continue to receive his salary as Superintendent, which she needed to live on. Second, maintaining Bache as the nominal leader would assist the Survey to maintain its activities un-interrupted, and to secure its Congressional appropriations without un-necessary scrutiny of its operations. Therefore, Assistant Julius Hilgard became the de facto leader of the Survey, with Henry playing a variety of complex roles, particularly as related to disparate members and committees of the US Congress, and the National Academy of Science and the Smithsonian Institution. Third, as long as Bache was the nominal leader of the Survey, then there was no struggle to appoint a successor.

At the same time, it quickly became apparent to Henry, Hilgard, and many others that Bache was finished, and that a successor for him would need to be found and installed. A raging debate and series of forays and campaigns on behalf of different potential leaders occurred between 1864 and 1867. The correspondence on this is both voluminous and scattered. Much of what is known to contemporary scholars converges on Henry's views and correspondence, which are skewed by the fact that Henry had definite preferences and a rigorous agenda about Bache's successor, with implications that would affect much more in American science outside the Survey.

Henry saw the search for an appropriate successor to Bache as an exercise in two arenas. First, there was the matter of the specific immediate fate of the Coast Survey. As Henry noted to Carlile P. Patterson, the Survey scientist and a potential Henry candidate as Bache's successor: ""It is indeed a very sad matter to be obliged to make arrangements for the successor of the Professor while he is still on the verge of the grave, but as you say we are only acting in accordance with what we believe would be his own wish could he express it; and for the best interest of the great work which has been the primary object of his active life."[16] Second, though, Henry wanted a successor of sufficient status in science (more like Science) that the new leader could fend off the inevitable political weakening of the Survey that Henry saw as a constant danger to all American scientific institutions, most importantly his own. As Henry noted to Nancy Bache: "It is well however for you to look critically to your affairs and be prepared for the worst, since, as a class, politicians are selfish and regard place and power more than gratitude or justice".[17]

[15] Henry to Lefroy,December 6, 1866, in Rothenburg, et al., Papers of Joseph Henry, Vol. 11, pp.93-94.
[16] Henry to Patterson, March 26, 1866, ibid., pp. 28-30.
[17] Henry to Nancy Bache, January 3, 1866, ibid;, pp. 3-3.

Henry preferred the candidacy of Benjamin Peirce, who was a professor of mathematics at Harvard, but who had also overseen the Survey's longitude calculations since the late 1840s. Pierce was also a Regent of the Smithsonian, and a fellow member of Henry and Bache's so-called Lazzaroni, the elite groups of scientists and their fellows that was possibly at the heart of American science in the middle of the 19th century, and was certainly at the heart of 19th century American science in the views of 20th century American historians of science. Unfortunately, Peirce was deeply ambivalent about the post of Superintendent, and he vacillated many times between accepting a potential role as the new leader or declining it. Meanwhile, there were other potential candidates. Internally to the Survey, Henry considered, and cultivated, Carlile Patterson, particularly during Peirce's pendulum swings away from the post. There was also Julius Hilgard, who was already functioning as the actual leader of the Survey. However, Henry thought his prospects to be dangerous. As he wrote to Nancy Bache: "The great objection to his success is that he is a Foreigner, and this objection will be urged, if he is a candidate against so many foreigners in the employ of the survey".[18] Hilgard was not, legally a foreigner, having been born in Germany, but raised in Ohio from the age of three, and a US citizen. But the Survey had been a welcome home to foreign-born scientists and personnel since its foundation, and this had been noted by many elements in American political life. Hilgard had liabilities that Patterson, for example did not. (And for all that, as we shall see, years later both men did serve as Superintendents of the Survey). Finally, there were candidates and potential candidates outside the Survey of sufficient scientific merit as to serve as potential leaders. These included Benjamin Gould of Harvard, and William Chauvenet, a professor at Washington University in St. Louis.

The developing struggle over Bache's successor was also complicated by new proposals, a constant of the history of the Survey, to remove it as an independent scientific agency under the Secretary of the Treasury, and move it under military control. Traditionally, it had been the US Navy attempting to take over the Survey or acquire responsibilities for hydrography in domestic waters that would make the Survey superfluous. But, in the aftermath of the Union victory in 1865, it was Ulysses S. Grant who proposed that the Survey be brought under the control of the Engineer Bureau of the US Army. As Henry noted to Nancy Bache, "General Grant went out of his way to say that the coast survey ought to be put under the charge of the Engineer department of the army. On the other hand, the navy Department has introduced a bill to the Senate for the establishment of a hydrographic bureau which appears to look towards the coast survey. The secretary of the Treasury thinks the survey ought to remain where it is under his charge, and that the fight between the navy and the war Department for the possession of it will end in the defeat of each. What an ambitious world we live in?—not ambitious to do good but to advance individuals".[19]

Peirce continued to vacillate, a matter of great peril to the participants. As Henry noted in his desk diary, "The most prominent candidates are Patterson and Hilgard of the coast survey. Mr. Cutts [an Army officer and Assistant in the Coast Survey] is also said

[18] Henry to Nancy Bache, February 3, 1867, Ibid., pp. 107-111.
[19] Henry to Nancy Bache, April 30, 1866, Ibid., pp. 51-53.

to desire the appointment who is also connected to the survey. Unless Professor Peirce will take the appointment, there will be a violent struggle for the place which may not only damage those engaged in the work but also those who take any part in the controversy."[20]

On February 17, 1867, Alexander Dallas Bache died, in Newport, Rhode Island. Preparations for his demise had long been underway. Bache's body was first brought to Philadelphia, his first home. Ceremonies were held in the chapel of the University of Pennsylvania, where he had been a professor. Members of the many other institutions in Philadelphia he had founded or been a member of attended. Then his body was brought to Washington, his second home, escorted by the leadership of the Coast Survey. The Congress was consulted about his body lying in state in the Capitol. The only precedents for this required Congress to adjourn for the day, but the Congress was in session, and duties at hand included passing an appropriation for the Coast Survey. Therefore, instead, and appropriately, the entire ceremony in Washington was in the facilities of the Coast Survey, and under the direction of Bache's staff. Survey headquarters on New Jersey Avenue was closed, and draped in black. A procession formed there, with virtually the entire body of the staff of the Survey in attendance, and then walked to Bache's residence for the funeral ceremony. Then Bache's body was carried to the Congressional Cemetery and laid to rest. Bache's place in American society and scientific life could be seen formally in the very organization of the funeral procession. As a contemporary newspaper stated:

The funeral procession will be formed at the Coast Survey office, on New Jersey Avenue at 3 p.m. on Sunday, in the following order:

Order of Procession:
Clergymen
Pall-bearers
Coffin-bearers
Hearse
Family
Members of the Cabinet
Officers of the United States Coast Survey
National Academy of Sciences
Officers of Smithsonian Institution
Light-house Board
Scientific Societies of Philadelphia
Representatives of Chambers of Commerce of New York, Philadelphia, and Boston
Sanitary Commission
Officers of the Army and Navy
City Councils[21]

[20] Henry's Desk Diary, February 24, 1867. Ibid., p.115
[21] The Washington Intelligencer, February 23, 1867.

A.D. Bache's Grave, Congressional Cemetery, Washington, DC

That evening, Henry wrote in his private diary: "Funeral to day of my old and highly respected friend Professor Bache. I have been more intimately acquainted with him for the last 34 years than I ever was with anyone except my own wife. The occurrence of his death would have been overwhelming had it happened suddenly but since he has died off as it were very gradually his departure at the last was not a matter of much sorrow. Indeed it was a relief to all connected to him".[22]

And so the Coast Survey, which had survived the abrupt death of its founder, Ferdinand Hassler, now had seen the long decline and death of Hassler's successor. Bache had truly been a giant in American science, but now he was gone. He and his Survey had triumphed in the Civil War, but now the war was over, and the Survey found itself in the very complex world of post-war American life, without its great leader.

What would be its fate? Who would succeed in the battle to determine its next leader? Where would the United States next go, and what new territories and responsibilities would the Coast Survey acquire and pursue? With the deaths of Hassler and now Bache, the Survey left behind an era in which the character of the Survey and its work was largely determined by the nature of the one superior leader of the organization.

[22] Ibid.

The next era now opening would not feature paramount leadership exercised by one leader alone. Instead, many personnel in the Survey would rise in positions of scientific and organizational authority. They would introduce new techniques, whole new fields of science, to Survey work. They would extend the activities of the Survey from the tropics to the Arctic Ocean. And many of them, some already at work for the Survey, and some soon to join, would develop productive careers at the Survey in the late 19th century that would last longer than any comparable careers of Survey personnel in the 20th and 21st centuries. Not just one, but many of them, would become the true and worthy successors to Alexander Dallas Bache.

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Benjamin Peirce and "The Science of Necessary Conclusions"[1] (1867-1874)

The tenure of Benjamin Peirce as Superintendent of the Survey (1867-1874) was unique in the history of the Survey. First, unlike every other director of the Survey, he didn't want the job and was only reluctantly recruited to it during the long and dark period of the unraveling of A.D. Bache and the late stages of the bloody Civil War and the aftermath. Second, unique in the history of the Survey, he attempted to run the agency from far outside Washington while maintaining his tenured professorship and teaching duties at Harvard University. Finally, he hired his son Charles Sanders Peirce to work for the Survey. There had been many occasions of "nepotism" in the hiring of family members of Survey personnel and Survey leadership since the beginnings under Hassler. But C.S. Peirce was probably the first, and was one of the only, younger family members hired to the Survey whose subsequent career surpassed the Survey career of the elder.

The Peirce administration was characterized by four distinct new directions in Survey work:

(1) a return to pre-war Survey activities and products, but now energized by mapping practices and much else that had been thoroughly transformed by the war experience; thus, particularly, the extensive war work of the Survey in tidal research in major harbors and hydrographic surveys of strategic rivers far above the head of tide continued and accelerated after war; and the Survey, having created its own war-related American Coast Pilot series in Bache's "Notes on the Coast," in the postwar period acquired the original publication from the Blunt family;

(2) the great expansion of the Survey into northern Pacific waters and then Arctic waters with the purchase of "Russian America" in 1867 and subsequent expansion into entirely new Survey research, including mapping animal distributions and ethnographic and linguistic mapping of native populations in Alaska and surrounding regions ;

(3) the initiation of the Great Triangulation Arc of the 39th Parallel which connected the Atlantic and Gulf and Pacific coastal geodetic networks into what would in later decades become the geodetic foundation for the first true continental datum, the North American Datum; and

[1] "Mathematics is the science that draws necessary conclusions" (Peirce 1870, p. 1)

(4) the thorough "internationalization" of Survey scientific practices in ever more extensive collaborations with scientists and agencies in other countries, characterized by collective research on common phenomena, including the beginnings of the Survey's research on gravitation pioneered by C.S. Peirce. Additionally, under Peirce the Survey greatly expanded expeditions outside American territory to participate in international cooperative observations of major celestial events like solar eclipses and Transits of Venus, although as early as 1860 the Survey under Bache had sent an observation party to Labrador to observe a solar eclipse[2]. Another new direction was increasingly sophisticated oceanographic research, expanded beyond the traditional Survey domains of American coastal waters and the Gulf Stream, to include deep ocean bathymetry and collection of ocean biological specimens, often in collaboration with the US Commission on Fish and Fisheries. This latter work was closely associated with Alexander Agassiz, who had worked in the Survey in 1859 as a hydrographer, but returned to collaborate with the Survey during Peirce's tenure as a foundational oceanographer. Finally, this new scientific initiative also included the application of increasingly sophisticated mathematical models and modeling to traditional Survey activities such as monitoring the tides at ports and the observations of key celestial events.

[2] See Alexander, Annual Report for 1860, Appendix 21, pp. 229-275.

Benjamin Peirce (1809-1880) and Transcendental Mathematics

Benjamin Peirce at Harvard College, undated photograph

Benjamin Peirce's tenure began in anxiety and suffering and uncertainty about the fate of the Survey, but ended in a period of productivity and success, overseen by a mathematician whose work, famously, only a few other mathematicians could understand.

Peirce's life and work outside the Survey deserves attention as his career says much about the transformations in American mathematics and science in the 19th century. Peirce was born in Salem, Massachusetts, in 1809. In 1825, he entered Harvard College. Essentially, he never left. As a young student he was instructed by Nathaniel Bowditch, who created the legendary aid to navigation known as the *American Practical Navigator*, first published in 1802. It succeeded the *New Practical Navigator* which dated to the late 18th century. Bowditch became impatient with the earlier book's errors and devised the new publication to correct them. Apparently, while teaching at Harvard, Bowditch made some calculation errors of his own which were found by the young Benjamin Peirce.

"Bring me the boy who corrects my mathematics," he is said to have declaimed.[3] Bowditch and Peirce remained closely associated for the rest of Bowditch's life, and it is appealing to see Peirce as Bowditch's successor. Apart from formal instruction, Peirce worked under Bowditch for about ten years editing and correcting the text and equations of Bowditch's magnum opus, his translation and commentary on the Marquis de LaPlace's *Mecanique Celeste*[4]. The latter is considered a landmark in American science, although in these days it is of interest mainly for the biography of Bowditch by his son Nathaniel Ingersoll Bowditch, a noted abolitionist, which was prefixed to the fourth and final volume of the work which was published in 1839 a year after Bowditch's death. Bowditch's *American Practical Navigator*, however, in revised and updated editions, has been continuously in print for over two centuries now. The publication was acquired by the US government, and is now a down-loadable public document available on-line.[5]

In 1829, Peirce graduated from Harvard with highest honors. Two years later he was appointed as a tutor at Harvard, and in 1833 he was made University Professor of Mathematics and Natural Philosophy. This position was unendowed. In 1842 the endowed Perkins Professorship of Astronomy and Mathematics was established and Peirce was transferred to that position which he occupied until his death in 1880. Hence, for most of his life he was closely associated with Harvard and with mathematics—but also astronomy and natural philosophy which in that era meant a large field of endeavors. The later Harvard College President Charles Eliot, also a mathematician and student of Peirce, characterized Peirce's mathematics as "transcendental". He also recalled an anecdote, perhaps polished over the decades, that indicated what Peirce was after in his mathematical quest: "An intelligent Cambridge matron who had just come home from one of Professor Peirce's lectures was asked by her wondering family what she had got out of the lecture. 'I could not understand much that he said; but it was splendid. The only thing I remember in the whole lecture is this—'Incline the mind to an angle of 45 degrees, and periodicity becomes non-periodicity, and the ideal becomes real'".[6]

In fact, Peirce's contributions to mathematics are not easily described. He published many small papers, as is common with mathematicians, on a variety of topics in a mathematical vocabulary that is utterly different from that of contemporary mathematics as to make his contributions difficult to decipher. His mathematical biographer, R.C. Archibald, noted that about one quarter of Peirce's publications relate to topics of pure mathematics while the other three quarters pertained mainly to astronomy, geodesy, and mechanics. He also noted that: "There seems to be no question that his *Linear Associative Algebra* was the most original and able mathematical contribution which Peirce made".[7] That publication was intimately associated with his directorship of the Coast Survey; the original 1870 first edition was a set of 100 lithographed copies for which the text and equations and diagrams were hand-written and then lithographed at the offices of the Coast Survey, using the very same lithograph stones that the Survey

[3] Matz, 1895, p. 172.
[4] Bowditch, 1829-1839.
[5] See the NGA URL
[6] Eliot, p.3, in Archibald, 1925.
[7] Archibald, 1925, p. 15.

under A.D. Bache had used to print the hand-written text of the volumes of Bache's celebrated *Notes on the Coast*.[8]

Peirce also published textbooks on topics in advanced mathematics and became known and valued in the United States as an authority on contemporary mathematical research. He also displayed a facility for the mathematics of precise astronomical positioning. These two subjects are what brought him to a professional relationship with the Coast Survey in the first place, along with the general convergence of men of science then occurring inside and outside the federal government.

Around 1848, the American Association for the Advancement of Science (AAAS) formed out of an earlier association more directed to the natural sciences. The first president of AAS was William Redfield. In 1849, Joseph Henry of the Smithsonian was elected the second president, followed successively by A.D. Bache, the Swiss emigrant naturalist Louis Agassiz, and Benjamin Peirce in 1852. In that same period, around 1848, Peirce contracted a formal relationship to the Survey, as essentially an overseer of astronomical positioning, in particular the longitude operations. Peirce continued in the employment of the Survey until his death in 1880. Further, the newly formed Smithsonian Institution required a Board of Regents for governance and appropriate overseeing by Congress. Peirce was nominated and served as a Regent, with Bache, for many years. All of these developments validated Peirce's rising status as a member of the emerging American scientific elite.

The members of the AAAS, and especially the inner-most elite, formed by the triad of A.D. Bache, Joseph Henry, and Benjamin Peirce and their close associates, the so-called "Lazzaroni", have long been a topic in the history of American science[9]. Hence, we need not discuss them here, other than to note that the next major scientific institution to arise, which included (and sometimes excluded) members of the AAAS and other American elite scientists, was the National Academy of Sciences (NAS) which was founded in 1863 to address the scientific needs of the Union forces in the war. Again, Peirce was nominated and then selected as one of the first members of the NAS. His roles in the AAAS and the NAS had the not-insignificant consequences of requiring his physical presence in Washington, D.C., for meetings and sessions. Joseph Henry, in particular, tried to encourage Peirce's participation in the work of the government in the capital as a way of maximizing his effectiveness.

Peirce's mathematical skills in direct application to sophisticated mathematical analysis for the Survey will be described next, but it is important to note that Peirce was capable of contributions to Survey work of a more diverse and general nature. One example is the anecdote supplied by W.E. Byerly, an elderly retired Harvard professor in 1925, who recalled Peirce in action as he had first experienced him in 1867, at a meeting of the American Academy of Arts and Sciences in Boston. "The first meeting of the Academy I ever attended gave him an opportunity to show his remarkable ability to think

[8] Peirce, 1870, and Bache, 1861.
[9] See especially Theberge, Building an American Science Community, at: http://www.lib.noaa.gov/noaainfo/heritage/coastsurveyvol1/BACHE8.html#BUILDING

clearly and quickly. The paper of the evening was a very elaborate one, describing the lecturer's investigations into the tides of the Gulf of Maine. An important member of the Coast Survey[10], he had been engaged all summer in hydrographic work at the mouth of the Bay of Fundy, but he confessed himself completely staggered by the phenomena he had observed and had just described to us, seemed to him absolutely inexplicable. At the close of the address Professor Peirce rose from his seat and began to ask leading questions. The lecturer, rather puzzled at first, began to answer them hesitantly but soon discovered that step by step he was being led up to a theory that met all his difficulties and dissolved all his paradoxes. It was as pretty a piece of work as ever I saw done, and was manifestly entirely unrehearsed".[11]

For the most part, though, Peirce's direct contributions to Survey progress were concentrated in the very difficult field of precise astronomical positioning. Under A.D. Bache, the Survey had expanded the scope of its investigations into terrestrial magnetism (now called geomagnetism), tides and currents, meteorology, and marine geology of the continental shelves and slopes. All these investigations required numerical analysis of increasing complexity.

The Survey also expanded the scope and range of its precise astronomical positioning, which brought into focus some problems that Peirce proved critical to resolving. Astronomical positioning, especially with respect to longitude, was closely correlated with accurate and consistent time, as measured at different stations. Bache's telegraphic timing system, the key to what became known as "the American Method" of longitude determination, required a system of telegraphs to correlate observations near-simultaneously. Internally to the United States, telegraphic longitude systems on the Atlantic coast were in place by the 1840s. Until the completion of the Trans-Continental Railroad in 1869, with its accompanying telegraph lines, there was no longitude tie to George Davidson's geodetic network of the Pacific coast. In the same year, under the work of B.A. Gould and others, as examined in the previous chapter, trans-Atlantic cable ties to Europe finally allowed the American longitude to be correlated more precisely with the Greenwich Meridian. Through the transcontinental and trans-Atlantic telegraph systems, then, the extremes of the geodetic networks were finally correlated by telegraphic time. In between the coastal geodetic networks, however, lay the vast area of the continent. Mountain peaks serviced by telegraph lines were rare, so traditional astronomical positioning was necessary. There were many sources of error in such observations, which were more or less susceptible to correction through meticulous calculations and corrections. Traditional methods of converging on a solution from the calculations, which generally involved some method of "least squares" adjustment, could not easily compensate for the fact that not all errors were equivalent.

Into this very difficult situation stepped Benjamin Peirce through his original contributions to the mathematics of the limits of observational accuracy. This subject has

[10] This was possibly Louis de Portales, who installed tide gauges along the coast of Maine, or possibly William Ferrel, whose appendices on tides and tidal forces began appearing in Survey annual reports in 1868.
[11] Byerly, 1925, pp. 6-7.

been addressed in greater detail by Theberge and so will be simply summarized here.[12] Essentially, Peirce theorized that such progress in accuracy that was possible would come from characterizing classes of errors, which could be more or less mitigated by different methods of correction or compensation. Hardest of these classes of errors were those based on measurement errors beyond the limits of human perception, which had long been noted (if not corrected) in astronomical work and telegraphic timing work. In Peirce's 1854 Survey annual report appendix, he noted that:

> "If the law of error embodied in the method of least squares were the sole law to which human error is subject, it would happen that by a sufficient accumulation of observations any imagined degree of accuracy would be attainable in the determination of a constant; and the evanescent influence of minute increments of error would have the effect of exalting man's power of exact observation to an unlimited extent. I believe that the careful examination of observations reveals another law of error, which is involved in the popular statement that 'man cannot measure what he cannot see.' The small errors which are beyond the limits of human perception, are not distributed according to the mode recognised by the method of least squares, but either with the uniformity which is the ordinary characteristic of matters of chance, or more frequently in some arbitrary form dependent upon individual peculiarities -- such, for instance, as an habitual inclination to the use of certain numbers. On this account it is in vain to attempt the comparison of the distribution of errors with the law of least squares to too great a degree of minuteness; and on this account *there is in every species of observation an ultimate limit of accuracy beyond which no mass of accumulated observations can ever penetrate.*
>
> "A wise observer, when he perceives that he is approaching this limit, will apply his powers to improving the methods, rather than to increasing the number of observations. This principle will thus serve to stimulate, and not to paralyze effort; and its vivifying influence will prevent science from stagnating into mere mechanical drudgery...."[13]

Peirce's key insight here helped free the Survey from enormous drudgery in observations, by shifting the nexus of research to the development of new instruments and methods, rather than merely "drilling down" through more observations without any increase in the capability of the system.

And so Benjamin Peirce acquitted himself mathematically in service to the Coast Survey. Even after his tenure as Superintendent ended in 1874, Peirce was appointed as "consulting geometer" to the Survey at a pay rate and per diem rate equivalent to that of

[12] See Theberge, NOAA History, Science and the Survey, on-line at http://www.lib.noaa.gov/noaainfo/heritage/coastsurveyvol1/BACHE8.html#SCIENCE
[13] Peirce, 1854, p. 109.

the Hydrographic Inspector.[14] Peirce served in that capacity until he died in 1880. As later Superintendent T.C. Mendenhall, himself an accomplished scientist, noted at the Survey's Centennial in 1916: "As a genius in mathematics and astronomy he is easily a star of the first magnitude in the Coast Survey galaxy".[15]

Benjamin Peirce Takes Charge

Peirce was a reluctant candidate for Superintendent for several reasons. The principal one was that by 1867 he had spent decades as an endowed professor at Harvard and did not want to leave Cambridge unless he had to. He was also wary of the political demands of the position, as he would be required to work personally to secure the funding from Congress that the Survey needed. His great counselor in this was Joseph Henry, who kept hard at it trying to persuade Peirce to take the position. "I have just returned from the Treasury Department and have the pleasure to inform you that the Secretary will nominate you without asking your acceptance. He is convinced that your appointment alone can prevent a struggle which will be damaging to all engaged in it as well as to the work... I doubt not that on proper representation the authorities of Harvard will allow you to retain your professorship and that such an arrangement can be made as to render your duties in the Survey agreeable"[16].

Eventually Peirce accepted the position, but it was still unclear to Henry that Peirce realized what, in fact, he would need to do in order to make the Survey function at the level it should as the premier scientific agency in the government. Here Henry collaborated with Peirce's new boss, the Secretary of the Treasury: "He [Hugh McCullough, Secretary of the Treasury] was anxious that you should become a little better acquainted with the members of Congress. He thinks that it is of the first importance to the future of the Survey that you should retain your position. If you should resign the President would not appoint the person you mentioned [Julius Hilgard, Assistant in Charge of the Survey] and the Survey would go out of the hands of science... If you could remain in Washington say two weeks immediately after the holidays and do as Prof. Bache and myself did, viz. make a regular business of calling on Senators and members, I think it would be well. We went together and devoted four evenings a week until we had visited all of the most prominent Members of both houses".[17]

Once Peirce took the position and applied himself to the work in Washington, he did quite well, no doubt to the delight of Joseph Henry. How this played out, and how much Henry was operating quietly behind the scenes, may be conveyed by the reminiscences upon Peirce by Charles Eliot, once Peirce's student in mathematics at Harvard, and later its President: ""When Professor Bache retired from the superintendency of the U.S. Coast Survey, he procured the appointment of his intimate

[14] Archibald, 1925, p. 11.
[15] Mendenhall, 1916, p. 137.
[16] Henry to Peirce, Feb.25, 1867. Henry Papers, Vol. 11, pp. 115-117.
[17] Henry to Benjamin Peirce, Dec. 10, 1867. Henry papers, Vol. 11, pp. 167-168.

friend Benjamin Peirce as his successor in the superintendency. Those of us who had long known Professor Peirce heard of this action with amazement. We had never supposed that he had any business faculty whatever, or any liking for administrative work. A very important part of the Superintendent's function was to procure from Committees of Congress appropriations adequate to support the varied activities of the Survey on sea and land. Within a few months it appeared that Benjamin Peirce persuaded Congressmen and Congressional Committees to vote much more money to the Coast Survey than they had ever voted before. This was a legitimate effect of Benjamin Peirce's personality, of his aspect, his speech, his obvious disinterestedness, and his conviction that the true greatness of nations grew out of their fostering of education, science, and art".[18]

A Return to Civilian Work in Harbors and Rivers; But the Rivers are Never the Same

The Civil War is remembered for epic slaughter in battles featuring humans running across battlefields in tactics that were essentially unchanged since medieval times; but the war was fought primarily on an industrial scale, in which the movements of vast quantities of men and materials by railroads and steamships were paramount. Postwar, the Survey returned to its traditional responsibilities for aids to navigation, charting, and geodesy, but these had now changed substantially, along with the industrial development they serviced.

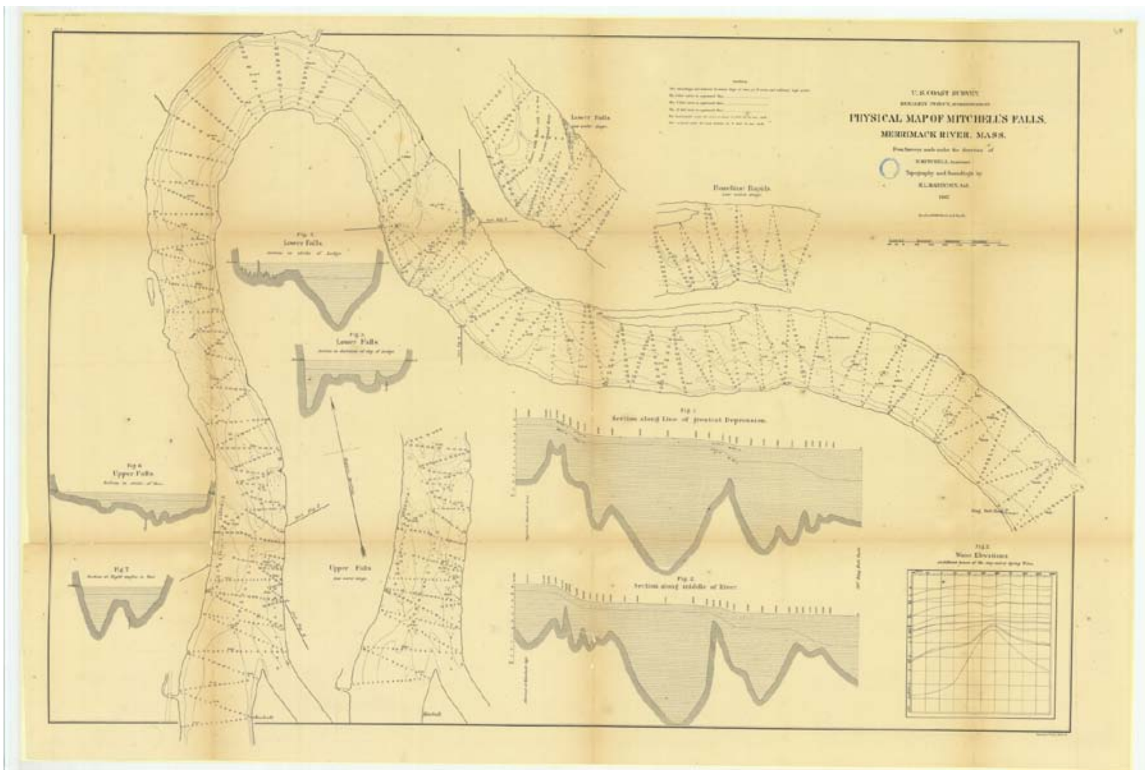
For the Survey, railroads connected to ships at harbors and ports, which needed continual re-surveys as they changed and expanded. Railroads required positioning, and they were accompanied by telegraph lines, and telegraphs allowed positions to be determined by the telegraphic method, Bache's "American method". Hence, the completion of the Trans-continental Railroad in 1869 was immediately accompanied by the Survey's positioning of San Francisco's longitude. This began the process of linking the coastal geodetic networks into a single system.

Much of the major coastal south lay in ruins including lighthouses and other aids to navigation which had to be replaced, re-positioned, and charted. Southern ports were clogged with damaged and sunken vessels which had to be surveyed and then removed or accommodated in some way. Ports and their infrastructure had to be repaired and replaced. And in the north, the vast industrial expansion that had supplied the northern forces required new infrastructure as well.

The Survey had worked, pre-war, at least as far as the head of tide in the rivers and bays and harbors it surveyed. During the war the Survey accompanied Union forces upriver as far as it took to achieve victory. Postwar this same process continued as the Survey performed increasingly sophisticated analyses of what may be called the industrial rivers of the United States, including the Merrimack, Raritan, Passaic, and Savannah Rivers, as well as Lake Champlain on the Atlantic coast, the Mississippi River

[18] Eliot, 1925, pp. 3-4.

on the Gulf coast, and the Columbia River and the great San Francisco Bay system on the Pacific coast. The work included traditional hydrographic surveying of the river depths, the construction of river bottom profiles, and monitoring of river runoffs and tidal flow volumes and patterns. As was mentioned in the anecdote about Benjamin Peirce's contribution to a Survey scientist's analysis of tidal patterns in the Gulf of Maine, the analysis could be quite complex, involving the research frontiers of numerical analysis of the era. The hydrographic survey of a portion of the Merrimack River in Massachusetts, featured below, was completed by Henry Mitchell and Henry Marindin who would continue as major hydrographic scientists in the Survey for many decades.



Physical Map of Mitchell's Falls, Merrimack River, MA surveyed by Henry Mitchell and Henry Marindin, Sketch No. 2, 1867

This hydrographic and tidal work was part of a great progression in hydrographic science that was really at the heart of the Survey's success. As Peirce noted: "Each succeeding year brings into view the practical wisdom of the plan upon which the survey was conducted by my predecessor. Under his direction charts of the large seaports were prepared early, to meet the most pressing wants of commerce and navigation. These were to be followed, and have been followed, by the issue in recent years of charts bearing more intimately upon the coast trade. At the same time, off-shore hydrography advanced, continuous observations were made on the tides and currents, and local surveys were prosecuted when their utility for public purposes was clearly set forth...The charts of comparison which accompanied these special reports soon enlisted the regard of city authorities for interests that were manifestly liable to injury from artificial encroachment on the water spaces, as well as from natural causes. As a consequence, local laws have been enacted in some cases, and it is hoped that, under their operation, or under some protective law of Congress, our chief harbors may be preserved from injury, as far as the laws of nature will permit. But the natural forces themselves, which are concerned in the formation and varying conditions of our coast harbors, are within the domain of calculation, and the results from such studies must bear ultimately upon the means adopted for preservation".[19]

These issues converged in new and productive ways in the matter of potential reclamation of tide-lands, which in the 19th century generally meant draining and diking the lands for agricultural production, whereas in the 21st century tide-land reclamation more usually means attempting to restore tidal forces and functions and reclaim degraded agricultural lands and salt ponds as wetlands. Assistant Henry Mitchell was a major pioneer in the Survey's research under Peirce. As Peirce noted, "the problems offered in the reclamation of land are the reciprocals of those which have been studies relative to the preservation of channels, and they pertain naturally to the domain of our physical surveys...Mr. Mitchell's discussion of the origins of the marshes and the wear of the outside coast, as inviting to further study, is deserving of special attention...Evidence from surveys and from many reliable observations certainly warrant the belief that the great gulfs and bays open in the direction from which storm-winds commonly blow, are extending into the continent, while all sheltered harbors and coves are filling up".[20] Here, Peirce displays the same awareness of great geophysical forces at work, and "as inviting to further study" as the Survey's scientists in the next century found the same processes and problems.

[19] Peirce, 1873, Annual Report for 1870, pp. 1-2.
[20] Peirce, Ibid., p. 8.

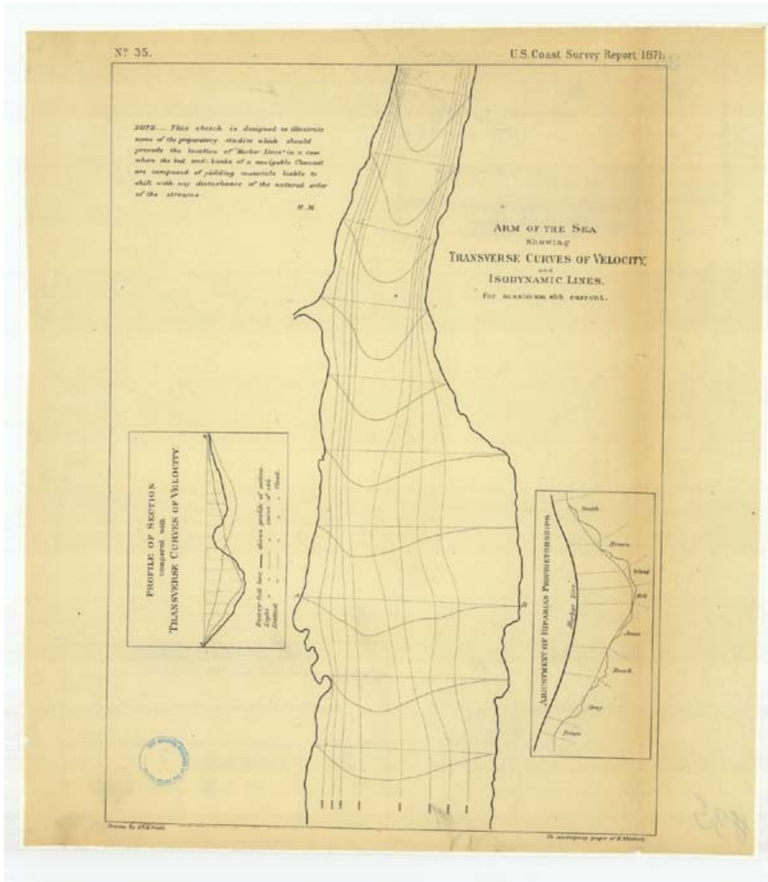
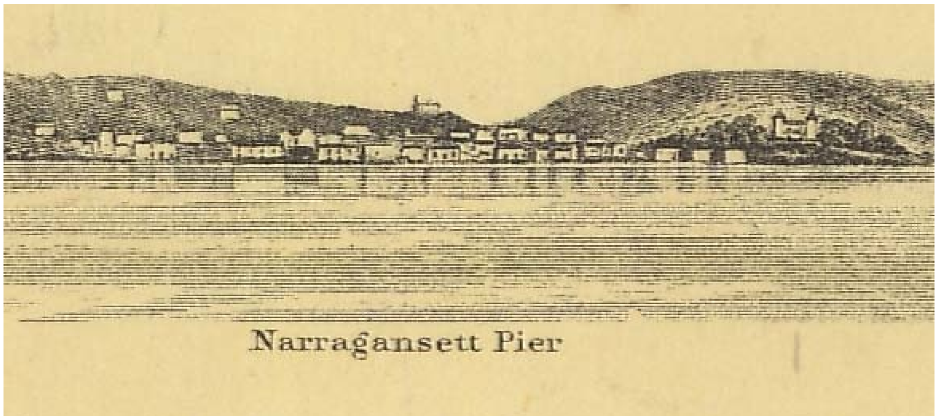


Figure 35, to accompany Appendix 10, "Hints and suggestions upon the location of harbor lines" by Henry Mitchell (1871)

New problems and new research required new venues for publication, or at least adapting older publications to new needs and constraints. The Coast Survey had been associated with the Blunt family, publishers of the American Coast Pilot series, since the beginning of the Survey. Edmund Blunt the younger was one of Ferdinand Hassler's assistants and ultimately died in service with the Survey. Bache's wartime *Notes on the Coast*, which had been influenced by George Davidson's *Pacific Coast Directory*, was succeeded by the Survey's purchase in 1867 of the Coast Pilots series of maritime guides from the Blunt family. The Coast Pilots continued in their traditional format for several years but were then replaced by the new series of *Atlantic Local Coast Pilots* which began under Peirce and was directed by John S. Bradford. The coastal view artist for this endeavor was John Barker, who was hired in 1873 as a worthy successor to John Farley, the original Survey artist of coastal views. Poignantly, one of Barker's early views includes Narragansett Pier, Rhode Island, which is where John Farley died after thirty-seven years with the Survey "and, at the approach of his last day, was faithfully engaged in field-duty"[21].

[21] Farley obituary, Annual Report for 1874, p. 16.



Narragansett Pier, from Approaches to Narragansett Bay, by John Barker (1873)

The New Coast Survey Headquarters

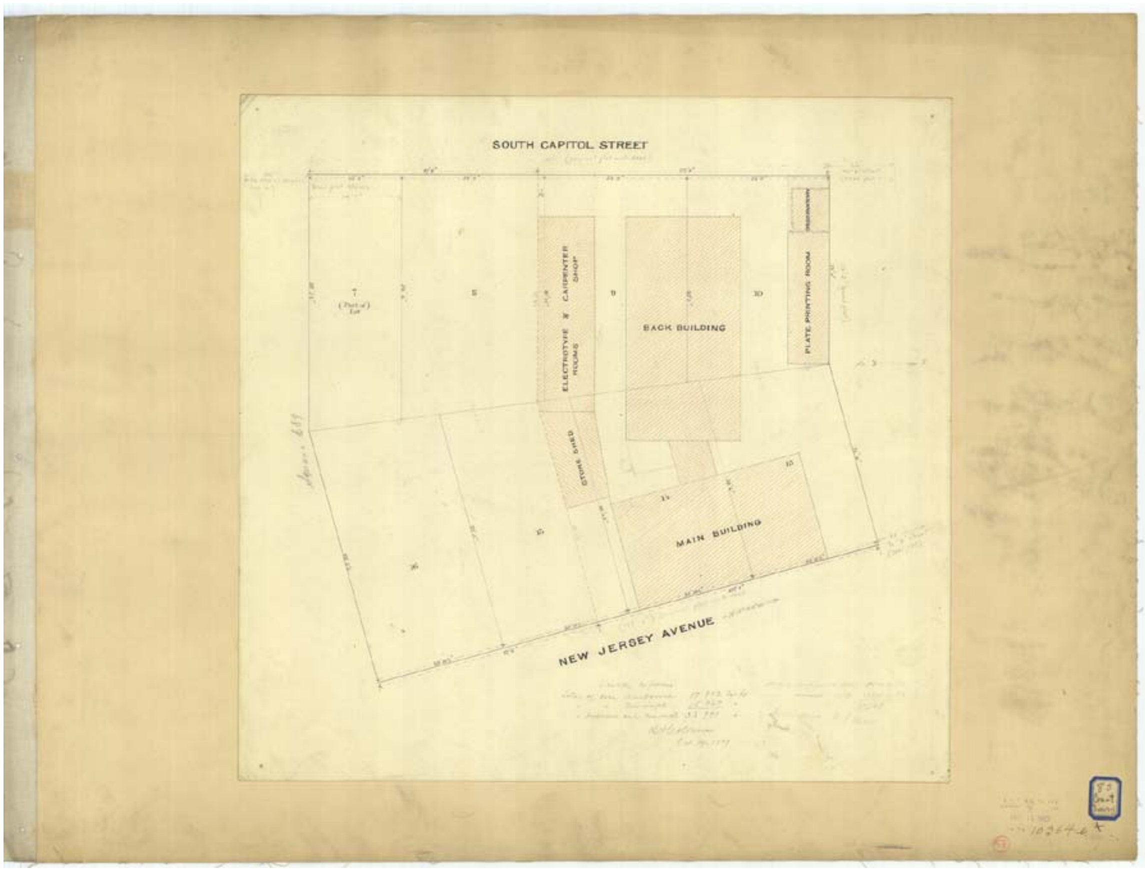
Cramped and inadequate quarters for work and research have been a recurrent theme in the history of the Coast Survey since the beginning. The Civil War was particularly difficult, both in the field, which meant on battlefields, and in the office, which generally meant in Survey buildings in the crowded, unhealthy, and difficult conditions of Washington during the war. Much needed construction for civilian needs was largely suspended during the conflict; consequently there was a great explosion of construction for both government and civil needs after the war.

In the case of the Survey, its major buildings were on what was then a steep side of Capitol Hill, on the west side of New Jersey Avenue SE, a block from the Capitol. The foundations of several buildings were apparently failing which was the trigger to a major new project and, of course, another round of solicitations to Congress for the funding. Here, as in much, Peirce, mostly living in Cambridge, Massachusetts, depended heavily on his Assistant in Charge of the Office, Julius Hilgard. As Peirce noted: "the ability with which the assistant in charge, J.E. Hilgard, esq., conducts the affairs of the office has relieved me from all anxiety with reference to that important division of the work... I would refer with pleasure to the new office quarters, in which, under the emergency constraining us to vacate the buildings heretofore occupied, the forethought and arrangements of the assistant in charge have secured accommodations long needed for the several branches of office work, as well as for the Coast Survey archives and instruments".[22]

The Survey complex consisted of a warren of five buildings, two of them newly built as part of this project, located in an irregular space bounded by New Jersey Avenue and South Capitol Road. The new buildings were designed by Adolf Cluss, one of the

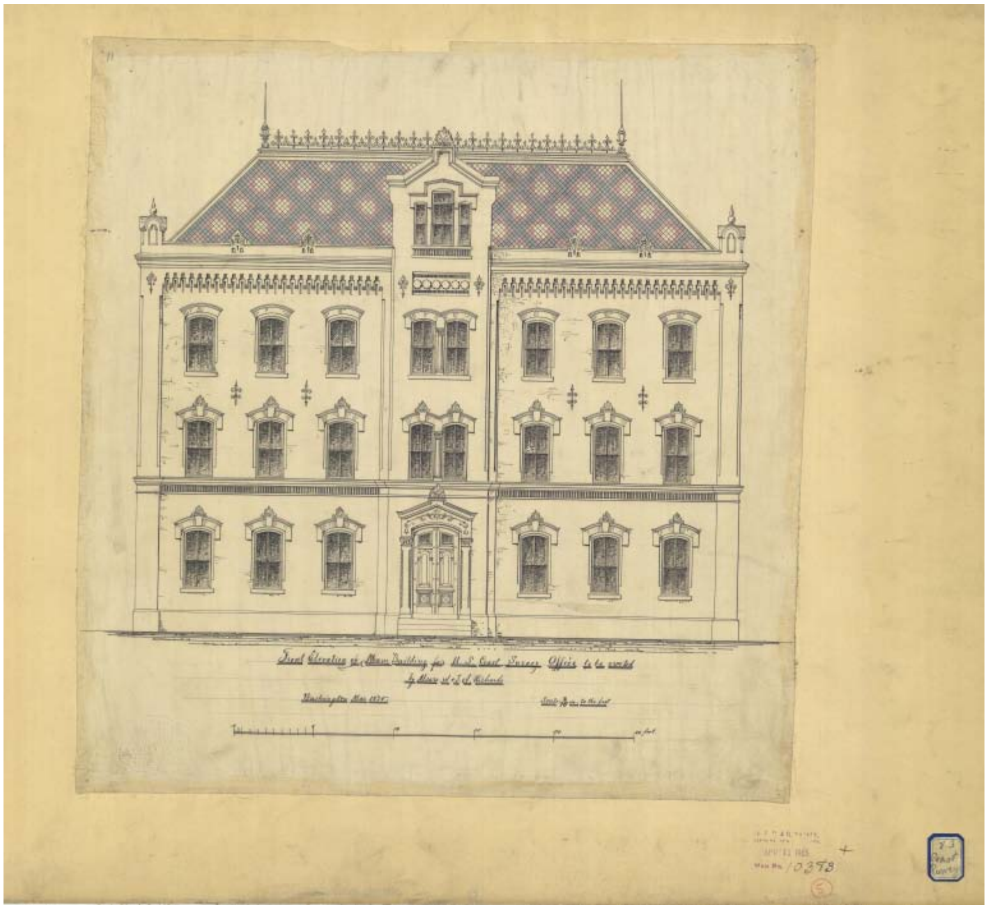
[22] Peirce, 1873, Annual Report for 1870. p. 50.

premier architects in Washington—whose first employment when he arrived in the US in 1850 had been a position on a Coast Survey topographic field party.



Survey Headquarters Site Plan Presentation Drawing (1870) by Adolf Cluss

The new headquarters complex included three older pre-existing buildings used for a variety of functions: electrotype plate making, the wood shop, general repairs and construction, storage, and printing. The printing shop was attached to a small magnetic observatory. The new buildings, called Main Building and Back Building, housed the heart of the Survey: the library and archives and plates, the offices of the major divisions, the instruments and instrument comparison shops, the Offices of Weights and Measures, the public facilities for purchase of maps and charts, and much else, including a set of rooms reserved for Peirce to occupy when he was in the Capital as he had no other home in Washington.



Main Building Front Elevation Presentation Drawing (1870) by Adolf Cluss

As it happened, an almost complete set of Adolf Cluss' presentation drawings for the site and the designs of the Main and Back Buildings was cataloged into the Survey's Library and Archives Collection. In addition, in 1870 the Washington Evening Star published a rather detailed description of the nature and organization of the Main and Back Buildings, and how they were to be constructed, by specific contractors and sub-contractors, many of whom were among the most politically well-connected enterprises in the Capital. The combination of the presentation drawings and the text give an unparalleled view into the way that the Coast Survey and its personnel actually worked, never before or after equaled for any Survey facilities.

Important Improvements
The U.S. Coast Survey Office.

This thoroughly organized scientific branch of the public service has been provided with most inappropriate and inconvenient quarters up to date. Located on the west side of New Jersey Avenue, to the south of the Capitol, the main offices are occupying a couple of dilapidated dwellings with defective foundations, at the brink of Capitol Hill, which are shaking and cracking under the influence of our sub-tropical gales, whilst the various divisions are located in miscellaneous dwellings of the adjoining squares, which were temporarily fitted up for office purposes as well as circumstances permitted. Their enterprising fellow citizens, Messrs. A and J.A. Richards, owners of some of those other houses, made a proposition to erect on liberal conditions at their own cost and expense, buildings that will supply the long felt want, promote the efficiency of the administration, and be a credit to a rapidly improving part of the city. This proposition has been accepted, the plans of architect Adolf Cluss have been approved by both parties last spring, and active building operations are proceeding as rapidly as good work will permit.

The new buildings are situated one square to the south of the Capitol, and are bounded, east and west, by New Jersey Avenue and South Capitol Street. The difference in the grade of the two streets is such, that exclusive of a coal cellar, the buildings show five full stories on South Capitol Street, with a high terrace wall in the rear which supports the sidewalk of New Jersey Avenue, whilst on New Jersey Avenue, three stories and an ornamental slate roof, a total height of 63 feet, show above ground. The area to be occupied by the department is irregular in shape, but in the average 112 feet front and 160 feet deep, and the buildings centrally located.

The main building on New Jersey Avenue is 117 feet long by 44 feet wide and constructed absolutely fire-proof. Connecting corridors constructed of brickwork, 15 feet wide by 16 feet long, join the different stories to a back building having a front of 44 feet by a depth of 92 feet. This building has hollow outside brick walls, heavy block partitions, and counter ceiling floors, so each story has a proportional amount of absolute fire-proof space. The sub-cellar is allotted to coal cellars, boiler room for a steam heating apparatus of the whole buildings, and chambers with ample cold air ducts from without, and miscellaneous storage rooms.

The first full story contains the mathematical instruments shops, as well as the instrument shops of the office of (standard) weights and measures, rooms for adjusting length-measures, and so on. The second story is appropriated for map rooms, records, storage of books and papers, printing press room, drying and backing room, and instrument storage room. The third main story room, which is three feet above the level of New Jersey Avenue, contains the main entrance, spacious vestibule, the offices of the assistant in charge, hydrographic inspector, rooms of tidal division, disbursing agent, office of weights and measures, and principally the office of Professor Pierce, the superintendent, from which a bird-eye-view of the city and a splendid panorama of the Potomac is had. The fourth and fifth stories are occupied by the computing division, drawing

> division, hydrographic division, engraving division, and private rooms of superintendent.
>
> Ample storage rooms are provided again within the steep slate roof of the main building, which has ornamental iron stairs reaching from cellar to roof. Wide corridors, dust shafts, elevators communicating with all the stories, wash basins and other modern accommodations are amply supplied. There are eighty-seven rooms of different sizes above the cellar, having an average clear height of twelve feet.
>
> The front on New Jersey Avenue consists of modern ornamental pressed-brick work, with heavy brown stone trimmings and belt courses, segmented window and door heads, pilasters and other projections; main cornice of galvanized iron; slate in tasty patterns of red, blue, and green.
>
> The departments of photographing and electrotyping are accommodated in a detached building in the yard and adjoining which is the carpenter shop.
>
> The value of the improvements will be $ 120,000, and they therefore lead the van in the way of the building operations of this dull season. Messrs. Thomas Lewis and J. McCollum are the contractors for brick-work; M.G. Emory and Bros. for curbstone work; Ch. Edmonston and Dowling Brothers for carpenters' work; Gray and Noyes for iron work; A.R. Shepherd and Brothers for plumbing and heating; Stewart and Fenwick for plastering; F. Stromberger for tin work[23].

The combination of the description and the presentation drawings offers a rare glimpse into the organization and functioning of the Survey, and also its role as a leading scientific agency in the government. Adolf Cluss was a friend and associate of many Survey personnel, particularly those who, like him, had emigrated from Germany in the wake of the failed Revolution of 1848. He, and they, were progressives in the context of post Civil War American society. This is reflected throughout the buildings' design, in features like abundant windows on all sides of the buildings, even in basement levels, elaborate and innovative ventilation systems, with steam heat for the winter and tunnels for cold air ducts for the summer, high ceilings, new gas lighting systems, and a host of features to make the buildings fireproof.

The New Jersey Avenue complex was the epitome of progressive scientific function in 1870; half a century later it was decidedly not. It would take the greatest leader of the Survey in the 20th century, E. Lester Jones, to provide an escape from the buildings that Peirce and Hilgard had worked so hard to create in the 19th century.

The Survey and the Deeper and More Mysterious Seas

[23] Washington Evening Star, July 25, 1870, p. 4.

The Survey under Bache pioneered soundings and explorations of deeper waters further offshore, and also research on the nature and structures of the Gulf Stream. When the Survey acquired responsibilities on the Pacific coast, it also acquired some level of responsibility for knowledge of the oceanic routes to reach the west coast, especially by crossing the Gulf of Mexico and the Caribbean, with land crossings in Central America, and then oceanic travel up the Pacific coast to the new American territories. With the purchase of Russian America, the Coast Survey acquired responsibilities extending up the coast of the Northeast Pacific and the Bering and Chukchi Seas all the way to the Arctic Ocean.

These responsibilities took the Survey ever farther offshore from American coasts, and to ever deeper waters, with ever more evidence about the large scale organization and evolution of continents and oceans. In Bache's era the first submarine canyons were discovered, and recognized to be canyons. Now, under Peirce, profiles across ocean basins were devised, with clues to much longer histories.

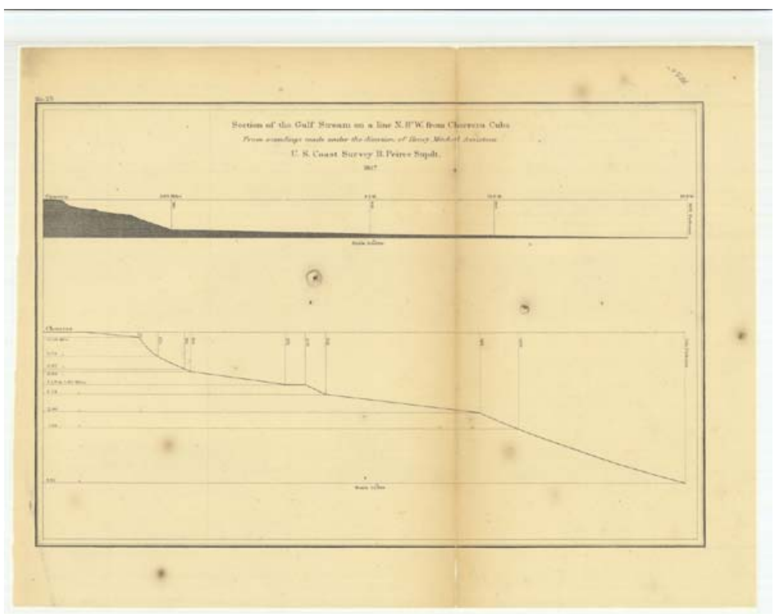
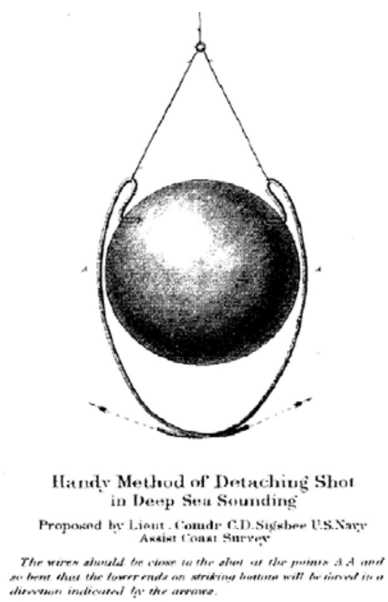


Figure 25 Section of the Gulf Coast on a Line N 8 Degrees West of Chorrera, Cuba from soundings made under the direction of Henry Mitchell (1867)

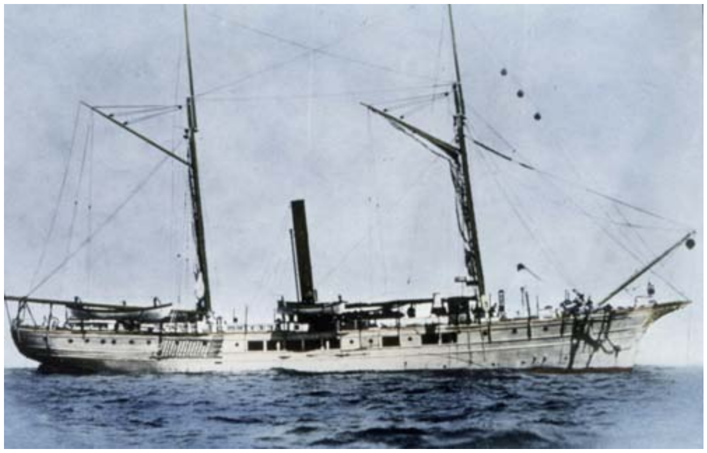
These longer, deeper, and more sophisticated explorations required new ships and new equipment and techniques—and, of course, new sources of funding. All these issues converge, in particular, in the return of Alexander Agassiz to service with the Survey. Agassiz was the son of the famous Swiss immigrant naturalist Louis Agassiz, who became the Chair of Natural History at Harvard. After rigorous instruction in Europe and then later at Harvard, Agassiz embraced the ocean. He accompanied his father on surveys, in association with the Coast Survey, off Nantucket and in the Florida reefs. He began to publish articles, mainly on matters of many kinds of marine organisms. Agassiz in 1859 had joined the Coast Survey and worked in California and Washington Territory for about a year. During the Civil War, Agassiz worked as an assistant in his father's Museum of Comparative Zoology at Harvard. After the war Agassiz turned his considerable skills to hard rock mining, first in Pennsylvania, and then copper mines in Michigan. He became superintendent of a rich copper mine enterprise, the Calumet and Hecla Mining Company. This did two things for Agassiz. It gave him a great fortune, which he could devote to further explorations of the ocean. And, it gave him a thorough grounding in the latest and most innovative technologies of large scale mining, particularly the uses of steel wire and winches to haul heavy materials at great distances. All this converged after the Civil War, under Peirce, when Agassiz returned to research work with the Survey. His wealth of knowledge on technology, not to mention his pecuniary wealth, led to a flowering of new technologies that could allow more reliable and accurate soundings in ever deeper water, coupled with techniques and equipment to secure samples of marine life and geological samples and bottom samples. A great associate in this research was Navy Lieutenant Commander Charles Sigsbee, who developed many elements of the technologies for deep sea soundings, using Agassiz' key contribution of steel wire winches for dredging and piano wire for sounding. [24]



Appendix 14—A Handy Method of Detaching Shot in Deep Sea Sounding, by Lieutenant Commander Charles Sigsbee (1874)

The collaborations of Agassiz and Sigsbee would really triumph onboard the Coast Survey's ship the steamer *George S. Blake* (1874-1905). The triumphs of the *Blake* will be detailed in subsequent chapters as it was only built in 1874 at the end of Peirce's tenure. But it was Peirce who secured the funding to build the ship, which was really the first modern American ship for oceanographic research. The *Blak*e was to be closely associated with the *Albatross*, a comparable new research ship, launched by the Commission on Fish and Fisheries, another of NOAA's legacy agencies.

[24] See Agassiz, http://www.history.noaa.gov/giants/ag.html



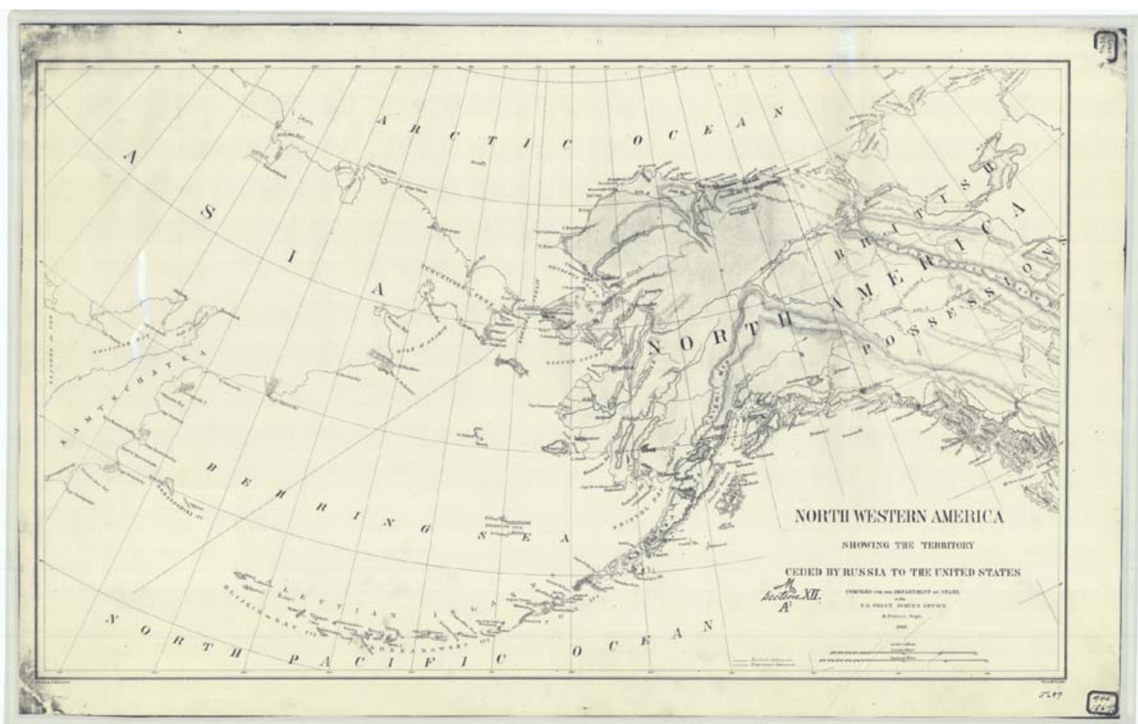
The steamer *Blake* (1874-1905)

The Great Expansion of the Survey and the United States: North to Russian America

The Civil War ended in 1865; Alexander Dallas Bache's decline ended in 1867. Many important matters in American life and the Survey itself which had seemingly been in suspended animation during and after the war came alive quickly in the beginning of Peirce's tenure. Matters of significance to the subsequent history of the Survey and also the nation converged in the momentous decision to pursue "Seward's Folly", the purchase, by the United States of the vast domain known officially as Russian America. In making the purchase, the United States acquired responsibilities for populations of natives who had had substantially different histories than those from what would eventually be known as "the lower 48 states" of the nation. And the United States inherited Russian environmental problems and Russian solutions. And finally, the nation acquired the services and skills of some remarkable scientists and activists of the Far North, whose influential careers in the 19th century would have great influence in the next century and a half.

The Coast Survey was integral to the purchase of Russian America. George Davidson, newly returned to San Francisco as the head of the Survey on the Pacific coast, was charged with leading an expedition with various scientific specialists in fields such as geology, botany, zoology, meteorology, ethnography, and other disciplines, on the Revenue Cutter *Lincoln*, to explore key critical coastal and insular areas of the territory. Their book-length report, which described the new territory in impressive detail, was published as an appendix in the 1867 annual report. Particularly noteworthy, in light of the subsequent history of the Survey in Alaska and all adjoining areas of the Far North, was the impressive attention to ethnographic descriptions of the tribes and peoples of the territory, along with lists of comparative vocabularies of key language terms in many native languages rendered in a consistent English-language orthography.[25]

Davidson received from the Russians, essentially as a part of the negotiated purchase of Russian America, a major set of Russian maps, charts, and atlases. These maps included recently published Russian maps and charts, and sets of historic maps dating back to the era of Vitus Bering. Bering, the Danish explorer and cartographer, sailed and mapped for the Russian Empire and had claimed Russian America in the first place. Originally there were three great land claims to the northern country in play: Great Britain, France, and the Russian Empire. After the defeat of the French in what the North Americans call the French and Indian War (1753-1763), that left Russia and Great Britain as the two claimants for Northwestern America. With Russia's decision to sell Russian America to the United States, the Russian Empire left North America. The trove of Russian maps Davidson received, and his party's own reconnaissance in 1867, resulted in the publication that same year of the Survey's first map of the new territory. The geography was new, but the map type was not. During the recent Civil War the Survey had created entirely new series of territorial maps of the parts of the country where the war was fought, or might be fought, based on a combination of previous maps and original research. The new map was an application of the same processes to the far north of the American continent.



North Western America showing the territory ceded by Russia to the United States (1867)

[25] Davidson, 1867. Alaska territory; coast features and resources. Appendix No. 18: 187-329.

During Peirce's tenure, George Davidson made two trips to Alaska, the second one in 1869. Both trips were linked to Kohklux, a powerful coastal native Tlingit chief Davidson met on his first trip in 1867. The chief had two encounters in life with Davidson. But they were important enough that Davidson remained occupied with aspects of the encounter for the remaining 40 years of his life. In 1867, when Davidson first came to Sitka, the island port that was the capital of Russian America, he already was anticipating a return visit for a total solar eclipse that would occur in August of 1869. When Benjamin Peirce became head of the Survey in 1867, he appointed his son Charles Sanders Peirce to the Survey, where he remained in one capacity or another until the 1890s. C.S. Peirce mapped the path of totality for the 1869 eclipse in anticipation of Survey teams being dispatched to various areas along the arc of totality for observations of the eclipse. The arc of the eclipse ran from North Carolina to Iowa to Canada and Alaska. The Survey positioned many different survey parties along the arc. For Davidson and his Alaska party, close inspection of the map revealed that most of the path of totality would pass along rugged glacier-draped mountain ranges in the interior from the coast. But there was a section of totality that crossed over to the coastal side of the mountains, accessible from the north end of the Lynn Canal, up the Chilkat River. That land was in the hands of the Tlingit, governed from their moiety clan village of Klukwan under the authority of Kohklux.

Eclipse Chart crop, by C.S. Peirce Figure No. 24, 1869

In 1867 on his first visit to Sitka, Davidson had arranged for Kohklux to be summoned to the capital to meet Davidson and discuss possible logistics for an eclipse expedition two years later. They clearly connected. In 1869, Davidson asked the new American military authority to request Kohklux come down to Sitka to meet Davidson. Things went very badly. Kohklux was brought to Sitka and thrown in jail; and, when Kohklux' warriors tried to liberate him, there was a fight and at least one warrior was killed. In this very dire situation, Davidson negotiated Kohklux' release from jail. Davidson and his small party left with Kohklux and his men for the Chilkat River. Davidson's description is dramatic: "A large war-canoe with a chief and six men of the Sitka tribe, carried part of my provisions and instruments. My experience upon this coast with Indian tribes was such that I declined any escort of soldiers. My party consisted of Mr. S.R. Throckmorton, Jr., as aid, and four men, and no interpreter. The tribe of Chilkats numbered 1,500, and was considered the most hostile on the coast, especially as General Davis had recently kept their chief ten days in the guard-house, and shot one or two of their men in trying to pass the guard. The officers looked upon my undertaking as reckless. I did not"[26].

Davidson visited the Tlingit capital village at Klukwan, and then established an observatory site on a mountain ridge above Kohklux's home village on the Chilkat River. The eclipse of August 7, 1869 occurred. It filled Davidson with that quintessential 19th century feeling of the sublime. The eclipse was disturbing to Kohklux and his people, but short-lived, and everyone was impressed that the phenomena had occurred just as Davidson had predicted. In response to the entire event and their relationship, Davidson and Kohklux and his two wives[27] made a remarkable exchange. On his side, Davidson produced a painting of the height of totality as he had perceived it through his telescope. The present disposition of this painting is unknown, but the oral history of it, among Tlingit at Klukwan, was that the painting was "red and black". [28] Davidson's drawing of the eclipe depicted the corona's colors in a manner very consistent with the Tlingit assessment.

[26] Davidson, Observations at Kohklux, Chilkhat Rivers, Alaska. 1869 Annual Report, Appendix No. 8, p. 178.

[27] Unfortunately, their names do not come down in history, but they were a pair of sisters, from native peoples who lived in the lower Stikine River, southeast of the Chilkhat River. Their people had separate trade routes over the coastal mountains and down to the Yukon River system.

[28] See Johnson, 1995.

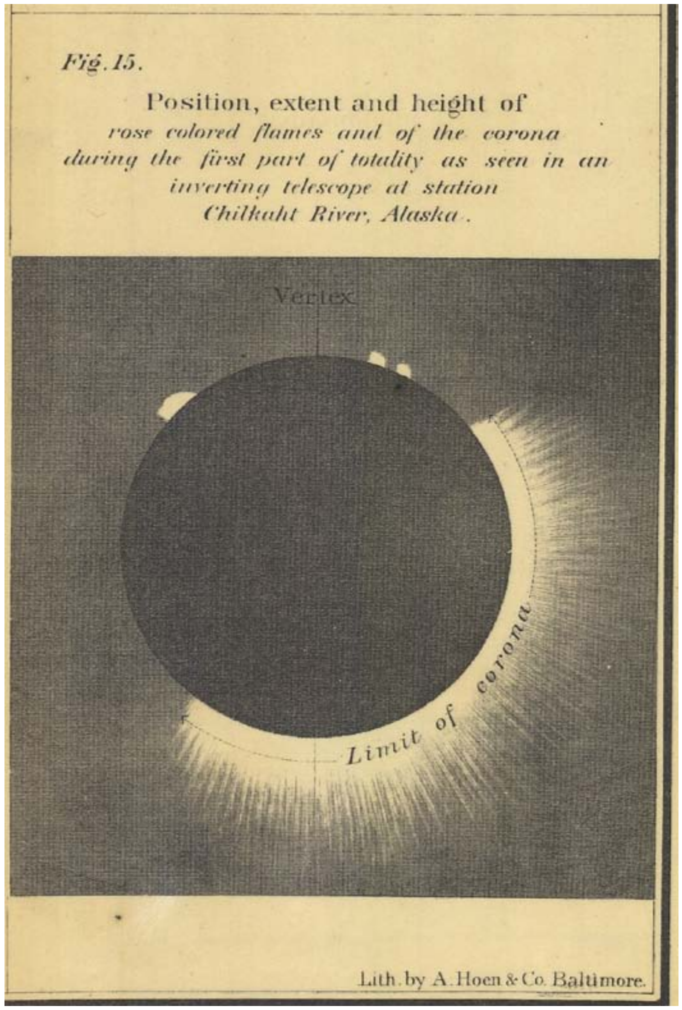
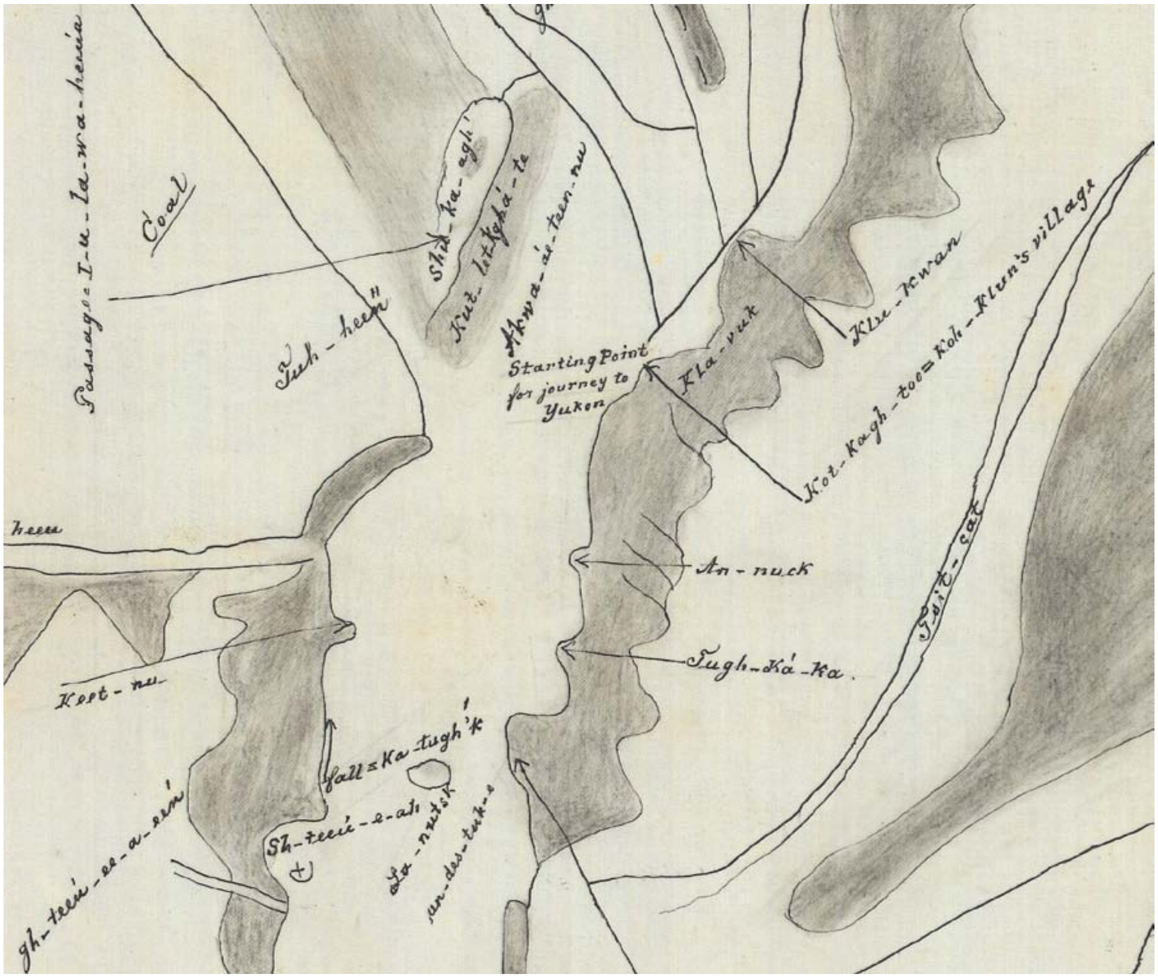


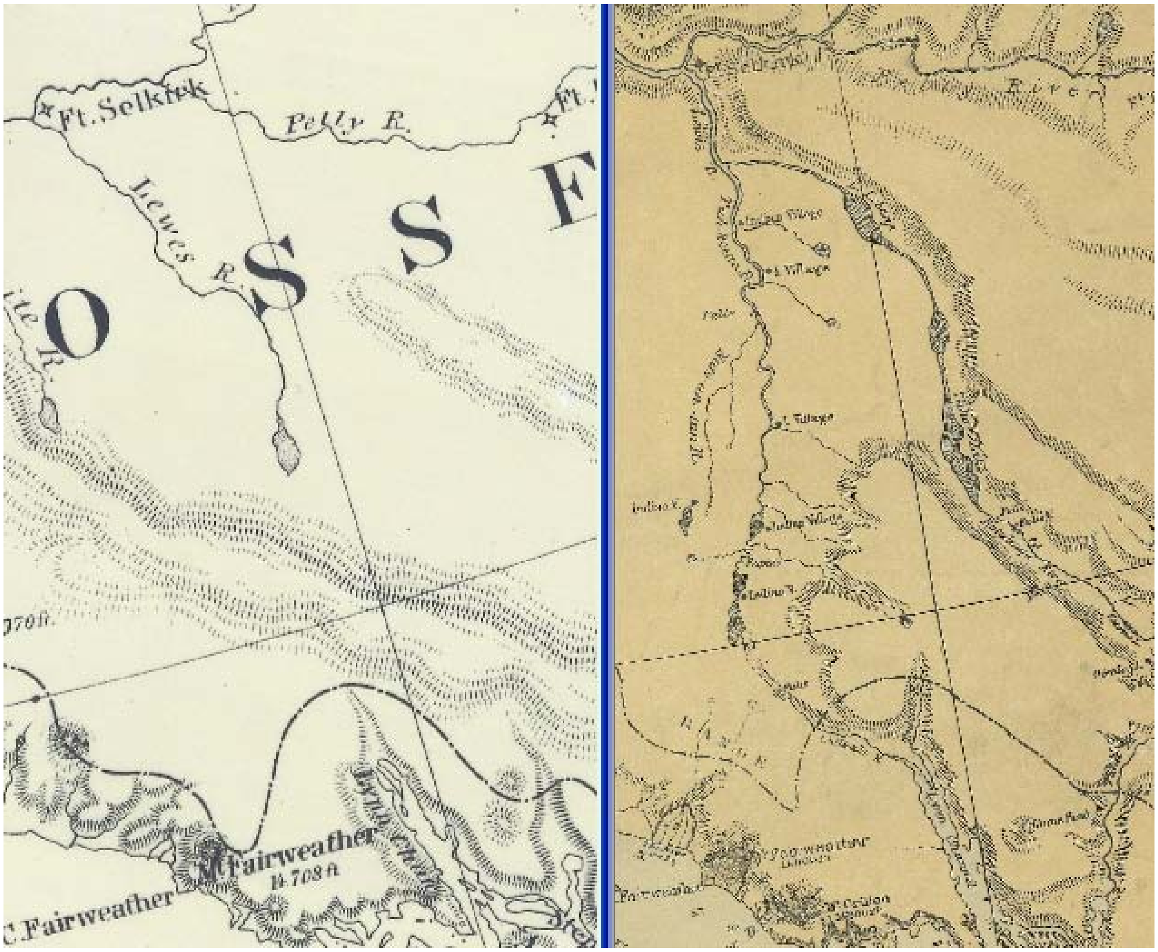
Figure No. 15, from Appendix No. 8, "Reports of Observations of the Eclipse of the Sun on August 7, 1869, etc." Annual Report of the Superintendent for 1869

In exchange, Kohklux and his two wives spent three days creating a large, complex map. The map depicts the geography between coastal Tlingit lands around the Lynn Canal, over the coast mountain ranges and down, via several different river systems, to the site of Fort Selkirk on the main stem of the Yukon River. The map was a complex collaboration with Davidson, in that Davidson annotated the map with very specific place names and brief descriptions of historic events using an English-language orthography to convey descriptors in Tlingit and several branches of the Athabascan language family now called Tut-Chon. The original map, now called universally, "the Kohklux map," is quite faint as it was drawn and annotated in pencil. Davidson asked permission to overlay the map original with Coast Survey tracing linen, and "pick up" the lines and mountain ranges in ink. The second version was then also annotated again by Davidson in conversation with Kohklux and his wives. The map is now recognized as a landmark of indigenous cartography in the 19th century.



"Starting point for journey to Yukon" crop from the tracing cloth version of the Kohklux map, officially T-2268 in the Survey's archives of topographic maps (1869)

Davidson returned form Alaska in late summer, 1869. By the end of the year, the Coast Survey produced its second edition of a map of the new American territory, by now re-named "Alaska" instead of "Russian America". A comparison between the same sections of the 1867 and 1869 maps, for the area between the Lynn Canal and the Yukon River, makes clear that the major contribution to refining the depiction of the terrain and its features was the cartography of Kohklux and his wives.

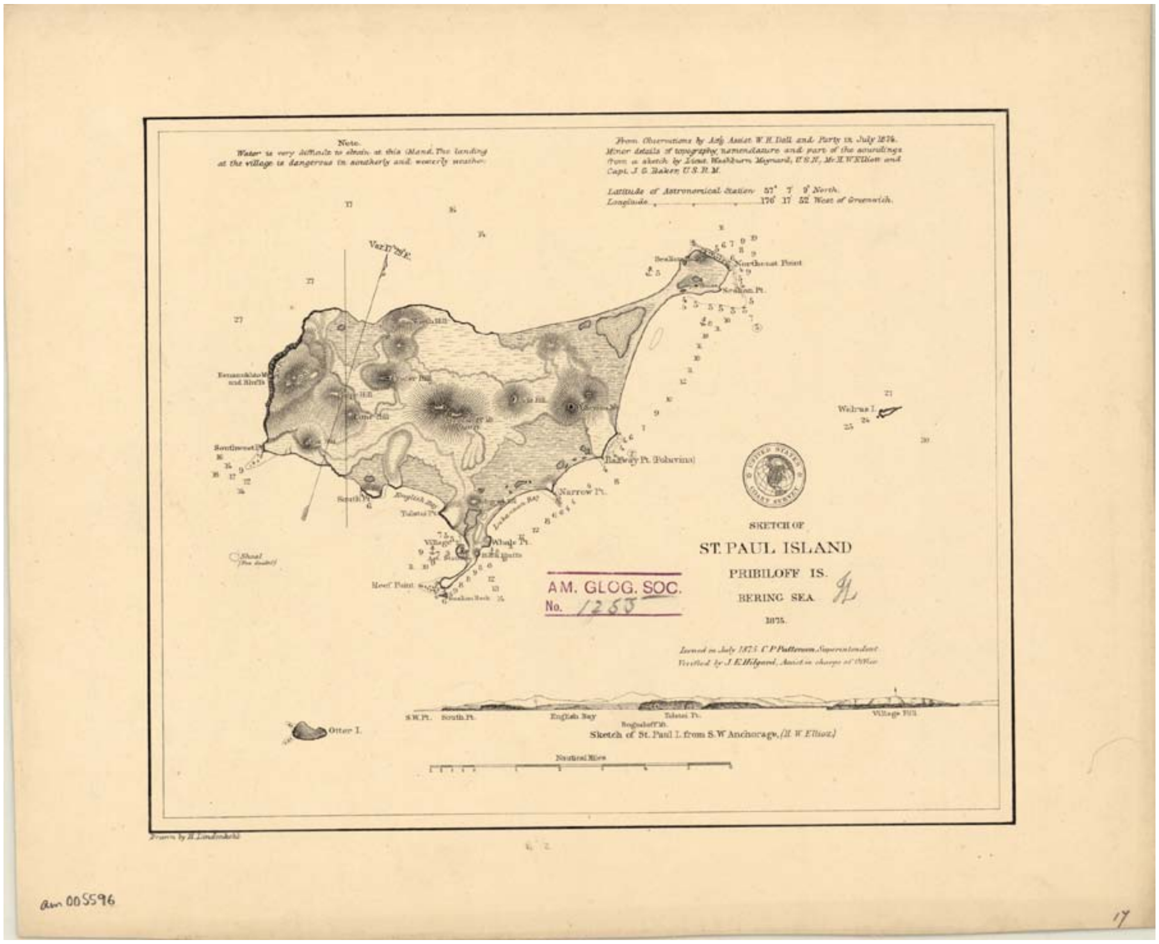


The terrain between the Lynn Canal and Fort Selkirk, in the Yukon, from the 1867 and 1869 editions of the Survey's map of Russian America/Alaska

By purchasing Alaska the United States acquired vast resources, but also profound Russian environmental problems and Russian environmental solutions. This was immediately recognized, and so the Survey initiated surveys and mapping of aquatic and terrestrial natural resources and their problems from the beginning. As a part of this enterprise, Davidson hired William H. Dall to the Survey with specific responsibilities for surveys and mapping in the Far North. Dall, at that time still a very young man, had first gone to Alaska and Siberia in 1865 as a member, and later leader, of the Western Union Telegraph Company's Telegraph Expedition. The Company was seeking potential routes for a trans-Pacific submarine telegraph cable crossing the Bering Straits between Siberia and Russian America . Dall worked for the Survey in pioneering explorations of the new territory and the seas adjacent to it, and also in major investigations of marine and terrestrial biology as well. Eventually, he transferred his employment to the US Geological Survey and the Smithsonian Institution. Fittingly, he is the only person for whom a mountain sheep and a porpoise and a seamount have been named.

William H. Dall in the uniform of the Western Union Telegraph Company Telegraph Expedition, 1865

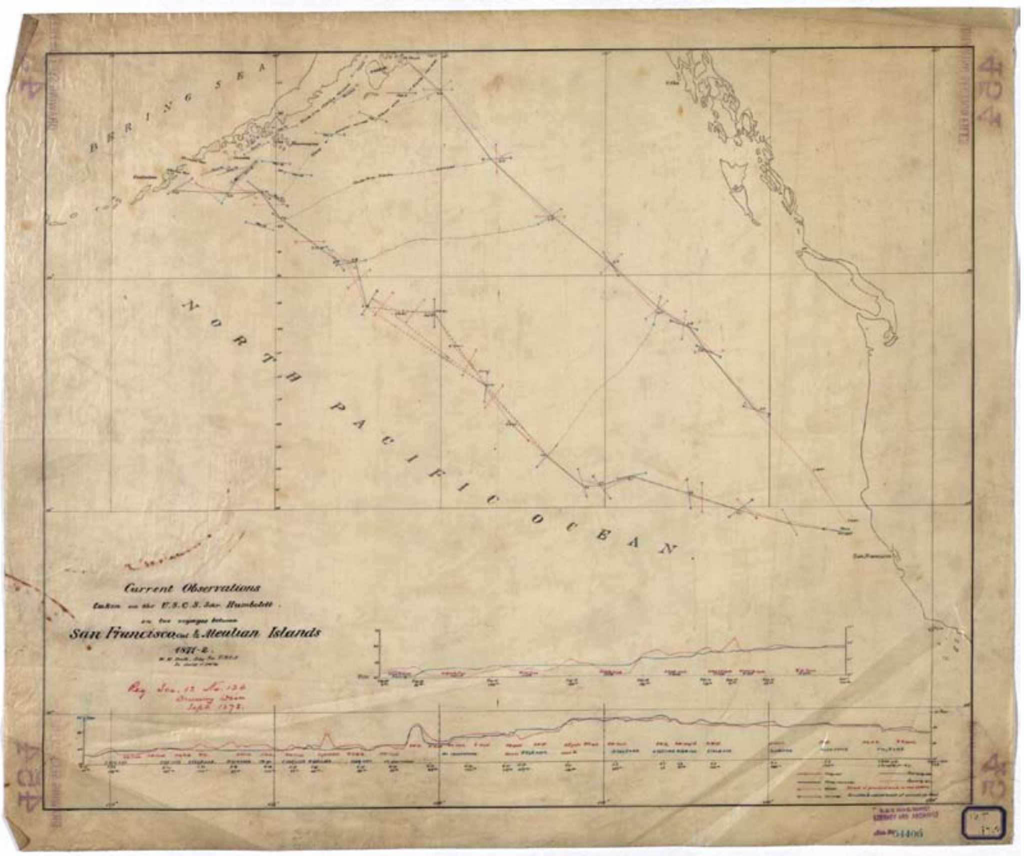
One of the most immediately critical environmental problems that the United States acquired with the purchase of Alaska was the disposition of the vast but shrinking populations of fur seals, whose major breeding grounds were limited to rookeries on the shores of St. Paul and St. George Islands in the Pribilof Islands near the center of the Bering Sea. In 1871-72, Dall made a voyage to the Aleutians as part of his first command of a Survey ship. Dall's recordings of sea and air temperatures, wind speeds and directions, and current speeds and directions were an important contribution to NOAA's vast repository of historic climate data from the far north. The next voyages he made included trips to the Pribilof Islands which he and his party surveyed. The party also included Henry Elliott, who was working as a Special Agent of the Department of the Treasury, which had been given responsibility for the monitoring and protection of the fur seal populations. Elliott evolved into a major cartographer of the fur seal rookeries, as well as a major advocate for the protection of the species, a saga that went on for decades. One of his first published efforts, in collaboration with Dall, was the Coast Survey's map of St. Paul Island which included an island view by Elliott.



St. Paul Island, Pribiloff Is., Bering Sea (1875)

Dall proved to be a skilled expedition leader as well as a very capable scientist. Davidson had journeyed to Alaska twice, for general reconnaissance and then the very specific expedition for the solar eclipse of 1869. Dall pioneered regular annual cruises to the vast new Alaskan territories and seas, leaving in the spring from the west coast, and staying up north in Alaskan and related waters until the onset of winter forced the ships back south, which is essentially the same pattern that the Coast and Geodetic Survey and now NOAA have followed for the next century and a half. Dall's first voyage resulted in a significant report on the positions of Alaskan ports and the nature and structure of tides and currents around them.[29]

[29] Dall, 1872, App. 10, pp. 177-212,



Current and Meteorological Observations taken by William Dall on the U.S.C.S. Sch. *Humboldt* in two voyages between San Francisco & Aleutian Islands 1871-2 (1872)

In the last year of Peirce's tenure, the annual report featured a map showing the vast area that Dall and his parties had explored in the relatively few years since Russian America had been purchased and Dall hired to the Survey.

Figure No. 21 Explorations of William Dall in Alaska (1874)

In summary, in Peirce's tenure the American purchase of Alaska opened a new and extraordinarily productive arena for the Survey. The Survey explored indigenous cartography, terrestrial cartography of the entire vast territory in regional context, circulations of air and seas in the Far North, and the beginnings of monitoring and mapping of marine mammal distributions and their management. Work in these fields has continued for the last century and a half.

The Great Triangulation Arc of the 39th Parallel Survey Begins

Under Superintendent Peirce, the Survey secured resources for new instruments and equipment, the exploration of new techniques, the application of traditional work methods to new and novel territories, and the development of entirely new applications of Survey work. These matters all combined in the initiative to link together geodetically the existing coastal geodetic networks. This eventually was known as the Great Triangulation Arc of the 39th Parallel Survey. This developed because of the convergence between the recognition of great errors in American terrestrial positions and the new need for greater accuracy in determining positions throughout the nation.

In 1869, the completion of telegraph lines across the country allowed the longitude of the Survey's San Francisco primary stations to be determined much more accurately than by chronometric methods. That meant that, given appropriate access to telegraph lines, more accurate determination of the latitude and longitude of points anywhere between the oceans was possible. These new determinations made it clear that there were grave errors in many places. As Peirce noted in his report for 1871: "at the state-house in Columbus, Ohio, the longitude deduced from observations made in October last by one of our most experienced assistants, proves that the previously accepted position is in error by as much as three miles. This discrepancy was not known when the governor of Ohio applied for the benefit of the provision made by Congress". [30] Ironically, less than a century later Ohio State University in Columbus became one of the greatest centers for geodetic research in the world.[31]

The reference to "the benefit of the provision made by Congress" concerns the great new need that had developed. Early in the Civil War, Congress had passed the Homestead Act of 1862. The Act provided a legal method by which US citizens or intended citizens "who had never borne arms against the U.S. government" could file applications for up to 160 acres of public land in the United States. There were various requirements, but key to the matter was the necessity to establish the position of the acreage satisfactorily for the standards of local land offices in the states or territories, which would then forward the applications to the General Land Office, the federal agency

[30] Peirce, annual Report for 1871, p. 5
[31] See Cloud, 2000.

overseeing the entire process. During the war, there was little pressure on the land office system, but that changed completely after the end of the war. People unsettled or displaced by the conflict, and people fleeing crowded eastern cities and also depleted eastern agricultural lands, poured towards the interior of the continent. The newly completed trans-continental railroad, and many other new railroads, turned the migration into a flood. The most critical problem with the entire homesteading system was the inaccuracy of the extant positions, especially the key monuments which "anchored" the different and un-related systems being set up in the states and territories. As Peirce noted:

> "By means of a limited number of well-ascertained points in each State, the existing maps might be corrected by State authorities, and used in the improved form, as they are used now, for general purposes. Special needs will in time press for the minute survey, first of one part and then another, until the whole area of each State is correctly mapped. If, therefore, positions are determined in advance, and in sufficient number for the area, more or less, after serving for the partial correction of State maps, the same points avail for the State authorities in making future topographical and geological surveys...Hence the work done by the Government in the geodetic connection of the Atlantic with the Pacific coast, as proposed in the estimates, incidentally avails for the geographical adjustment of large and populous areas in the West, and presents a motive for early action in regard to correct State maps, in the issue of which the Government has collateral interest, through the requirements of the postal service".[32]

Peirce's proposal was a masterful chess move by the Survey in the context of both the states of the American interior, and rival powers and agencies in the federal government. In the immediate present, states and territories needed accurate positions for individual state systems that were adequate for the needs of platting homesteads and providing a generally coherent mapping system, whatever that might require. And the Survey was already providing occasional determination of positions for such systems, where they were urgently required, as for example in the newly opened Wyoming Territory. Here positioning was coupled with major research in the impact of the atmosphere on astronomy.

[32] Peirce, Ibid. p. 5.

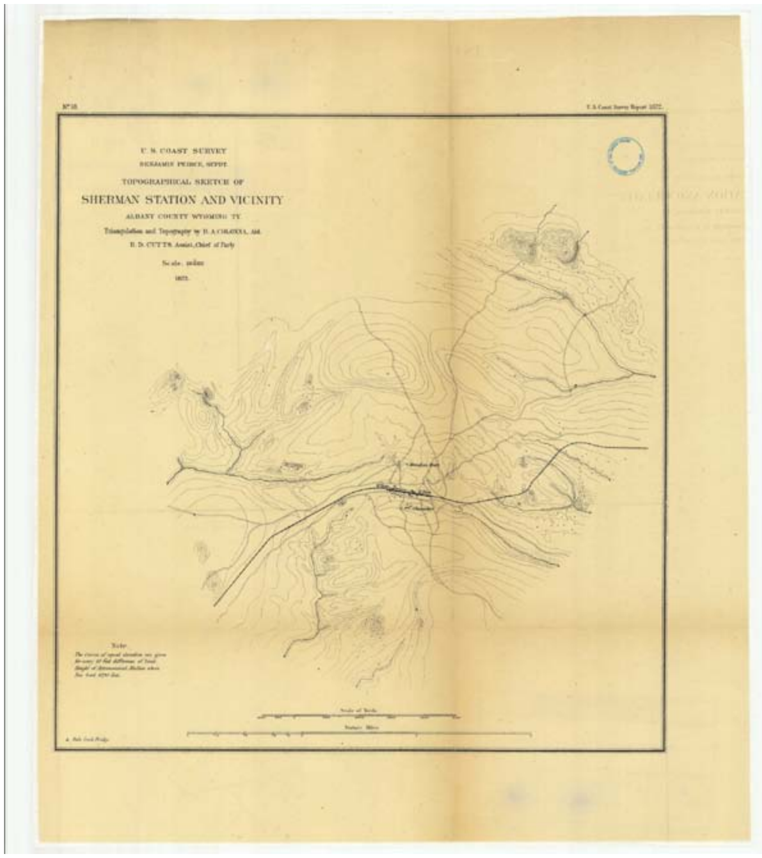


Figure 18: Observations at Sherman Station and Vicinity, Wyoming Territory, 1872

The scientific occupation of the Sherman Station reveals much about the increasingly sophisticated and integrated investigations of the Survey, and its inter-relationships with other American scientific institutions. Pursuant to resolutions passed by successive meetings of the American Association for the Advancement of Science (AAAS), appeals were made to Congress to fund "establishing an observatory and maintaining a scientific corps, for one year or more, at one of the highest points of the Pacific Railroad, and particularly at the eastern rim of the Utah basin". The purpose of the observatory was to occupy the highest point possible, with the best equipment, "'in order that the celestial phenomena observed with the telescope, noted by photography, or analyzed by the spectroscope' could be compared with similar observations made near sea-level, with a view to determine the advantages to be gained for the advancement of astronomical science, by an elevation of the instruments above nearly one-third, and certainly the densest strata, of the atmosphere".[33]

But what Peirce was proposing was, instead of more of that, that the Survey be funded to create an integrated geodetic network of such high precision and accuracy that states and territories could use the determined positions both for early use in registering homesteads and titles, but also for later subsequent mapping purposes that would require

[33] Cutts and Young, 1872, App. 8, p. 75.

much higher accuracy than the initial application required. That way one system would work for both early and later applications, instead of requiring re-surveys at much higher accuracy (and much higher cost) later on. And, as he notes, the geodetic network would fulfill federal purposes for mapping related to the national postal system. But he was also pursuing a clever strategy in the context of new and powerful rivals within the postwar federal agencies.

Behind his reference to the fact that "the same points avail for the State authorities in making future topographical and geological surveys" lay an enormous contention. Many elements of the postwar U.S. Army were organizing explorations of the west for topographical and geological purposes. John Wesley Powell had created the nascent Geographical and Geological Survey of the Rocky Mountain Region, and there were other ambitious players jockeying to create new federal initiatives and agencies which would inevitably come into conflict with the Survey. What Peirce proposed, then, was that the Coast Survey would rapidly and accurately develop the geodetic network that all subsequent *topographical* and *geological* surveys, be they state or federal, could tie into. That way, the Survey would retain control (and funding) for the national geodetic network, regardless of the political fates of the various initiatives to establish new agencies and budgets for exploring and mapping the national interior.

And the Survey's approach to the proposed trans-continental survey was disparate enough to fit the varying geography and topography of the very different terrains that the nation encompassed. The foundational geodetic networks that the Survey created on both the Atlantic and Pacific coasts were based on triangulation from hills and mountain peaks to other peaks. To cross the great middle of the country would eventually require the construction of artificial peaks, as in the great Bilby towers. But, there were other possibilities, utilizing the same great technologies that the Coast Survey utilized in the Civil War.

In particular, Julius Hilgard, the Assistant in Charge of the Office at Survey headquarters, was an early advocate for creative utilization of the vast new railroad networks for geodetic work. As he noted:

> "In many of the states of the Union that lie west of the Allegheny Mountains, the execution of a trigonometric survey, as a basis for a correct map of the country, would be a hopeless undertaking in the present state of its cultivation. But a careful measurement of the railroad lines traversing it in every direction, according to the methods which it is here proposed to develop, would afford a network not inferior in accuracy, and well calculated to furnish valuable additions to our knowledge of the figure of the earth if a proper system of determinations of latitude and longitude were combined with it.
>
> "Irrespective of the object of obtaining data for a correct map of the country, the methods here proposed are especially adapted to the measurement of arcs of parallels or meridians—geodetic work properly

> speaking—a matter in which we are, as a people, greatly in arrears to the demands of modern civilization. While in all nations of Europe eager efforts are making to ascertain the dimensions and configurations of our globe, America is doing nothing in the common cause except what the survey of the coast and the lakes incidentally accomplish. Some of the railways running north and south in the valley of the Mississippi, and others traversing it in an east and west direction, are admirably adapted for the ascertainment of such data. No more valuable and permanent additions to science could be made by associations desiring to contribute something to the sum of human knowledge than the admeasurements of such arcs—no mode of connecting his name with the history of the human race deserves more the attention of a Maecenas.
>
> "The writer would by no means be understood as advocating the methods he submits in preference to that of triangulation where that is readily practicable. On the contrary, they are to be considered as only supplementary to the latter, which should always be used when the ground is favorable, and which, as will be seen, forms a necessary part of the scheme".[34]

Note then that for the personnel of the Survey, the objectives for the triangulation arc and ancillary work spanned the major objectives of the nation, to provide the geodetic foundations for "a proper map of the country" and also "the dimensions and configurations of our globe".

To the American public, and also most historians, the post Civil War era is popularly identified with heroic reconnaissance expeditions "west of the 100th Meridian", down the Grand Canyon, down some other canyon, always westward into some proverbial Unknown. But so it came to pass, under Peirce's initiation, that the staff of the Coast Survey initiated a major enterprise that, in the western states, traveled in the opposite direction, heading eastward, ever eastward, and from mountain peak to mountain peak, as the Coast Survey worked from both the Atlantic and Pacific coasts to tie the separate geodetic networks into one unified system. And in doing so, there are very specific reasons why the major part of the arc of the triangulation system was designed to roughly parallel the 39th degree of latitude, and not some other parallel. The story concerns the essence of Hilgard's desire for the Survey to "contribute something to the sum of human knowledge".

The Coast Survey and Increasingly Internationalized Science

The Coast Survey was, of course, "born international" from its foundation by Ferdinand Hassler, who immigrated to the United States with his own personal iron meter

[34] Hilgard,1867. pp.140-141. Gaius Micaenas (70BC-8BC) was a Roman advisor to Caesar Augustus, and a major patron of the arts and science.

bar standard. Further, Hassler's successor, A.D. Bache, was hugely receptive to European scientific personnel and methods. In fact, during his earlier career as an educator who established Central High School and Girard College in Philadelphia, Bache had toured European schools and academies of science and technology, and wrote a multi-volume report of his findings. And finally, the Survey as it developed was filled with European immigrants with polytechnic school educations, who brought a thoroughly international perspective to their work in the Survey. These converged in the Survey.

In the early 20th century, Cleveland Abbe, the great meteorologist and former Survey scientist, looked back almost 70 years to the late 1840s. At that time, he noted, there was a "primary triangle" (that most important symbol of geodesy) formed by A.D. Bache, Charles A. Schott, the Survey's greatest computer, a graduate of the famous polytechnic school at Karlsruhe, and Julius Hilgard, whose German family immigrated to Ohio when Hilgard was a young boy. According to Abbe, this triangular foundation—two legs of which were German immigrants—was the basis for the success of the Survey under Bache.[35] With Bache gone, the other two legs remained, and Peirce replaced Bache as a thoroughly internationalized scholar.

The Peirce superintendency happened to coincide with—and of course, also aided—a remarkably productive and cooperative period in an array of disciplines associated with the geophysical sciences. As earlier noted, Julius Hilgard had lamented, in 1867, that: "[w]hile in all nations of Europe eager efforts are making to ascertain the dimensions and configurations of our globe, America is doing nothing in the common cause except what the survey of the coast and the lakes incidentally accomplish".[36] He was referring, in part, to the establishment of the International Geodetic Association (IGA), which held its first meeting in 1864 in Berlin. From the beginning, there was a premium on international cooperation in research, sharing data, and establishing and maintaining appropriate standards of reference in lengths, weights, all measures, forces, and other critical units.

Essentially, the Coast Survey became a participant in major internationalized science, with or without any specific Congressional mandate to do so. The figure of the earth cannot be locally determined—it requires vast quantities of data from many different locales. The Survey accelerated the processes by which units and instruments were standardized in conformance with new international standards, which was a major objective of the IGA's founding. This enterprise then merged with the newly expanded agenda of the triangulation arc of the 39th parallel. As Hilgard had noted in 1867, the United States was doing little to advance the "common cause" of geodesy apart from work incidental to the surveys of the coast and the lakes (meaning, in the latter case, the Lake Survey of the Great Lakes by the US Army Corps of Engineers). The great arc survey and its extensions to the side via railroad lines, as Hilgard proposed, could open up most of North America to "the common cause".

[35] Abbe, 1915, p.3.
[36] Hilgard, 1867, p. 140.

In anticipation of expanded research opportunities in many new places the Survey designed and built new classes and types of instruments for broad application across large areas. An example is the Survey's theodolite magnetometer (1872). The instrument measured the horizontal component of the local magnetic field at a location anywhere the Survey worked. As terrestrial magnetic fields are important but weak, the instrument was an incredibly delicate and sensitive instrument, yet it was designed for the field, and designed to be carried across the continent on mule panniers. The instrument, and many others designed similarly, were purposed to achieve two of Peirce's goals at once: the instruments could provide accurate local magnetic variation virtually anywhere, so that state and local mapping projects could make accurate local compensations for magnetic variation from true north; at the same time, the use of the instruments on a systematic plan could populate data fields across the continent, which could aid the investigation of geophysical problems and issues far beyond the scope of local mapping systems.

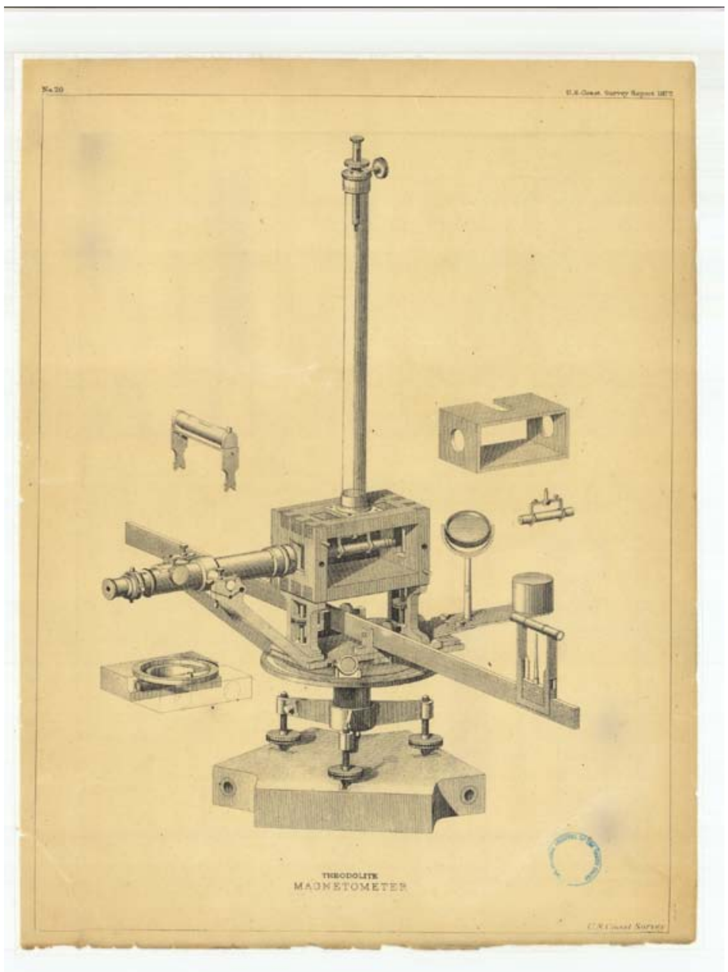


Figure 20: Theodolite Magnetometer (1872)

This much more nuanced approach to the totality of geophysical data measured at stations also extended to greatly accelerated research by the Survey on the many sources of deflection of the vertical as observed at stations. "Deflection of the vertical" refers to the disparity between the position of the true zenith above a point (straight up relative to the center of the earth) and the apparent zenith, as disclosed by the local gravity field. A suspended plumb bob will hang perpendicular to the local gravity field at any given spot. If that plumb bob at the site doesn't point precisely to the center of the earth, then the difference between its direction and the direction of the true zenith, for that spot, is the deflection of the vertical at that spot. This is of immediate concern to the geodesist as horizontal angles observed between points are affected by this phenomena as the observing instrument, although level relative to the local gravitational field, is not observing angles in the surface perpendicular to a line extending to the center of the earth. This in turn will cause erroneous azimuths (directions) between those points and could ultimately cause errors in the calculated geodetic positions.

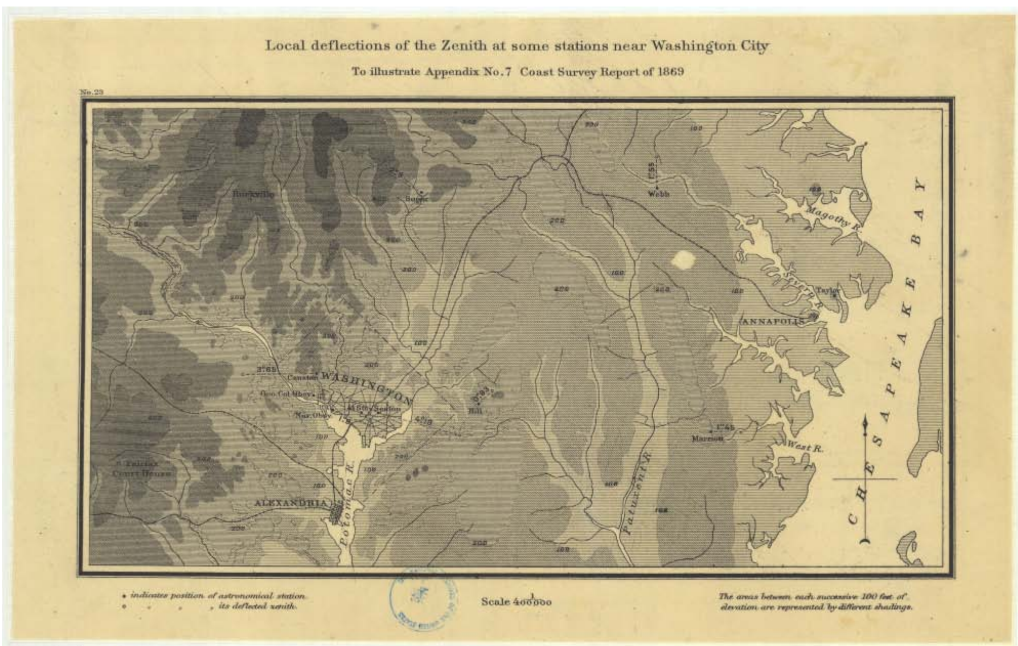


Figure 23: Local Variations of the Zenith at some stations near Washington City (1869)

Precise survey work in the United States, India, and elsewhere, had been demonstrating significant patterns of variation in deflection of the vertical for several decades before Peirce's tenure, along with patterns of deflection that indicated some consistent disparity between the mass distribution of oceanic and continental crusts. Resolving these patterns would require understanding much more about local and regional variations in the local gravitational fields, as well as much more about the composition and structure of the earth's crust. The Survey scientist who led the way in these new investigations was the son of the Survey's Superintendent.

The Gravity of Charles Sanders Peirce

Charles Sanders Peirce (1839-1914)

C.S. Peirce has been mentioned occasionally in this chapter already. C.S. Peirce was the third of four sons of Benjamin Peirce, who also had one daughter. He grew up in Cambridge and was educated at Harvard, just like his father. He first worked for the Coast Survey in 1859, as a field aid in Maine helping conduct magnetic observations. The other assistant had been drafted for the Civil War; Peirce never served in the war. In 1867, when Benjamin Peirce became Superintendent, he appointed C.S. Peirce as a Survey aide, later elevated to an assistant. During the period between his first work for the Survey in 1861, and his permanent employment in 1867, Peirce apprenticed at the Harvard College Observatory where he was introduced to spectroscopy and trained on the Observatory's first spectroscope in 1867. Peirce introduced the instrument and its use to the Survey, using the Harvard instrument for observations of the same total solar eclipse in 1869 that had bonded George Davidson and Kohklux. Peirce observed the eclipse in Kentucky; in doing so, he became one of the first to observe the spectrum of the element argon, made visible at totality.[37]

C.S. Peirce brought at least three sets of skills and talents to his work at the Survey. First, he was a gifted and imaginative cartographer who designed novel and unusual maps that proved very useful, as first seen in the maps of the zone of eclipse totality he created for the observer parties for the 1869 eclipse. Second, C.S. Peirce displayed extraordinary talent for meticulous observation, measurement, and analysis of extremely fine data. He had a natural affinity for measurement, and the measure of measurements, at a very propitious time for such skills. Indeed, in 1872 there was called an international conference on metrology (the science of measurements) in Paris. Benjamin Peirce appointed Assistant in Charge of the office Julius Hilgard to represent the Survey and the United States at the conference. Hilgard, it should be noted, was establishing a reputation as a skilled designer of instruments for measurement of many kinds related to measuring materials of great significance to American commerce as well as science. These included an innovative spirit-meter (which refers to measuring the

[37] Crease, 2009, p. 40

alcoholic content of a fluid). This was a significant period in regards to such matters, as much of the federal government's revenue came from taxes on alcohol. There had been many scandals involving bribery of revenue officials, and Hilgard's new spirit-meter, which was designed to be implanted within the piping systems of the distillery to preclude tampering and bribery, had great consequences for government revenues. As the Commission on Internal Revenue noted of Hilgard's new devices in 1871: "These instruments distributed under the present system of inspection, seem to give general satisfaction, and their accuracy and uniformity have relieved the trade of the embarrassments resulting from errors in gauging."[38]

In Hilgard's absence, Peirce the elder appointed his son C.S. Peirce in charge of the office, which in part made him in charge of the Survey's Office of Weights and Measures. His experiences with the Office led to research topics he pursued for the rest of his life. But a major new research direction for C.S. Peirce and the Survey also developed, not in relation to Measures, as such, but with regard to Weights, which is to say—forces.

It was C.S. Peirce who really introduced the Survey to modern gravitation research, and who pioneered gravimetric pendulums which became the basis for Survey gravity work for the next half century. However, his major gravimetric work didn't begin until he was able to secure a standardized reversible pendulum. Designed by Friedrich Bessel and built in Hamburg, the instrument was designated by the IGA in 1872 to be the standard instrument for a global network of gravimetric surveys. However, so many instruments were ordered for the 1874 Transit of Venus, that it wasn't until 1875, after Benjamin Peirce's tenure, that his son C.S. Peirce was able to acquire a pendulum and begin the Survey's gravity work. [39]

The third great skill and talent that C.S. Peirce brought to the Survey, proving him very much the son of his father Benjamin, was a masterful approach to dealing with the sources of scientific error. In this, he was clearly his father's son, since the analysis of errors was also much a part of the mathematical career of Benjamin Peirce. And both father and son were involved, their entire scientific lives, with precise astronomical sightings and timings. Astronomical data, in particular, was plagued by errors based on optical and atmospheric distortions, timing errors, and above all human errors in perception and action. Peirce had a refreshingly humble attitude towards the process: "The non-scientific mind has the most ridiculous ideas of the precision of laboratory work, and would be much surprised to learn that, excepting of electrical measurements, the bulk of it does not exceed the precision of an upholsterer who comes to measure a window for a pair of curtains"[40].

Peirce encountered a system that had evolved to account and correct for errors principally through amassing numerous observations and adjusting them to converge on a solution by methods of least squares adjustment. Peirce's key insight was that different

[38] Report of the Commission of the Internal Revenue for 1871, p. vi.. In True,1913.
[39] Crease, ibid., p. 41.
[40] In Crease, 2009, p. 39.

types of errors had their own disparate relationships to the theoretical true values sought, and hence these different types of errors should be partitioned and adjusted separately. As he noted in his first major treatise on the subject: "When it is necessary to combine, by least squares, observations of different orders of precision, they are weighted proportionally to h squared [h is one of several critical values in the analysis]. If we have two series of observations, one of which is as accurate as you please, and the other as inaccurate as you please, a better result than that which the most accurate series of measures gives can always be got by combining with it the least accurate series, provided that the proper weights be given to the two series. This proposition seems paradoxical, and is not admitted by very many competent heads, but I cannot see how the conclusion can possibly be evaded. It does not depend at all on any of the peculiar principles induced by the method of least squares, but rests on the fundamental axioms of probabilities. Indeed, it may conveniently be based on the principles of logic itself".[41]

Peirce had a complex and troubled career, both in the Survey and outside it. However, he made major contributions to the work of the Survey in many fields. And the work in the Survey, as indicated above, was to him a fertile field for explorations of "the principles of logic itself" which certainly was his life-long preoccupation.

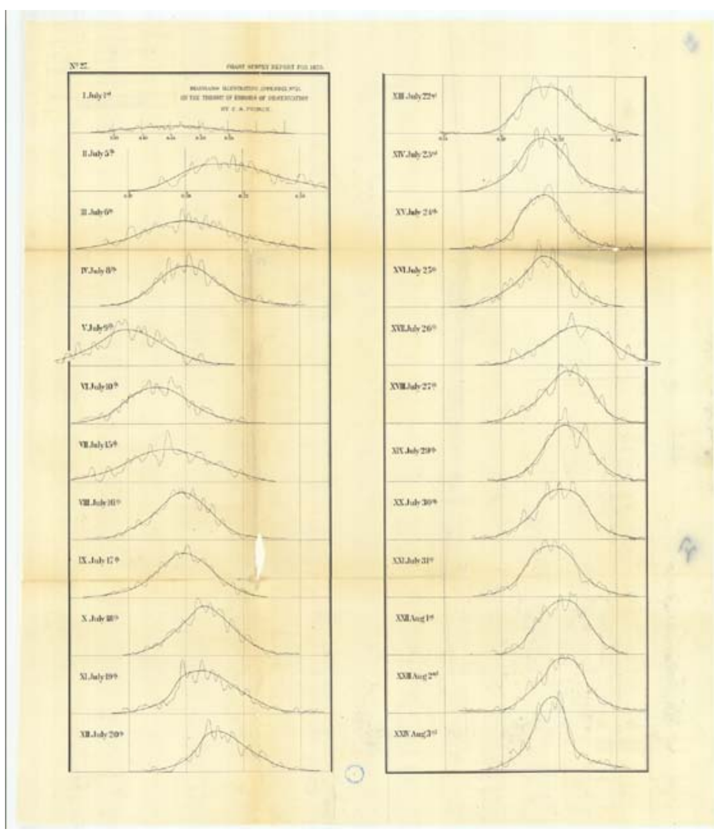


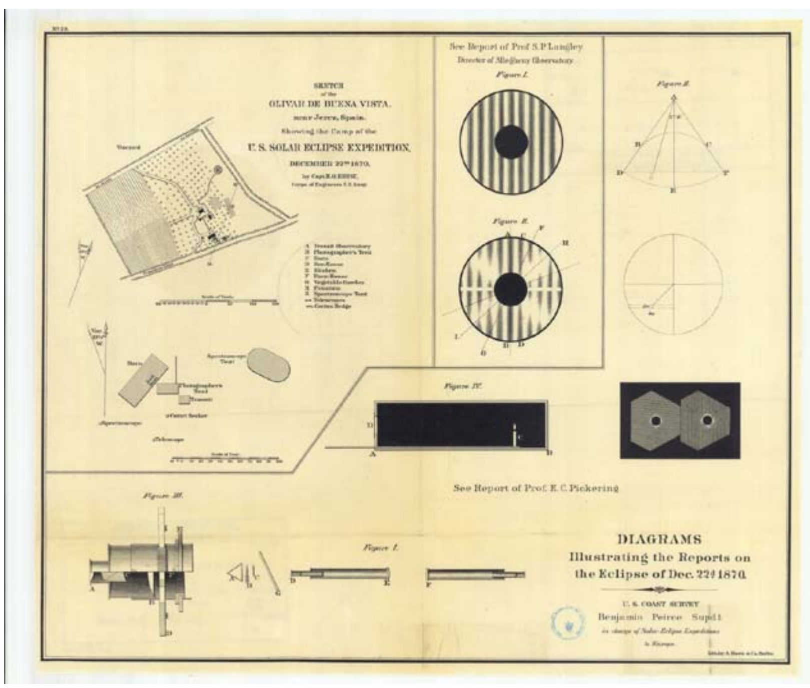
Figure No. 27 Diagrams illustrating App. No. 21 on the theory of errors of observation by C.S. Peirce (1870)

[41] Peirce, 1870. App. No. 21, p. 207

Benjamin Peirce, the Survey and the Cosmos

Benjamin Peirce's final years as Superintendent were a zenith, both figuratively and literally. In many ways, Peirce's research objectives for the Survey—and, of course, the carefully cultivated Congressional funding to support them—allowed Peirce to return to the very subjects that occupied him as a young man, when he worked for a decade editing and correcting Nathaniel Bowditch's translation and commentary on LaPlace's *Mecanique Celeste*. Much of LaPlace's masterpiece was devoted to the analysis of relative motions of celestial bodies in the solar system, from which, through elaborate and difficult mathematical analysis, LaPlace deduced various properties, particularly masses, of the celestial bodies. Survey scientists were deeply engaged in closely related research. These investigations included William Ferrel's attempt to construct a better estimate for the mass of the Moon, based on an analysis and discussion of the patterns of tide in Boston Harbor[42].

Survey scientists also participated in a spate of internationally organized observations of major celestial events in Peirce's final years as Superintendent. George Davidson's observation of the total solar eclipse in 1869, with Kohklux in Alaska, has already been discussed. The next year, in 1870, there was another solar eclipse, and Survey personnel were dispatched to various places outside the United States to observe it. In particular, several parties were sent to Europe. One Survey party was quartered on a Spanish farm on the site of a Roman villa.



No 28 Sketch of the Olivar de Buena Vista, near Jerez, Spain showing the camp of the U.S. Solar Eclipse Expedition (1870)

[42] William Ferrel, 1870, App. 20, pp. 190-200.

A notable participant in that expedition was Charles A. Schott, the Survey's greatest computer. But, as his old friend Cleveland Abbe noted, "Schott always availed himself of every opportunity to forsake the office to breathe the pure air implied by geodesy and hydrography".[43]

Eclipse Expedition, 1870, Spain. Schott with the Davidson Meridian Instrument (from the B. Colonna and F. Bailey Photograph Collection)

And George Davidson himself left the country again, in 1874, for observations of the celebrated Transit of Venus, in one of many Survey parties sent to the field for observations. In Davidson's case, he went to Nagasaki, Japan, for the Transit. His party included Otto Tittmann, a future Superintendent of the Survey, and his wife Elinor and son George, who were enlisted as data recorders as their party was short of personnel. While setting up the observatory site, Davidson and company utilized a submarine telegraph cable between Russia and Japan, using Bache's "American method"," to determine the longitude of the Nagasaki observatory site with geodetic precision. This became the POB (point of beginning) for the Datum of Japan.[44]

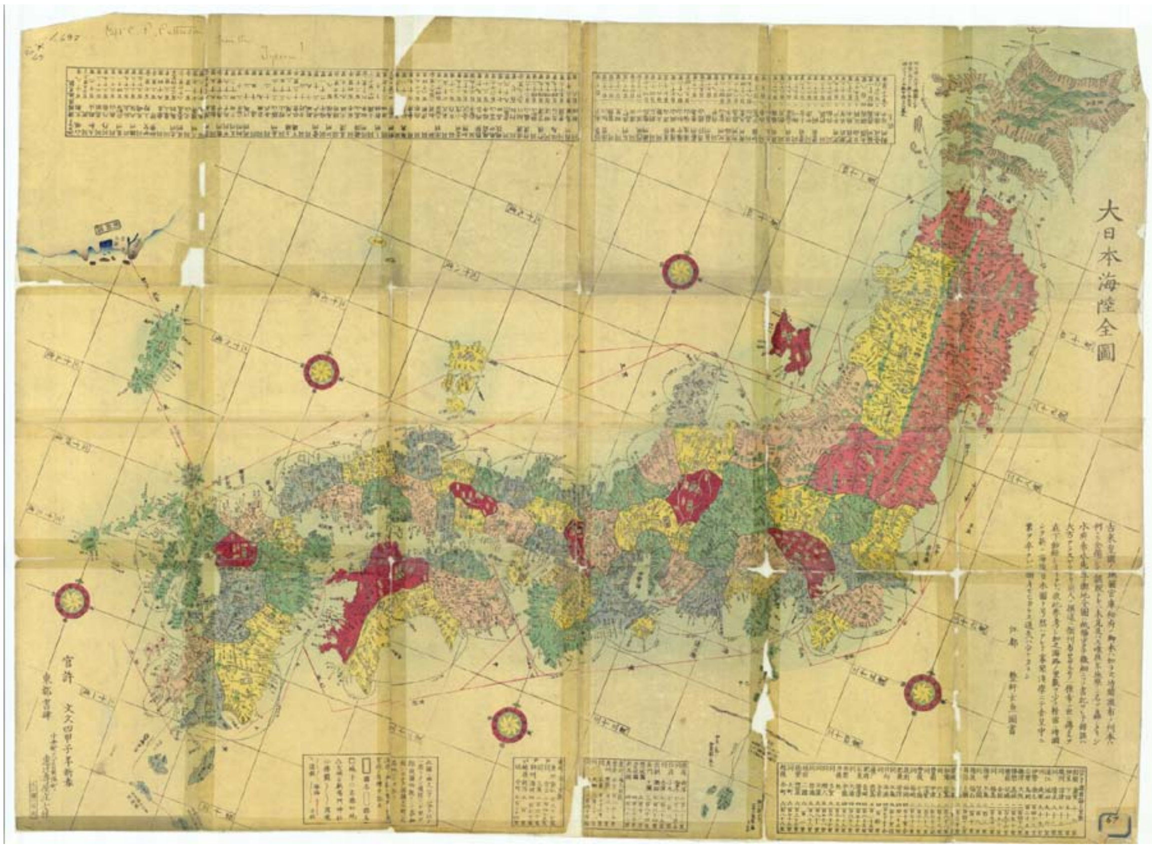
Davidson reflected on his astronomical experiences at higher elevation in the California Sierras, and across to the east along the 39th Parallel Arc, about the importance of obtaining observatory sites at high elevation if possible. This also reflected the meticulous comparative astronomical work that Survey personnel had performed at the Sherman Station in Wyoming Territory. "The judgment which I expressed about four years since of the importance and necessity of great elevations from which to make astronomical observations of precision, and subsequently, of the importance of observing the transit of Venus at great elevations (Special report and letter to the late Superintendent) was amply confirmed by my experience at Nagasaki". [45]

The "late Superintendent" Davidson referred to was Benjamin Peirce, who had not died. Rather, at the culmination of a brief but hugely successful period of seven years as the successor to the great A.D. Bache, Peirce decided to return to full-time work at

[43] Abbe, 1913, p. 12
[44] See Numata, 2009 and 2010.
[45] Davidson, 1875, App. No 13, p. 228.

Harvard, feeling that the Survey was on sound footing and an appropriate successor was at the ready. It was Peirce who organized the celestial expeditions and found Congressional funding for them. But Peirce, whose most important mathematical treatise began with the statement that “mathematics is the science of necessary conclusions”, had decided that his Survey career required a necessary conclusion of its own.

When George Davidson returned from Japan with a very historically significant vivid colored wood block map of Japan, he was returning it as a gift from the Tykoon, the powerful military aide to the Emperor for—Captain Carlile P. Patterson.



Map of All Seas and Lands of Great Japan. A gift to Capt. Patterson from the Tykoon!

Benjamin Peirce, the reluctant Superintendent, had revitalized the Survey after the war and the decline and death of A.D. Bache, the great leader. The vitality of the Survey was made apparent by Patterson’s selection as the next chief. For the first time in the history of the U.S. Coast Survey, the Survey’s leader was chosen from the Survey itself. A momentous era in the history of the Coast Survey was about to begin. It would see the end of the Coast Survey itself—and the birth of the U.S. Coast and Geodetic Survey.

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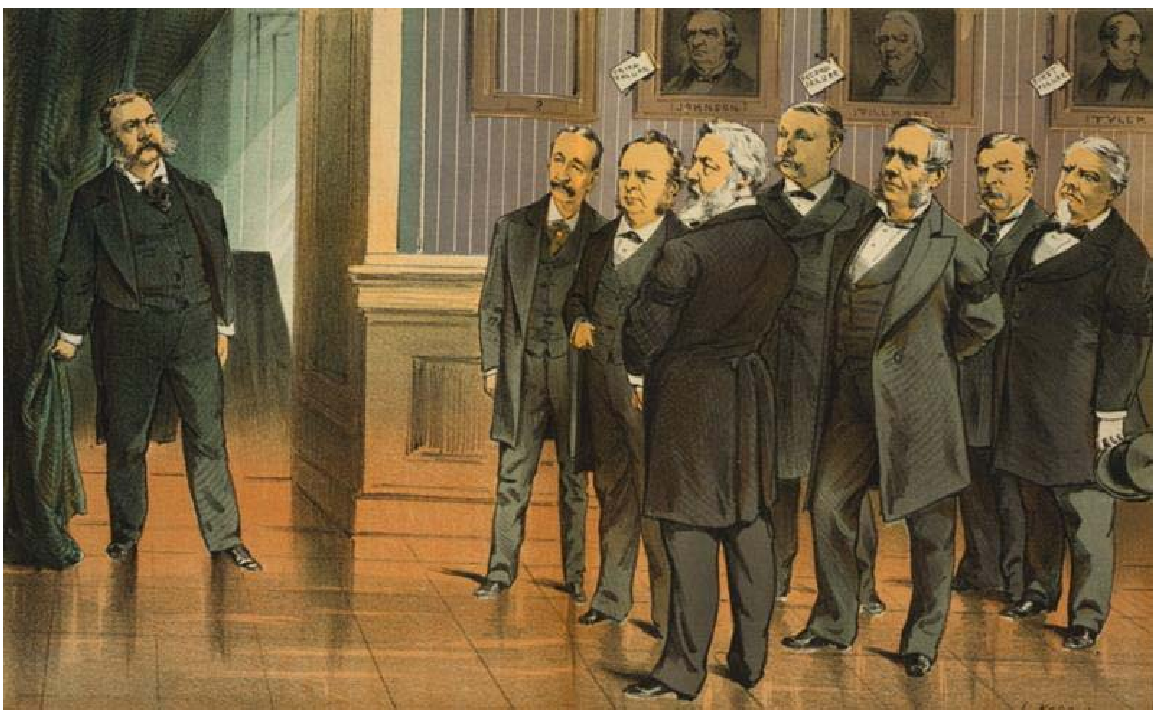
The Decline and Fall of Professor Hilgard (1881-1885)

Julius Eramus Hilgard in 1875 (left) and undated but later (right)

Two dramatic events in the city of Washington in the hot summer of 1881changed the history of the Coast and Geodetic Survey utterly. Both events were immediately experienced as separate tragedies; it would take some years for the full implications of their compounding to be realized. The first event was the assassination of President James A. Garfield on July 2, 1881 by a disgruntled office-seeker named Charles Guiteau in the main Washington train station. Although Garfield survived until September, he had been seriously wounded, and a series of medical errors compounded his injuries and eventually led to his death. During that time of crisis, Carlile Pollock Patterson, the 4th Superintendent of the Coast and Geodetic Survey died suddenly on August 15, 1881.

Patterson's death precipitated an immediate crisis for the Survey. Patterson had been an able leader, and was exceedingly well-connected to the leadership of American science and society. Continuity in the succession of the Survey's leaders had been aided for decades by the interventions of Joseph Henry, the Secretary of the Smithsonian Institution, but by 1881 he had been dead three years. For the first time since Ferdinand Hassler's death in 1843, there was no one great American champion of the Survey to pull the strings concerning the Survey's leader and its relation to Congress.

President Garfield's death led to far-reaching changes in the organization of the federal government, which took many years to take effect, by complex developments and processes. Garfield was succeeded the day after his death on September 18, 1881, by Chester A. Arthur (1829-1886), who served out the remainder of Garfield's single term. Garfield was a member of the Republican Party, and specifically the "Stalwart" faction, which was relatively opposed to reform of the civil service system and the abolition of political patronage in federal and state employment and appointments. Apparently to the surprise of many, Arthur's positions changed radically upon becoming President.



1881 cartoon from Puck showing President Arthur meeting his Cabinet. On the wall behind them are one empty frame and portraits of Andrew Johnson, Millard Fillmore, and John Tyler, the other three Vice-Presidents who succeeded Presidents who died in office.

President Arthur, once in office, became a champion of reform in the federal government, particularly known for his success persuading Congressional passage of the Pendleton Civil Service Reform Act of 1883. The law established the United States Civil Service Commission, which placed many and possibly most federal jobs under a merit system (the Coast and Geodetic Survey had promoted on merit since the time of Ferdinand Hassler) as opposed to previous methods of obtaining positions and maintaining them. These changes had varying effects on the many disparate federal agencies. And they invited a new era of vigorous scrutiny, by Congress and the press, of the functioning of federal agencies and their expenditures, in particular. Further, the US Geological Survey had been established in 1879, only two years before the deaths of Patterson and Garfield, and the considerable overlap between their work and that of the Survey created an inevitable jockeying for status and authority. And, on top of that, the Navy Hydrographic Office and its allies was preparing yet another campaign to take over the Coast and Geodetic Survey, as the Navy had periodically attempted for over half a century already. All these matters converged to influence the fate of Superintendent Patterson's successor.

An Introduction to Julius Erasmus Hilgard (1825-1891)

The Survey of the Coast began with a brilliant foreign immigrant, Ferdinand Hassler. After his untimely death his successor, the eminently connected American scholar and teacher A.D. Bache turned the Survey into the premier scientific agency in the federal government by a process that involved, in no small part, the ready inclusion of gifted foreign immigrants and their skills into the Survey. After Bache's decline and death, the eminent American mathematician Benjamin Peirce revived and extended the scientific research initiatives of the Survey in a very productive period, even though in many ways his was a caretaker administration, as he continued as an endowed professor at Harvard throughout his tenure. When Carlile Patterson became his successor in the only smooth transition in leaders the Survey had ever experienced, he became the first Superintendent of the Survey to have risen through the ranks of the Survey. All these disparate paths to leadership of the Survey then converged in the ascendancy of the 5th Superintendent, Julius Eramus Hilgard.

Hilgard was born in 1825 in the town of Zweibrücken in what was then the Palatinate, in what is now Pheinland-Pfalz, in western Germany. His father gave up a successful career in jurisprudence in Bavaria to immigrate to the United States "under the mistaken impression that ideal social and political conditions were to be found on a remote farm in Illinois, whither he accordingly transplanted his large family" when Julius was 10 years old. There the Hilgard family lived an agrarian existence, the Hilgard children largely home-schooled by their father in most subjects, except mathematics. From a very early age, Julius Hilgard's mathematical talents were recognized, and he instructed his father as well as his siblings in the subject. The Hilgard family's intellectual pursuits were largely isolated from their neighbors, and conducted primarily in German. Julius learned English primarily from books, and throughout his life he spoke the new tongue with a pronounced accent[1].

[1] Tittman, p. 462.

In 1843, Bache succeeded Hassler as Superintendent of the Survey, and its great transformation began. That same year, 18-year old Hilgard met Bache in Philadelphia, and in a subsequent letter to Bache Hilgard noted several errors in the formulas used to calculate geographic positions. Bache immediately offered him a job, but in a subordinate position, given his youth. Hilgard reputedly replied that he would rather do “high work at low pay than low work at high pay”, and Bache hired him to the Coast Survey[2]. It was the only job he ever had for the rest of his life.

Sixty-eight years after that day in 1843 when Bache hired Hilgard, Cleveland Abbe published a memoir on the life of Charles Anthony Schott, the Survey’s great computer. In that memoir, he stated that at the heart of Bache’s transformed Survey was a primary triangle formed by Bache, Schott, and Julius Hilgard. Bache was the well connected American leader and the major ideas man; Schott was the great brain, although he also excelled at fieldwork and sought every opportunity “to breathe the pure air implied by geodesy and hydrography”[3]; Hilgard complemented them both by acquiring skills in every arena of the scientific activity of the Survey, but also functioning as a superb manager of the staff in the field and the office. “Hilgard’s mind, in so far as his professional duties were concerned, was eminently practical. While directing large interests on the broadest plans, he grasped and gave attention to the minute and varied details of the work entrusted to him, introducing economies, by perfecting methods, in many ways, as, for instance, in substituting tapeline measurements along the sandy beaches for the slow and expensive methods of triangulation in vogue along the heavily timbered southern coasts”.[4]

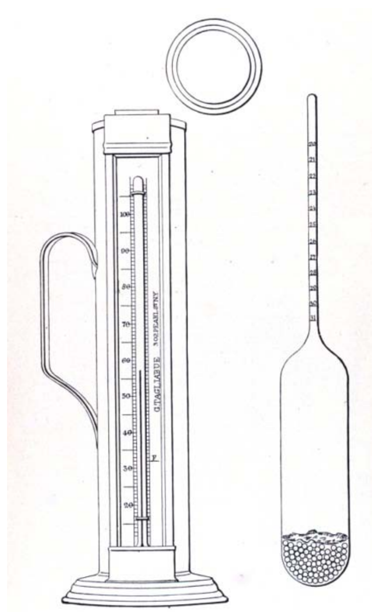
Hilgard was thoroughly versed in Survey field work, and headed a hydrographic field party at the age of 21, but his talents in administration and management of personnel were so critical that he soon became the Survey’s first non-military Assistant in Charge of the Office. As such, he was at the center of the Survey’s political, economic, and social life in Washington. For a short period of time shortly before the Civil War, he left the Survey, for reasons not presently known. However, in 1861, he resumed his old position, in large part to take charge of defending the Survey against another attempt by the Navy to absorb the Survey, this time under the excuse of the war. “[He] was recalled by Bache at the outbreak of the war, when the existence of the Survey was threatened by hostile legislation, to return to Washington and help save and maintain it”[5]. He successfully repelled the Navy’s takeover bid, while at the same time the Survey and the Navy fought the war triumphantly and scientifically.

Hilgard was skilled at instrument use and instrument design, which led to increasing responsibilities in the Office of Weights and Measures. There, he helped shape the legislation introducing the metric system into the United States and he prepared

[2] Tittman, p. 463.
[3] Abbe, p. 89.
[4] Tittman, p. 464-465.
[5] Ibid, p. 463.

the standards of measurement that were distributed to the various states[6]. In 1872 he organized the Survey's initiative to determine telegraphic longitude between Europe and the United States using the trans-Atlantic cable, thereby integrating the great European observatories at Greenwich, Paris and Potsdam with their American counterparts, a feat which he afterwards described as a diplomatic triumph. He represented the United States at the convention in Paris to form the international bureau of weights and measures, and was later offered the directorship of the agency, but he declined it, and stayed with the Survey.

Hilgard had a great affinity for mechanical and scientific apparatus, and served as a judge of these at the Centennial Exposition in Philadelphia in 1876. He designed a number of important scientific instruments, including an ocean salinometer, which was used on voyages of the Survey ship *Blake* and the Fish Commission ship *Albatross* to measure the salinity of deep ocean water samples.



Hilgard's Ocean Salinometer, from Lt.-Commander Tanner's "Report on… the Albatross" in the Report of the Commissioner of Fish and Fisheries, 1883

Seawater salinity is closely correlated with seawater density. Hilgard was dissatisfied with the so-called "bobbing hydrometers" then used at sea to measure sea-water density. In 1877, he converted a hydrographic instrument to a hollow prism, minimum deviation refractometer to determine density optically. This was the beginnings of refractometry in physical oceanography[7]. Hilgard's technique of determining fluid density by refractometry was then developed by many other instrument makers, and instruments based on his idea became standards in oceanography.

[6] Tittmann, p. 464.
[7] Seaver, et al., p. 268

Figure 49. – Réfractomètre FÉRY. (photo Y. Berard)

The Fery Refractometer, based on Hilgard's design

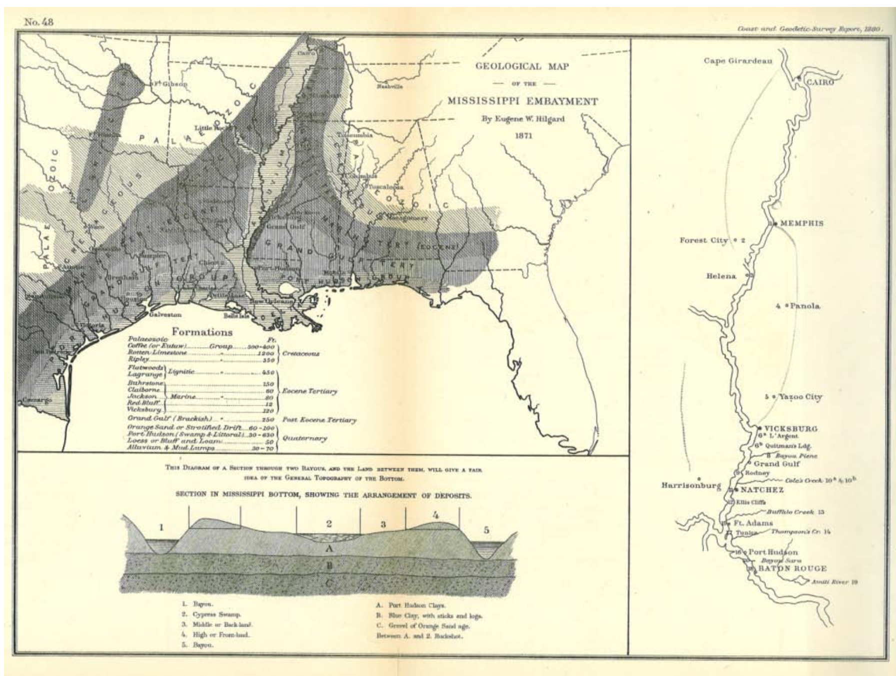
Hilgard, until the very end of his long career in the Survey, was universally admired and respected for his brilliance, initiative, and great generosity. He was a charter member of the National Academy of Sciences, a member of many American and international scientific societies, and served a term as President of the American Association for the Advancement of Science. While still a young man, he acquired the honorific of Professor Hilgard, and even while serving as Superintendent of the Coast and Geodetic Survey he was commonly referred to in the press as Professor Hilgard.

Professor Hilgard was a well-regarded public speaker, and his lectures were often published. As was noted in 1875, "[h]is essay on 'Tides and Tidal Action in Harbors' first published as a lecture before the American Institute, is remarkable for its lucid and terse exposition of principles without the aid of mathematical symbols. While possessing great facility in employing the aid of the higher mathematics, Mr. Hilgard systematically avoids, as far as practicable, their introduction in his writings, preferring to use logical statements of the processes of reasoning".[8]

In the late 1870s, while serving still as Assistant in Charge of the Office, he taught lecture courses on extended territorial surveying at Johns Hopkins University. It is ironic, then, that these lectures at the university in Baltimore were the only occasions in his life when Professor Hilgard ever attended a school. His career was hence contrastive to that of his younger brother, Eugene Woldemar Hilgard (1833-1916). Seven years younger than his older brother, as a very young ma he followed his brother to Philadelphia and then to Washington to meet Julius Hilgard's companions at the Coast

[8] Youmans, p. 618.

Survey, but when an opportunity arose to return to Germany to study chemistry, he took it. After a varied academic career, he received his PhD. under Professor Bunsen (as in the Bunsen burner) and returned to the United States, where his scientific career began in agriculture and geology in the state of Mississippi, on the eve of the Civil War. Despite chaotic times, Hilgard made pioneering discoveries about the geological history of the Mississippi River embayment (a term he coined) and the relations between geology and soil formation and agriculture. In 1880, as the Survey was very active in geodesic leveling of the Mississippi River system, along with Henry Mitchell's new role as the Survey representative to the Mississippi River Commission, the Survey published Eugene Hilgard's 1871 map of the Embayment in the annual report for that year.[9] Eventually Hilgard transferred to the Agricultural School at the University of California, Berkeley, where he spent the rest of his scholarly life. Hilgard Hall is named for him.



Geological Map of the Mississippi River Embayment, by Eugene Hilgard, 1871

The Coast and Geodetic Survey, Congress and the President, and Science in the Federal Government

The traditional approach to the history of the Coast Survey and other institutions of American science has been largely "from the top down", concentrating on the highest levels of leadership and policy and funding; this present enterprise is part of another approach entirely, an attempt to discern the history of the Survey "from the fieldwork up". Nevertheless, Hilgard's administration as Superintendent, and those of the next two successors, cannot be comprehended without reference to the standard histories of

[9] See E. Hilgard, 1871, and Little, Appendix No. 12, annual report for 1880

science in the 19th century, for never before this era nor since was the Survey buffeted and threatened by forces bent on great change in the agency, including its entire elimination. In the 1870s and 1880s there was a series of events, scandals, investigations and commissions, alliances and betrayals, which affected the Survey. In the middle of this period, in 1885, in about one month, Professor Julius Hilgard plummeted from his status as one of the most admired and productive scientists in the American government to that of a dishonest drunkard, the only leader of the Survey in its entire history who was forced to resign from office. But making sense of this dramatic fall requires attention to events both preceding and following his disgrace.

The 1870s and 1880s were a period of great contradiction in the sciences in the federal government. On the one hand, it was a tremendously productive period, characterized by major explorations of the deep ocean and elsewhere by the Survey, and a series of overland explorations of the inter-mountain west and its complex geology, and explorations and research in the Pacific from tropical islands in the south to the vast domain of Alaska and the Arctic in the north. New federal agencies were created and whole series of landmark publications were issued. On the other hand, the same time period was characterized by a profound shift in public and Congressional sympathies towards funding science by the government, such that for the remainder of the century "the Coast [and Geodetic] Survey and other scientific bureaus were continually harassed by the forces of economy".[10] Throughout its existence the Survey had fought off the U.S. Navy's attempts to take over the Survey; now it had to face similar overtures concerning newly created agencies, particularly the U.S. Geological Survey. Throughout this period, Democrats were steadily restoring their pre-war powers, so the Survey's relationships with Congress in general and specific Congressmen were changing rapidly. Finally in 1884 Grover Cleveland was elected the first Democratic President since before the Civil War. Within his first year in office, and his first set of political appointees, Professor Hilgard was dismissed and disgraced, but the Survey's travails would continue for over a decade more.

A short chronology of significant events that led to Hilgard's fall, and the aftermath, should begin with the Congressional request to the National Academy of Sciences to examine and make recommendations concerning the proposed new Geological Survey and its relationship to the Coast Survey. The NAS report, released in 1878, advocated the transformation of the Coast Survey into a Coast and Interior Survey in the Department of the Interior, with responsibilities for a national geodetic network and topographic mapping of the interior, in addition to nautical mapping and allied research along the coasts. This new survey would be complemented by a separate Geological Survey, with separate functions concentrating on mineral exploration and mapping and allied research. Instead, the Coast Survey became the Coast and Geodetic Survey, still under the Department of the Treasury, while in 1879 the Geological Survey was created in the Department of the Interior and given primary responsibilities for topographic mapping outside the coastal areas. In 1881, Hilgard succeeded Patterson as head of the Survey, while John Wesley Powell replaced Clarence King as head of the Geological Survey. Relations between these theoretical rivals were actually quite cordial,

[10] Manning, 1975, p. 188.

as Hilgard and Powell had become close friends during the years of negotiations and planning about the new survey. In 1882, Hilgard sponsored Powell's membership to the National Academy of Sciences, while at the same time beating back yet another attempt by the Naval Hydrographic Office to take over the Survey.[11] In 1884, Congress set up a joint committee to investigate the entire suite of scientific agencies in the federal government. The Commission worked for two years, and hence overlapped, and to some extent triggered, the fall of Professor Hilgard.

William B. Allison (1829-1908) Republican Senator
from Iowa and Chairman of the Allison Commission.

The Allison Commission was set up nominally to investigate all scientific agencies in the government. It's official title was "the Joint Commission to consider the present organizations of the Signal Service, Geological Survey, Coast and Geodetic Survey, and the Hydrographic Office of the Navy Department, with a view to secure greater efficiency and economy of administration of the public service in said bureaus.[12]

[11] Rabbitt, p. 9, 62.
[12] Allison, 1886.

In reality, there were two separate major investigations. The first was centered on the Coast and Geodetic Survey, and its relationship (or the lack thereof) with the Navy on the one hand, and with the new Geological Survey on the other. The second major investigation was concerned with the Signal Service of the U.S. Army, and particularly with its meteorological research and activities. Here the major question was whether a nascent national weather bureau should be a military or civilian institution[13]. A related matter, not directly addressed by the Allison Commission but closely related, was whether or not the Naval Observatory and its functions should also be turned over to civilian authority.[14]

The Allison Commission's deliberations were complicated by the fact that in 1884, Grover Cleveland was elected President. Thus in 1885 a Democratic administration entered Washington with political priorities that differed sharply from the successive Republican administrations that had occupied the White House for over a quarter century. The new Secretary of the Treasury appointed a brace of new auditors, including a former Confederate officer from Texas named James Q. Chenowith, who entered the Capital with an agenda. Within the year Professor Hilgard was to fall from grace.

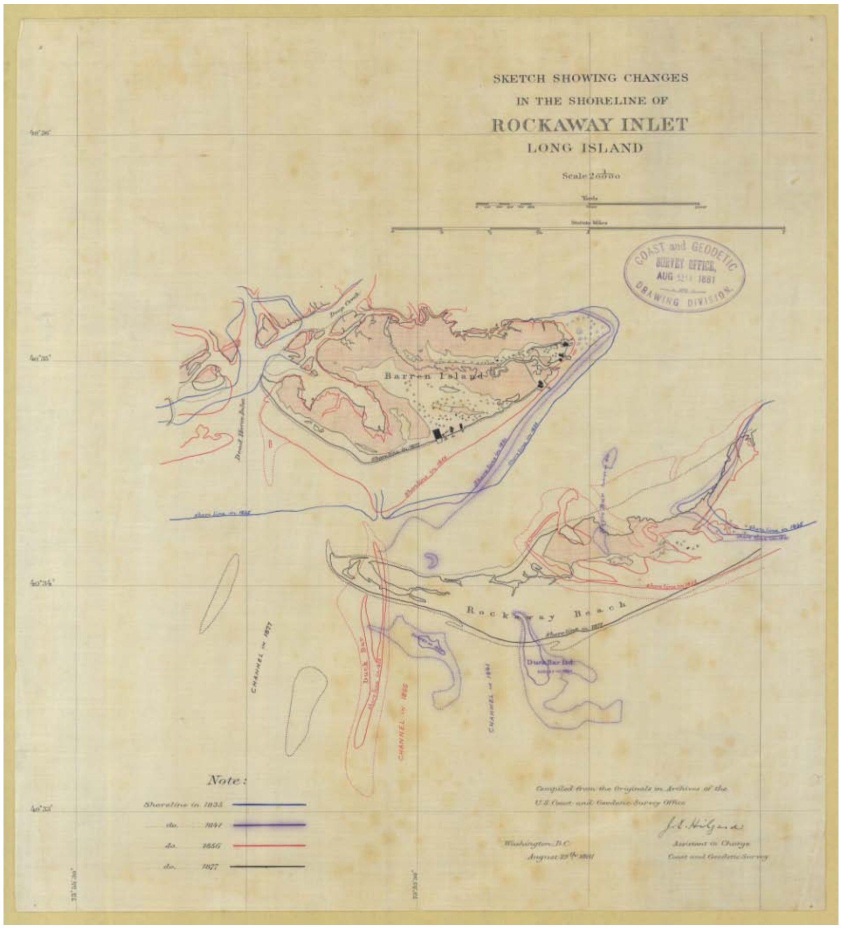
With this introduction to Julius Hilgard as a man and a scientist and a leader of the Survey, and the larger political context of the era, let us take a look at the realized work of the Survey during the short and abruptly truncated tenure of Professor Hilgard. Hovering in the background is the axe that is soon to fall, but then again, this is also just another episode in the very complex relationship of the Survey to the rest of the federal government and the thrust of science in American history[15].

Hilgard and the Survey at the transition in 1881

Julius Hilgard joined the Survey in 1843, when he was eighteen. Thirty-eight years later, Superintendent Carlile Patterson died, and Hilgard faced his third chance of becoming the head of the Survey. He had been considered, but rejected, by Joseph Henry as a successor to Bache in 1867, and he was evaluated again by Henry in 1874 when Benjamin Peirce decided to relinquish his absentee post and focus completely on his career at Harvard. With Patterson's sudden death, Hilgard had another chance at the position, at 56 years old. Apparently his chance came too late. By the time of his ascendancy, he had acquired some sort of physical and mental illness, which was either deeply mysterious or was of such a nature that it was never discussed. Hilgard's memorialist Otto Tittman, who had himself been Superintendent later on, described the sorrows of Hilgard's later life. He and his wife had 4 children, of whom 3 died young, and the last lived to be a young adult and then died, "leaving him childless and overwhelmed by grief at a time when a fatal illness had already begun its inroads on his mental and physical strength. This disease had seriously impaired his health when he

[13] Hawes, 1966.
[14] Rabbitt, pp. 9-10.
[15] The best overview to this remains Dupree, 1957, but much useful information may be found in Rabbitt, 1980, and Manning, 1975 and 1988.

was appointed to the superintendency, which, to use his own words, came ‘too late’. He was conscious of his failing strength and ability while still occupying the position of superintendent, on more than one occasion he gave expression to the wish that the burden of his duties might be shifted to other shoulders”.[16]



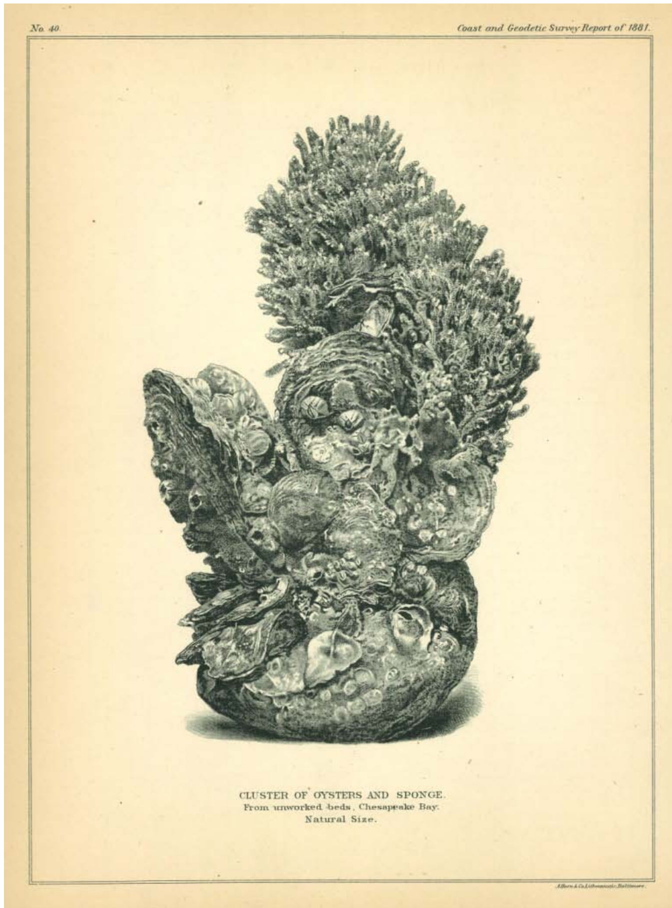
Changes in the Shorelines at Rockaway Inlet 1834 to 1881 approved by
Julius Hilgard, “Assistant in Charge” August 21, 1881

When Carlile Patterson died suddenly , Julius Hilgard was immediately made the acting Superintendent in a role he had played during the Civil War when Bache was incapacitated, and which he also played for much of the Peirce superintendency, while Peirce remained in Cambridge, Massachusetts. But Hilgard, capable as he was, was still a foreign immigrant who spoke with a pronounced accent. It would be months before the U.S. Congress officially ratified him as Superintendent, leaving him in his perennial role in the Survey: “Assistant in Charge”.

The range of projects completed or published in that fateful year of transition shows the Survey’s remarkable productivity, despite the mounting pressures to economize and trim budgets. Superintendent Patterson had directed Lt. Francis Winslow

[16] Tittman, 1895, p. 465.

to begin the Survey's oyster work with biological research on oyster biology and reproduction, coupled to mapping oyster beds and reefs in Chesapeake Bay and Virginia rivers geodetically. Sadly, Patterson didn't live to see Winslow's great treatise.[17] Winslow's techniques for oyster research were the foundation for all subsequent American progress in the complex science of oysters.[18]



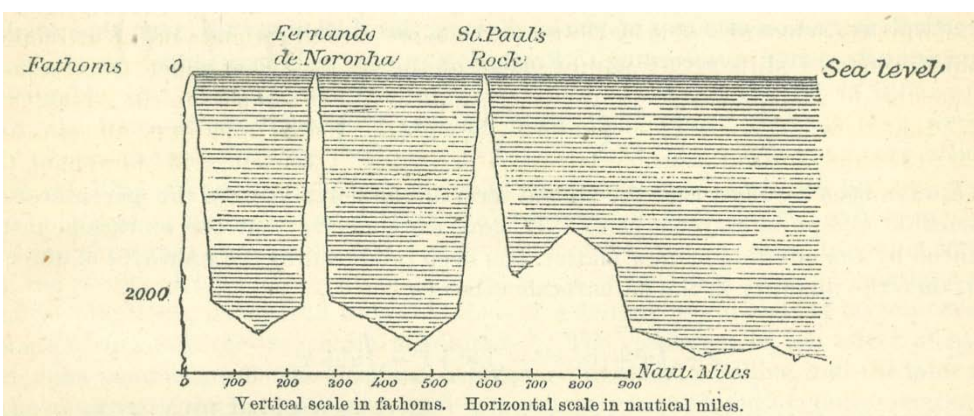
No 40, Appendix 11, Francis Winslow's first treatise on the status of natural oyster beds in Chesapeake Bay and tributary estuaries

1881 was the centennial of the end of the Revolutionary War signified by Cornwallis' surrender at Yorktown. The Survey created a specialized chart to commemorate the centennial. The chart featured contemporary topography and hydrography from recent surveys, with an inset map of the town of Yorktown as first surveyed in 1851, the 'oldest" version of the town the Survey had. The original copper plate was lavishly engraved, and then the plate image was transferred for lithographing and printed with a special dark "antique" ink. "The mapping merits the praise it has received from the topographical draughtsmen who have seen it"[19].

[17] Winslow, 1881.
[18] Keiner, pp.74-75.
[19] The Washington National Republican, October 3, 1881.

Chart 3007 Chesapeake Entrance and Yorktown Peninsula

The Survey's polymath Charles S. Peirce continued working on many research projects, including new map projections based on elliptical functions[20], work on fundamental standards of measurement as chief of research in the Office of Weights and Measures, and, finally, his pioneering research in the determination of the value of gravity as measured with systems of pendulums. Through his work, he deduced the ellipticity of the earth,[21] and he began to develop compensations for the gravity imbalances common to coastal observation sites, as they were located at the boundary between oceanic and continental masses and densities. As in many other matters, his research anticipated earth science methods and theories half a century or more ahead.



[20] See Craig, 1882.
[21] See Peirce, 1881.

Islands and oceanic crust. Form report on
Gravity corrections for coastal and island pendulum stations
From Peirce, Appendix No. 15, Annual Report for 1881.

Superintendent Peirce acquired the Survey ship *Blake*, and Superintendent Patterson had deployed it for pioneering deep-water soundings in the Atlantic and the Gulf of Mexico. Under Superintendent Hilgard, that work crystallized in ever more complex models of the deep sea terrain offshore.

Deep Sea Soundings in the Gulf of Mexico and the Caribbean,
with profiles and depiction of basins, Sketch No. 21, 1881

Essentially at the other end of the oceans that the Survey was responsible for mapping, William Dall, who was developing another entire research career as a mollusk specialist at the Smithsonian Institution, synthesized his own and other's data on sea currents and temperatures in the Bering Sea and adjoining waters, where he had been exploring since the 1860s.

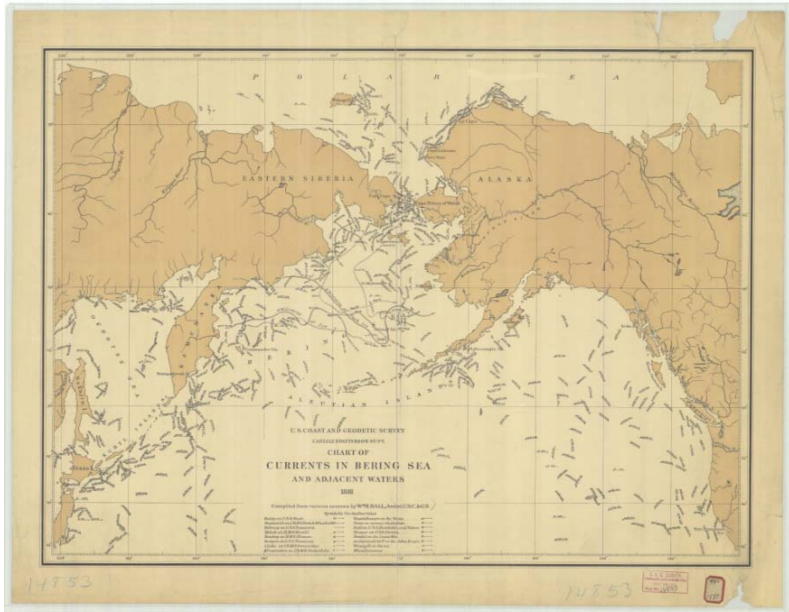
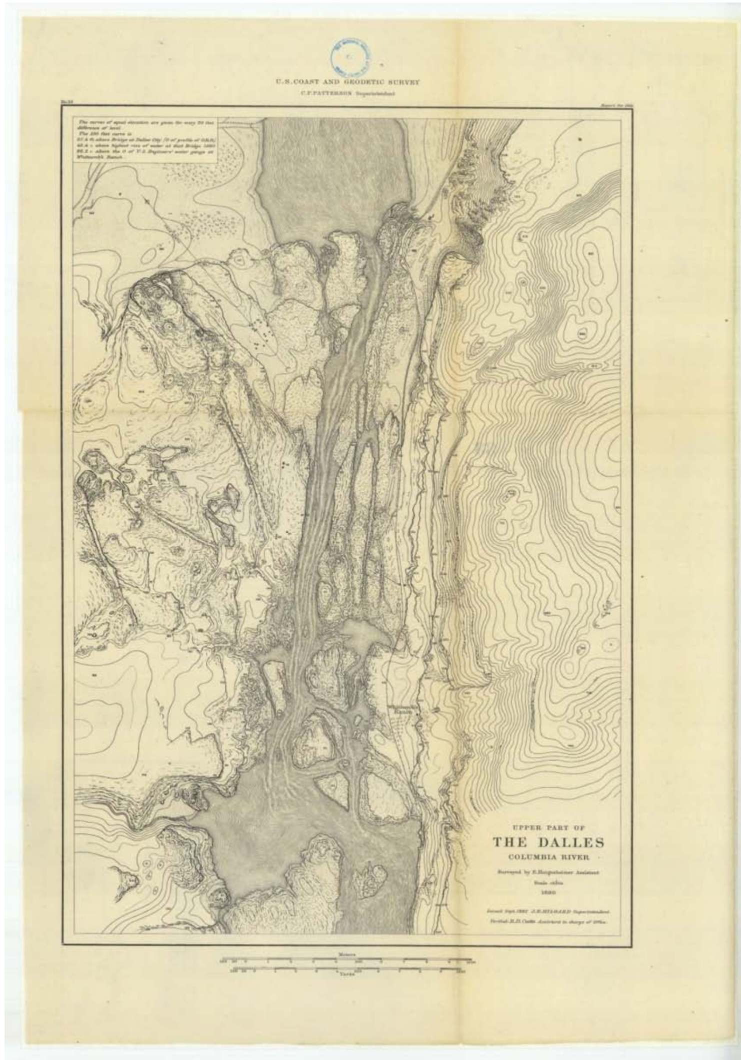


Chart of Currents in Bering Sea and Adjacent Waters, compiled
from various sources by William H. Dall, 1881[22]

Edwin Hergesheimer, the master draughtsman of the Survey, continued his research in new and improved methods of topographic mapping and especially new standards of graphic conventions for specific landscape element classes, both botanical and geological.[23] He appears to have had a great affinity for volcanic landscapes and especially recent volcanism. His masterly studies of the landforms at The Dalles, on the Columbia River in Oregon and Washington, are extraordinarily detailed. He also developed novel graphic patterns to describe the eddy currents in the river.

[22] See Dall, 1880.
[23] See Hergesheimer, 1881, 1883.

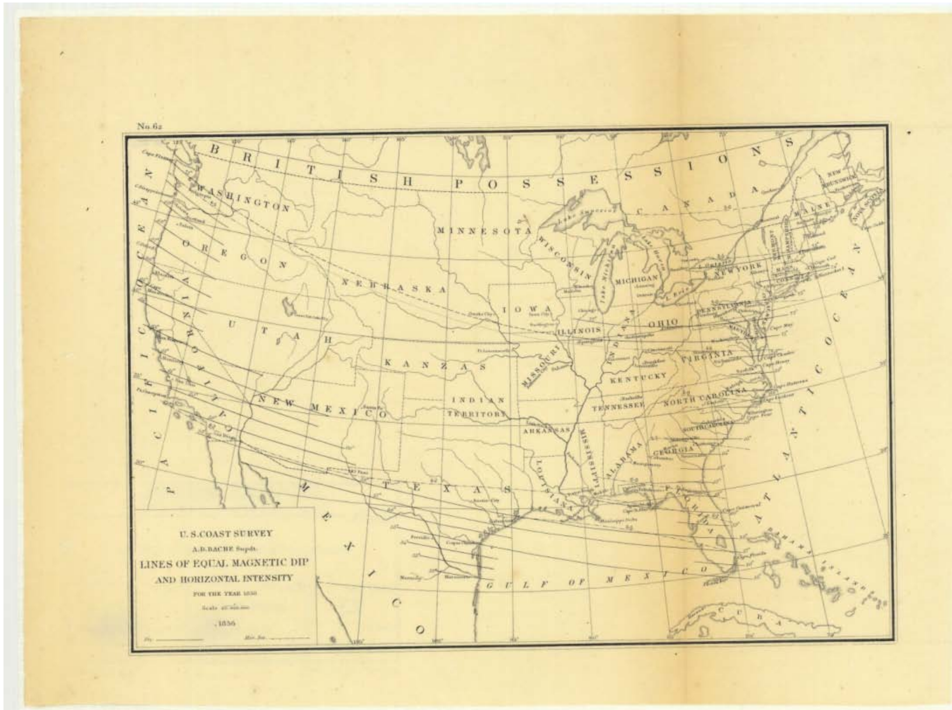


The Dalles on the Columbia River
Sketch No. 33, 1881

The Magnetic Year 1882 in the Survey

Research in terrestrial magnetism in the Survey really began under Superintendent Bache. As a young assistant, Julius Hilgard had collaborated with Bache to create and publish the Survey's first isogonic charts (charts of the lines of equal magnetic declination) in 1855 and 1856[24]. These were calculated for the continental United States back to the epoch of 1850, when the Survey began work on the Pacific coast.

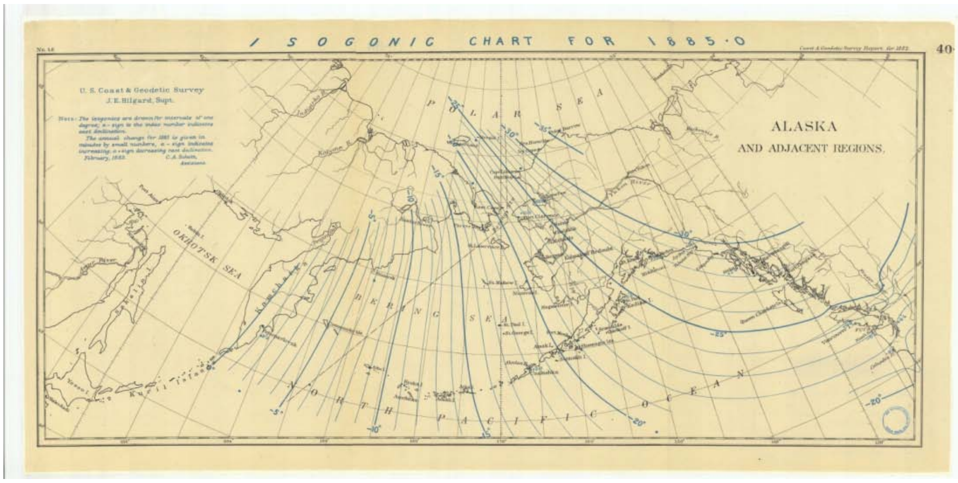
[24] See Bache and Hilgard, 1856. See Bauer, 1902, for the history of magnetic research in the Survey.



Lines of Equal Magnetic Dip and Horizontal Intensity
For the Year 1850, by A.D. Bache and J.E. Hilgard, 1856

In one of the few pleasing symmetries of Hilgard's short tenure, the Survey produced a new set of isogonic charts, projecting to the immediate future, to the epoch 1885.0 (January 1, 1885). As Charles Schott noted, "Of late years the magnetic work of the Survey, both in the field and in the office, having been pushed forward very actively, as may be seen in the recent publication of results, it appeared equally desirable to bring this new material into use at the earliest practicable moment".[25] Fittingly, one of the new isogonic charts was the first the Survey produced for Alaska and adjoining regions. George Davidson prepared a major work in astronomy, a field catalogue of 1278 stars with their mean places for the epoch year 1885.0.[26] This project was a very early instance of modeling and forecasting a geophysical parameter.

[25] Schott, 1856, p. 277.
[26] See Davidson, 1883.

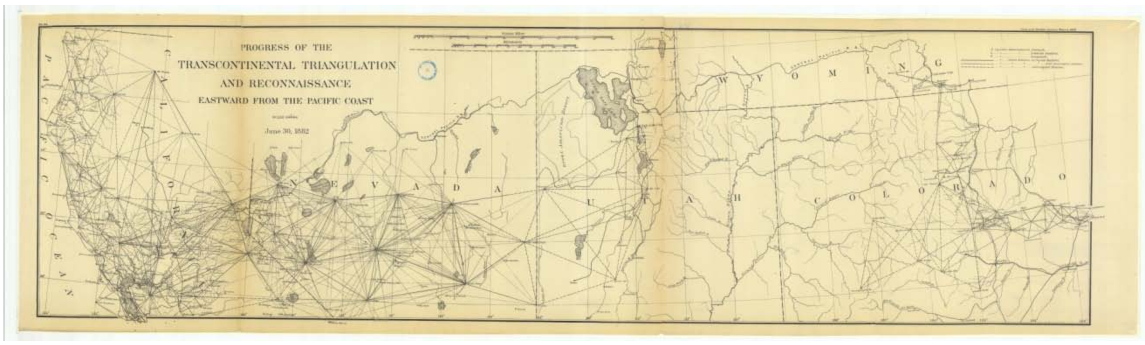


Isogonic Chart for 1885.0 for Alaska and
Adjoining Regions Sketch No. 40, 1882.

The ship *Blake* had over several years made sufficient soundings to reveal the basic structure of the Gulf of Mexico. Various Survey scientists, especially Adolf Lindenkohl, extended these investigations into pioneering research in what would now be called physical oceanography. Lindenkohl correlated the patterning of sea temperatures at the surface and at the bottom in a series of large hand-drawn and color washed original bathymetric maps, which would be foundational to subsequent publications in later years, presented in English in the Annual Report appendices, and in German in Petermann's Geographische Mitteilungen.

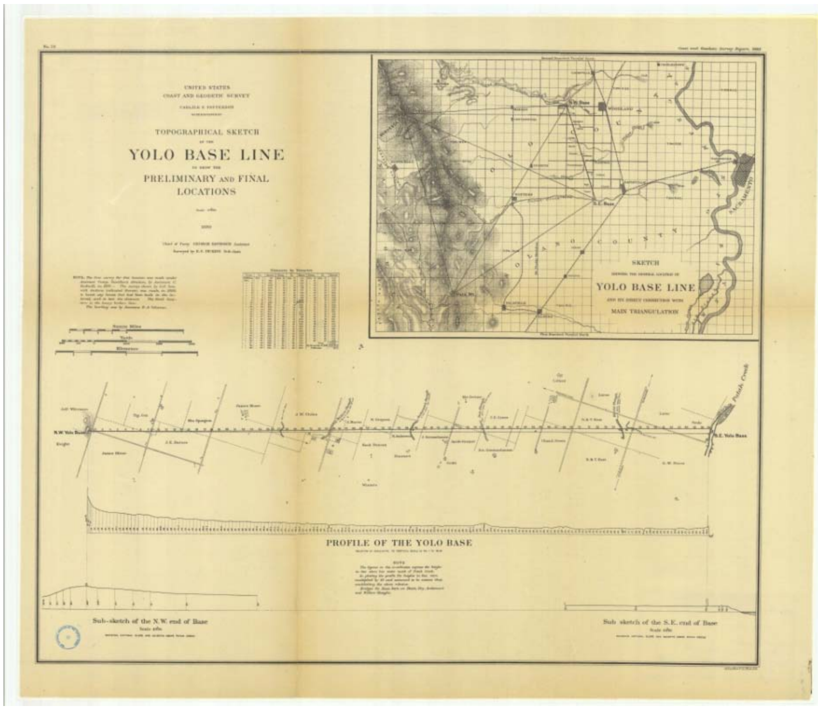
Waters of the Gulf of Mexico Showing Currents, Surface and Bottom Temperatures and Soundings
By Adolf Lindenkohl, 1882

The Great Arc of the 39th Parallel Survey had begun in 1871. 11 years later, in 1882, the network from the west had been completed only as far as central Nevada. From the east, reconnaissance had only been completed to Uncompaghre Peak with no observations having been completed from the Rocky Mountains to Salt Lake City. Although reconnaissance had been completed to Uncompaghre Peak from the east, large sections of the projected survey scheme remained to be done.



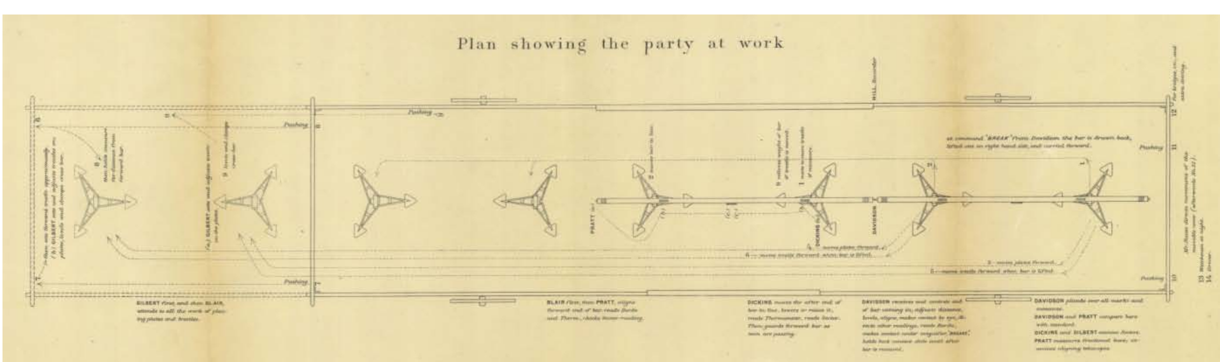
The Western Triangulation Network, No. 24, Annual Report for 1884

Many of the geodetic survey personnel returned to the western end of the network for continued work strengthening the Davidson Quadrilaterals. For various reasons, Davidson had revised his great western base line, the Yolo Base Line, located in as flat a terrain as could be found in the Sacramento River valley, with base line end monuments that could also be sighted clearly from the key sites of the original two quadrilaterals.



Topographical Sketch of the Yolo Base Line
To show the Preliminary and Final Locations, 1882

In 1882, the base line was re-monumented and measured, using the newest iteration of precise measurement, the Survey's 5-meter base apparatus. Davidson published 4 sketches in the annual report showing key hardware elements of the assembly, the construction plans for bridges to cross arroyos encountered on route, etc. The base line party in operation required a degree of coordination and precise, repeated operations by a team functioning almost like a living railroad train, slowly progressing along the track, and shielded from the intense California sun by a moving tent structure. Davidson showed the precise choreography of the team members as they made two sets of observations and moved one incremental step forward[27].



[27] See Davidson, 1882.

Use of the 5 meter Base Apparatus
Plan showing the party at work, 1882

Cartographic production work was not greatly diminished by the growing pressures to reduce budgets, and in fact, in lieu of expensive field operations it was often cheaper and easier to increase cartographic office work to deal with the inevitable backlog of work. Several aspects of the throughput of cartographic work and intellectual labor in chart making may be seen by examination of an interesting pair of map "originals" that the Survey found important enough to register into the Library and Archives Collection.

Unfinished Chart 672 Santa Monica to Point Conception (1881)

The unfinished manuscript chart shows how Survey hydrographers created grids of soundings in order to characterize the bottom as completely as possible. They then sketched shallow depth contours, and also determined which subset of soundings to keep on the chart, eliminating some because they cluttered the map.

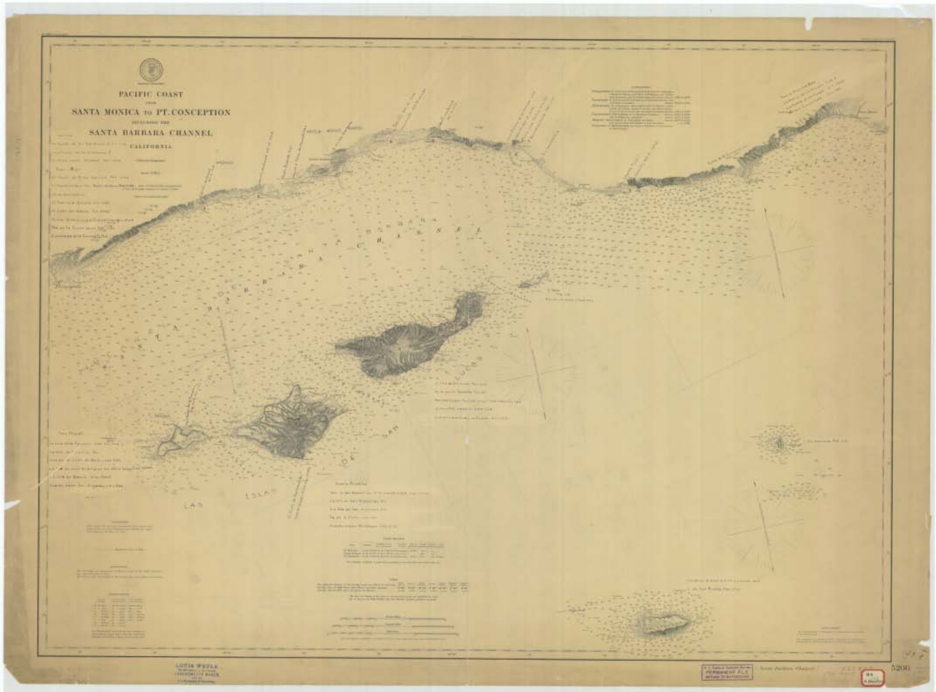


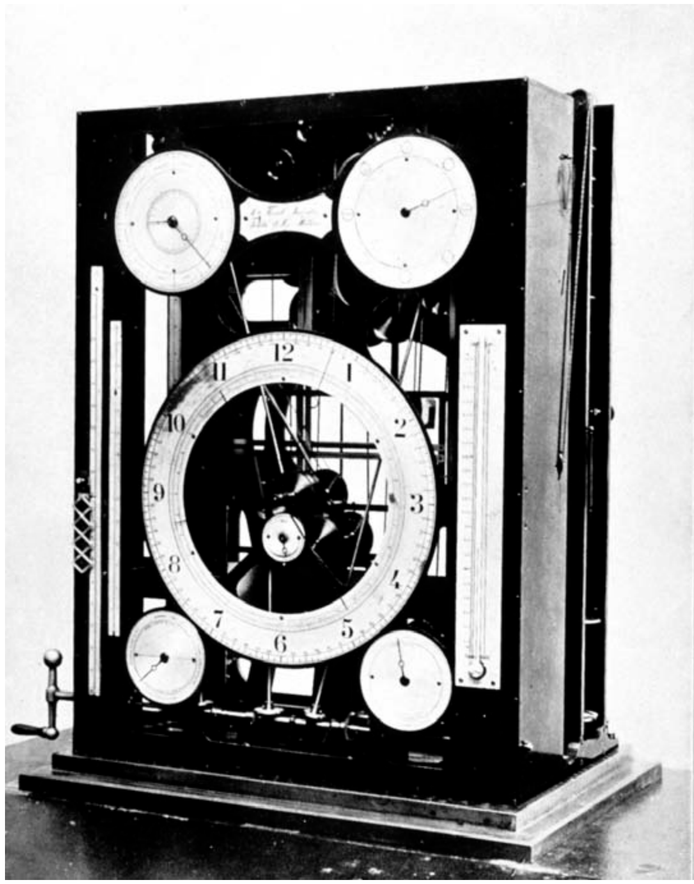
Chart 5200 Pacific Coast Santa Monica to Pt. Conception
With historic place names by George Davidson

Geometry and the curvature of the earth limited the Survey's abilities to position soundings in the straits between the near and far Channel Islands—it would take the eventual development of Radio Acoustic Ranging in the 1930s, which was perfected using these very islands as an experimental laboratory, to "fill in" the chart.

The published version of the chart was a lithograph photographically transferred from a print from the original engraved plate. The much lighter print density of the coastal and island topography on the published chart, compared to the unfinished original, reveals the distinction between engraving and lithographing. This published chart is further interesting in that it was one of George Davidson's sets of sailing direction-scaled charts covering the entire Pacific coast that he hand-annotated with the many disparate place names for prominent places, mainly capes and points, as they were named by historic explorers and cartographers going back to Spanish, English, and Russian explorers back to the 1500s.

1883 and the Turning of the Tide

By Hilgard's tenure, William Ferrel had worked for the Survey for almost two decades. He did many kinds of investigations, but his major contributions were to develop methods of harmonic analysis applied to recurrent phenomena, and studies of weather and ocean phenomena, and global atmospheric and current circulations. Ferrel had been recruited to this work by Benjamin Peirce in 1867 when he became Superintendent. Much of this work culminated in 1883 with the completion of the construction of his Tide Prediction Machine by the engineering firm Fauth and Co. in Washington, DC. William Thompson (Lord Kelvin) had completed the first mechanical Tide Predicting Machine in 1872-73, summing ten harmonic components. The Ferrel Tide Predicting Machine utilized 19 harmonic constituents, and was the first machine that could predict the derivative of the predicted tide, i.e., the time and amplitude of tidal maxima and minima.[28]



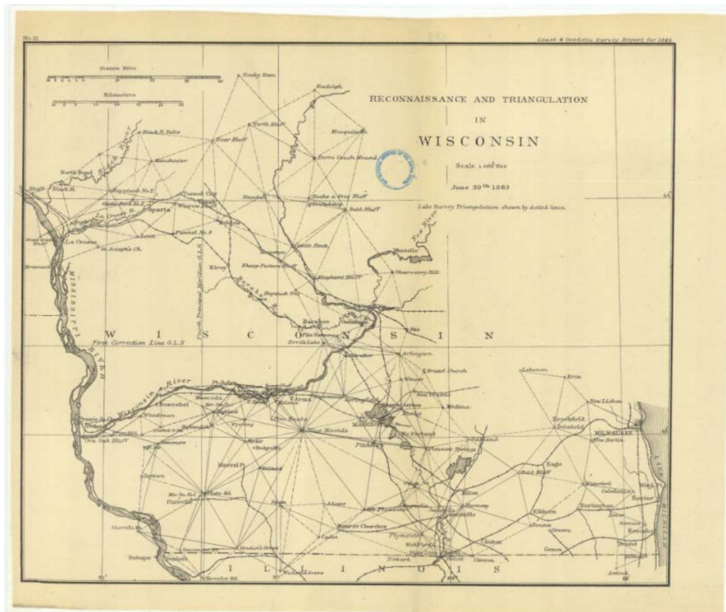
Ferrel Tide Predicting Machine

The Ferrel machine was used continually by the Survey until 1912, when it was displaced by Tide-Predicting Machine No. 2, one of the wonders in the history of analog computers. Eventually it was made obsolete by digital computers.[29] The Ferrel machine is now in storage in the Smithsonian National Museum of American History, and the No. 2 machine is in the NOAA Science Center attached to SSMC-4, Silver Spring, Maryland.

Geodetic survey crews continued the slow march across the continent from east and from west to continue work on the 39th Parallel Arc network. At the same time, the Survey continued working outward to the north and south extending first and second order geodetic control that could in turn be the basis for state and local positioning

[28] Cartwright, 1999, p. 106.
[29] See Hicks, 1967.

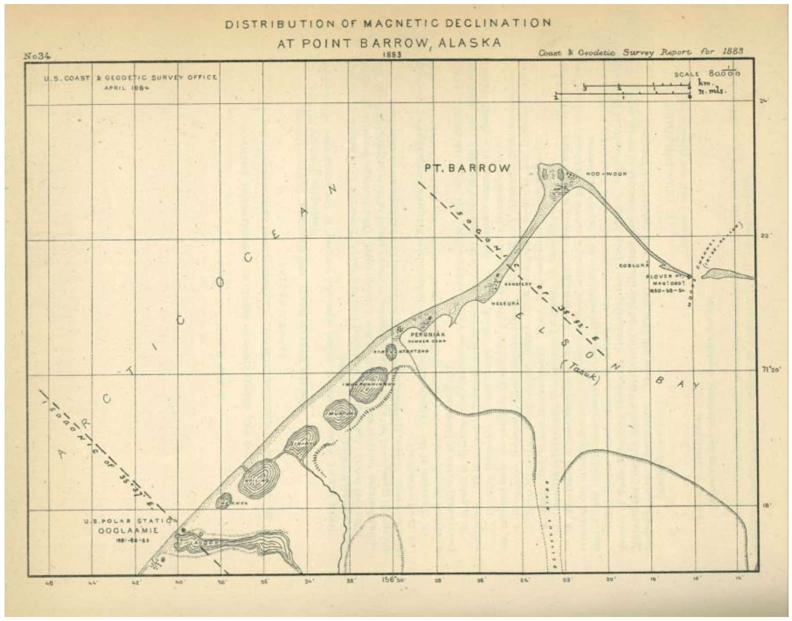
systems. One interesting element of this work completed in 1883 was the extension of Survey control into and across Wisconsin. In doing so, the Survey "tied in" to the Great Lakes geodetic network created by the Lake Survey of the Army Corps of Engineers. Less than a hundred years later, the Lake Survey would merge with the Survey in the National Ocean Survey.



Reconnaissance and Triangulation in Wisconsin
Including ties to the Lake Survey network, 1883

The Survey also participated in various ways with the American contributions to the first International Polar Year. The Survey contributed magnetic instruments and trained Army personnel who occupied a magnetic observatory at the U.S. Polar Station, at Point Barrow, Alaska from 1881 to 1883.[30]

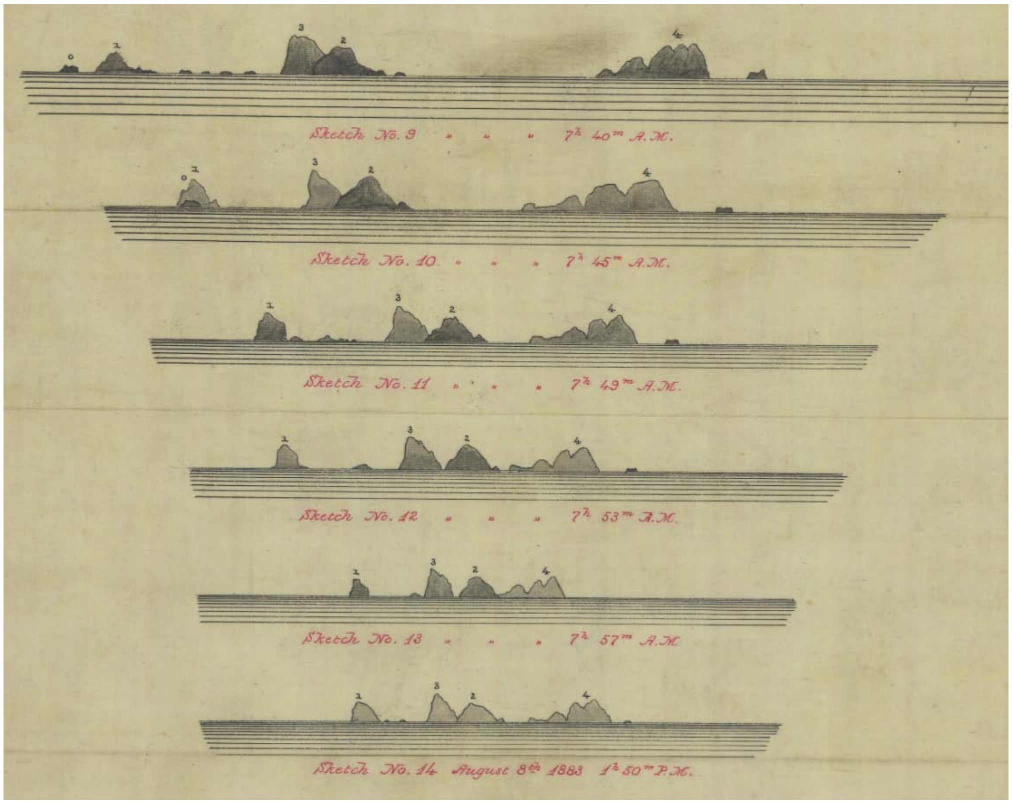
[30] See Schott, 1883.



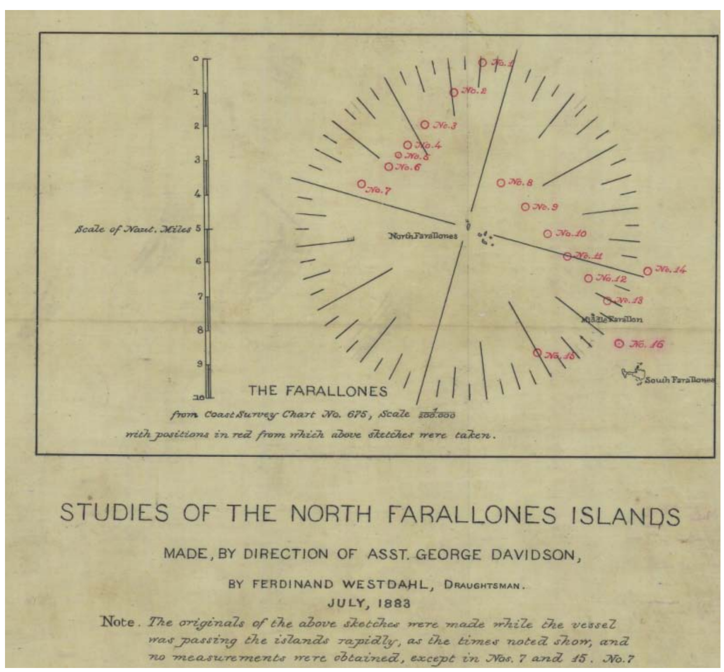
The Polar Year base and various Iñupiat compounds
At or near Point Barrow pm the Arctic Ocean

On the west coast, George Davidson was working on the plan for what would become his magnum opus, the 4th revised edition of the Pacific Coast Pilot, which would be published in 1889. In preparation for that volume, and in anticipation of a series of hundreds of new Pacific coastal views to replace the original views by William McMurtrie, dating back to the 1850s, George Davidson asked Ferdinand Westdahl to become an artist draughtsman of coastal views for the enterprise.

Ferdinand Westdahl (1843-1919) was a uniquely skilled hydrographer and geodesist who was also a draughtsman of unparalleled skill. He was born in Sweden and educated at the Swedish Navigation School. After immigrating to the United States, he worked for the Western Union Telegraph Company as part of its reconnaissance of telegraph cable routes between Alaska and Russia, which was also the gateway work to the Survey for William Dall. Westdahl joined the Survey in 1867. He was, until his death as the oldest living officer in the Survey, almost always at work on the Pacific Ocean, from California to Alaska to the Philippines. He and John Barker, who worked exclusively on the Atlantic coast, were the two greatest masters of coastal views in the Survey. Interestingly, the very foundational views of his career were carefully preserved. In 1883, George Davidson gave him a precise training exercise: sketching the cluster of small islets known as the North Farallones Islands, outside the Golden Gate in the Pacific. He had a bark at his disposal, and he sketched the islands at varying distances, from several locations and perspectives. It was Westdahl's version of "36 Views of Mt. Fuji".

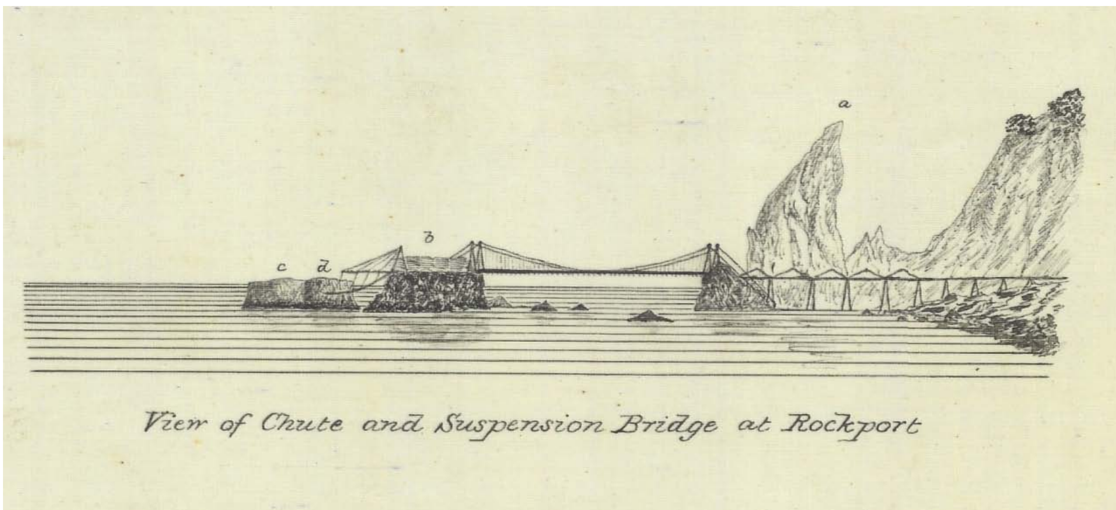


From Ferdinand Westdahl's Studies of the North Farallones Islands, 1883
Annotated tracing cloth version of the original views, now in the Library of Congress



Legend, Westdahl's Studies of the North Farallones Islands, 1883
A total of 17 views drawn in July, 1883

Between 1884 and 1886, Westdahl produced at least 400 views from the Mexican border at San Diego to Vancouver Island and the Georgia Strait. He also produced an unknown number of views as side drawings on topographic maps (t-sheets). These offer unparalleled sketches of the maritime technologies and transportation and commercial systems of the Pacific coast in an era before there were even rudimentary coast roads along most of the Pacific coast. Westdahl also utilized a convention of receding parallel lines to convey the waters of the ocean, imparting a calm zen-garden look to his drawings.



View of Chute and Suspension Bridge at Rockport, California
By Ferdinand Westdahl, from T-sheet 1322, 1883

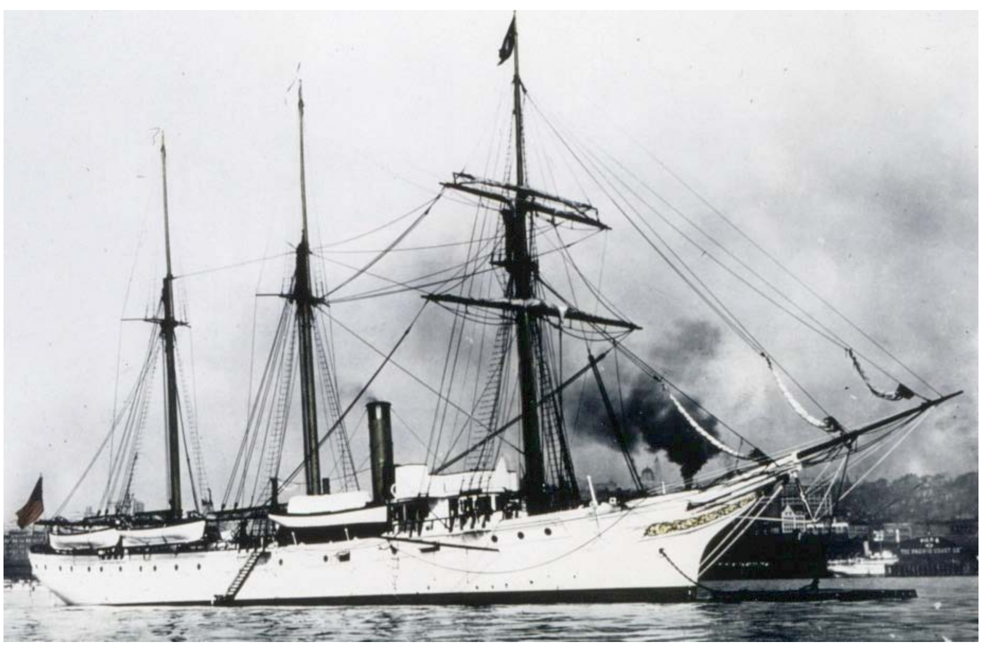
1884 The Last Good Year

President Arthur served out the term of the slain President Garfield and ended his career as President. In the election of 1884, Grover Cleveland was elected President, the first Democrat to occupy the position since before the Civil War. A difficult era of investigations and recriminations began in 1884 even before Cleveland's election, in a series of Congressional investigations. These, as they began, were not primarily concerned with the alleged improprieties and inefficiencies in federal agencies that would trigger Hilgard's downfall in 1885. As mentioned earlier, the Allison Commission hearings and investigations had two great objectives, one of which involved finding the right place and context for the Coast and Geodetic Survey, and its proper relationship to the work of the Naval Hydrographic Office on the one side, and the new US Geological Survey on the other. The testimony presented at the hearings, preserved and published in voluminous editions, offers extremely detailed data on the Survey and its functioning. In

1884 the reactions to the data were largely laudatory, but that would change radically the following year.

But 1884 began with as joyous a ceremony as can be imagined. Three years after Superintendent Patterson's sudden death in 1881, the Survey hydrographic survey vessel *Carlile P. Patterson* was christened in the cold January of 1884.

> "Miss Katie Patterson, the daughter of the late Superintendent, christened the vessel with a gaily decked bottle of champagne. At 11 o'clock the steamer glided gracefully into the water, her arch of Stars and Stripes floating in the breeze, while the surrounding tugs uttered their usual melancholy notes, indicative of welcome. Then everybody shook hands with everybody else and the ladies said the launch was 'just too beautiful for anything"…The *Carlile P. Patterson* is destined to survey the coast of Alaska, the scheme for the continuous survey of which was first planned by the later Superintendent… It was under the direction of the present Superintendent, Prof. J.E. Hilgard, that the special appropriation of $100,000 for the building of the vessel became available… The vessel will be manned by 13 officers and 40 men, who will be detailed from the Navy Department. Her first sail for Alaska will be in the Spring, and it is expected that she will be ready for active operations in the beginning of March, 1885".[31]



The Survey Ship *Carlile P. Patterson* (1883-1919)

[31] New York Times, January 16, 1884.

In 1884, the Survey published the first new chart series for the Potomac River since the charts created during the Civil War. These were unusual, particularly for the level of detail in the urban mapping of the City of Washington.

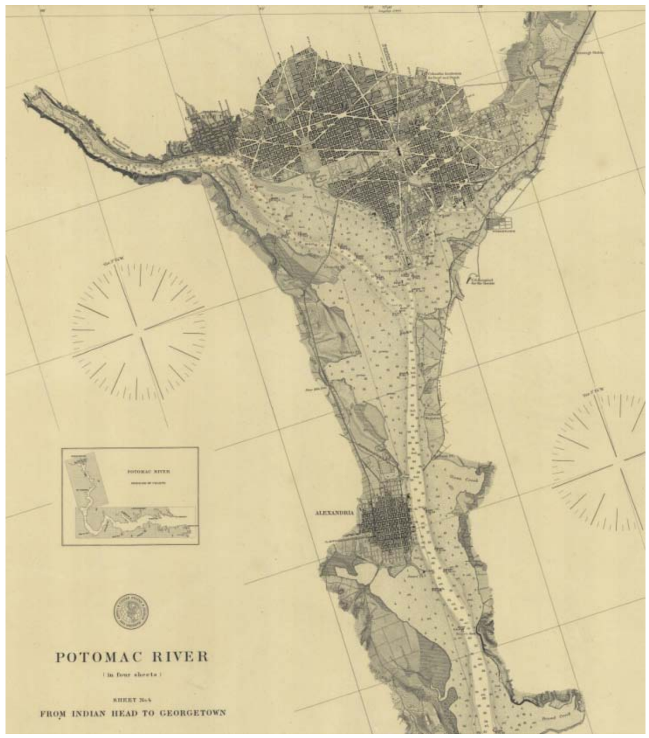
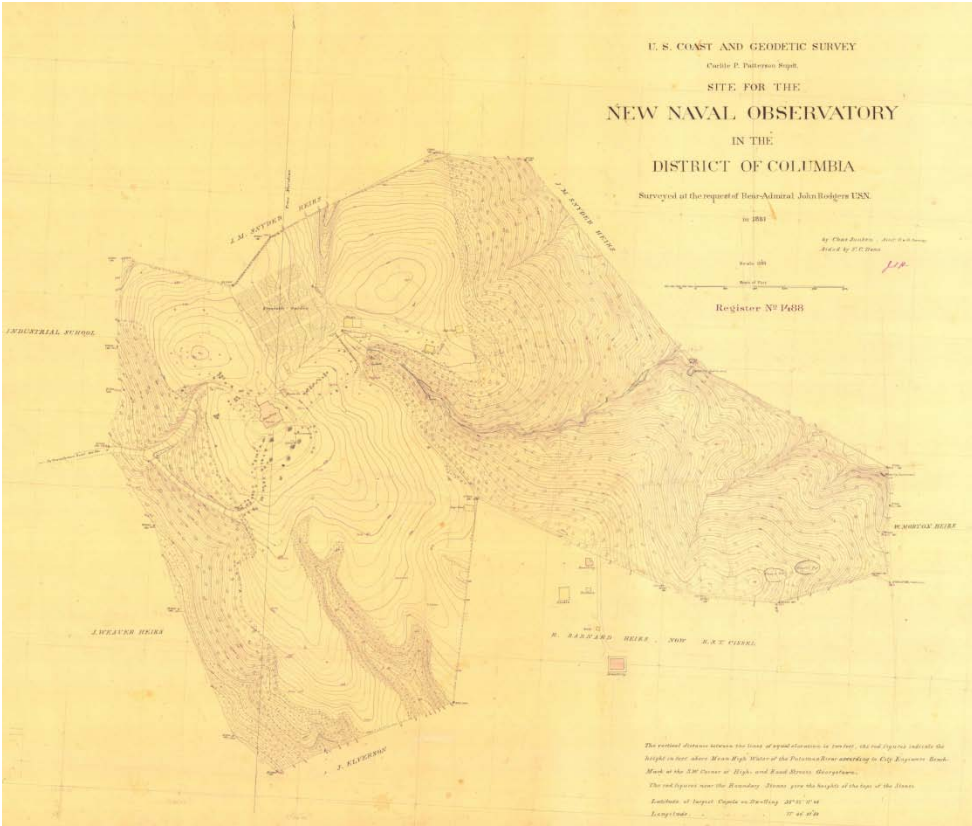


Chart 391 Potomac River, Sheet No. 4 1884
Cropped to show the City of Washington as distinct
from the County of Washington

Even though the Organic Act of 1871 had erased the distinction between the City of Washington, and the County of Washington, combining them along with the previously independent city of Georgetown in the unified District of Columbia, the Survey's map shows only the City and Georgetown. Later, Congress would authorize the Survey to map the areas of the previous county. During Hilgard's tenure, the Survey created a triangulation system and monuments designed to support a plane table survey of the entire District outside what had been the City of Washington.

The Survey did other surveys for specialized purposes outside of its usual mapping responsibilities. One such assignment under Hilgard's tenure was the task of preparing a detailed topographic map for the proposed site of the new Naval Observatory.



T-1488 Naval Observatory Site

Charles S. Peirce's invention and development of whole new classes of map projections based on systems of equations of elliptical functions led to a flowering of novel map projections for new applications (although many of Peirce's innovations, like the quinquncial projection were so advanced it would require half a century and the invention of aviation to make use of them). In 1884, the Survey released the North Atlantic Track Chart, the first long range route planning chart in its history, and the forerunner of many brilliant and cartographically superb aeronautical planning charts in the 20th century.

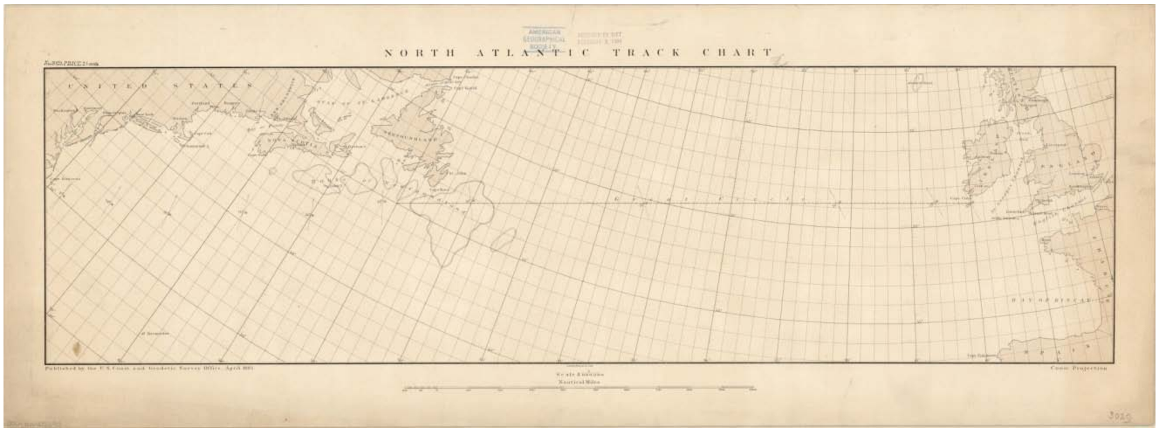
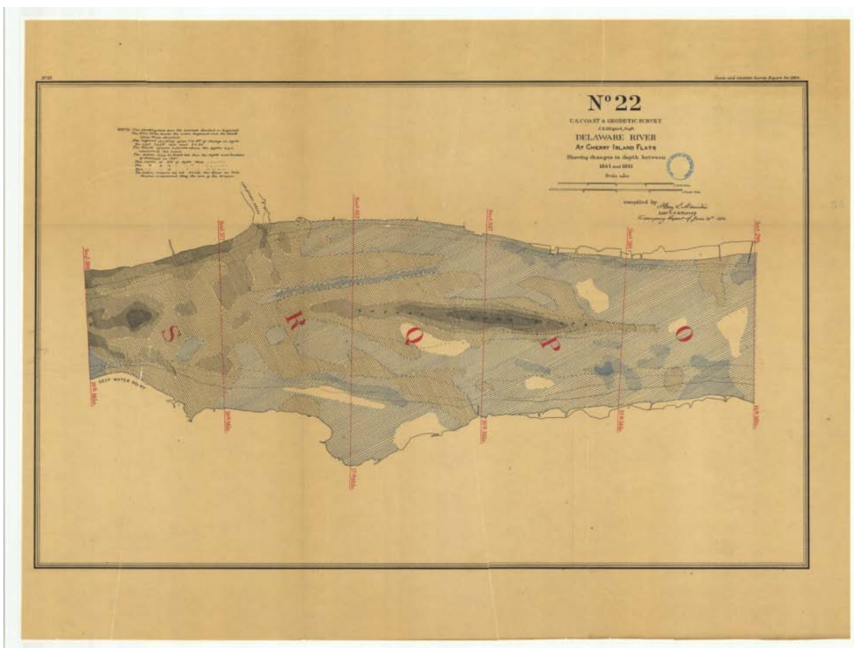
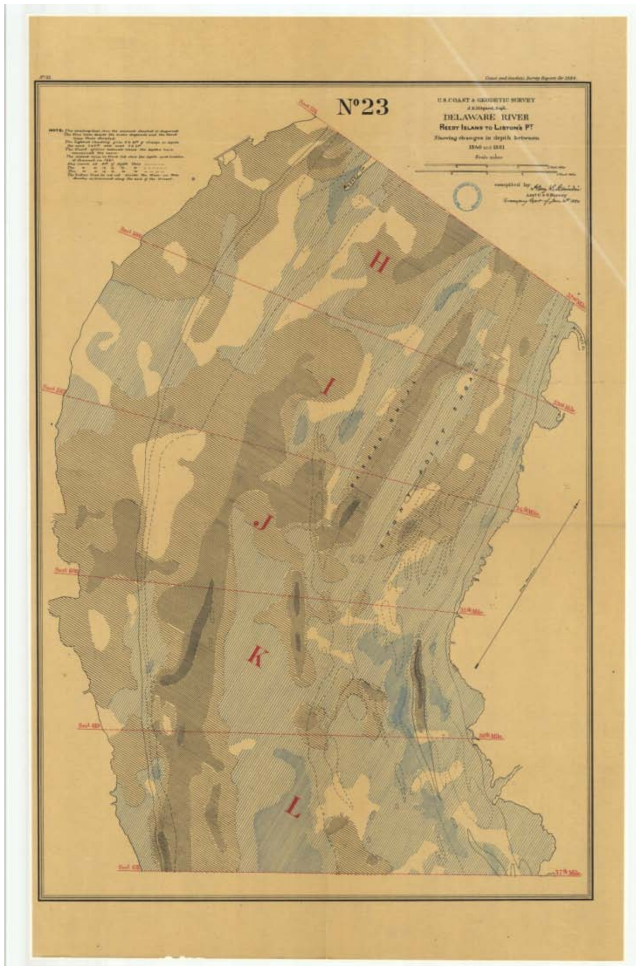


Chart 3029 North Atlantic Track Chart 1884
Developed on a Conic Projection

Cartographic sophistication was coupled with advanced hydrographic studies in Henry Marindin's study of hydrological and hydrographic changes in the Delaware River between the Survey's original studies in 1840-41, and Marindin's repeat studies in 1881.



Delaware River at Cherry Island Flats showing
Changes in depth between 1841 and 1881
by Henry Marindin, No 22, 1884

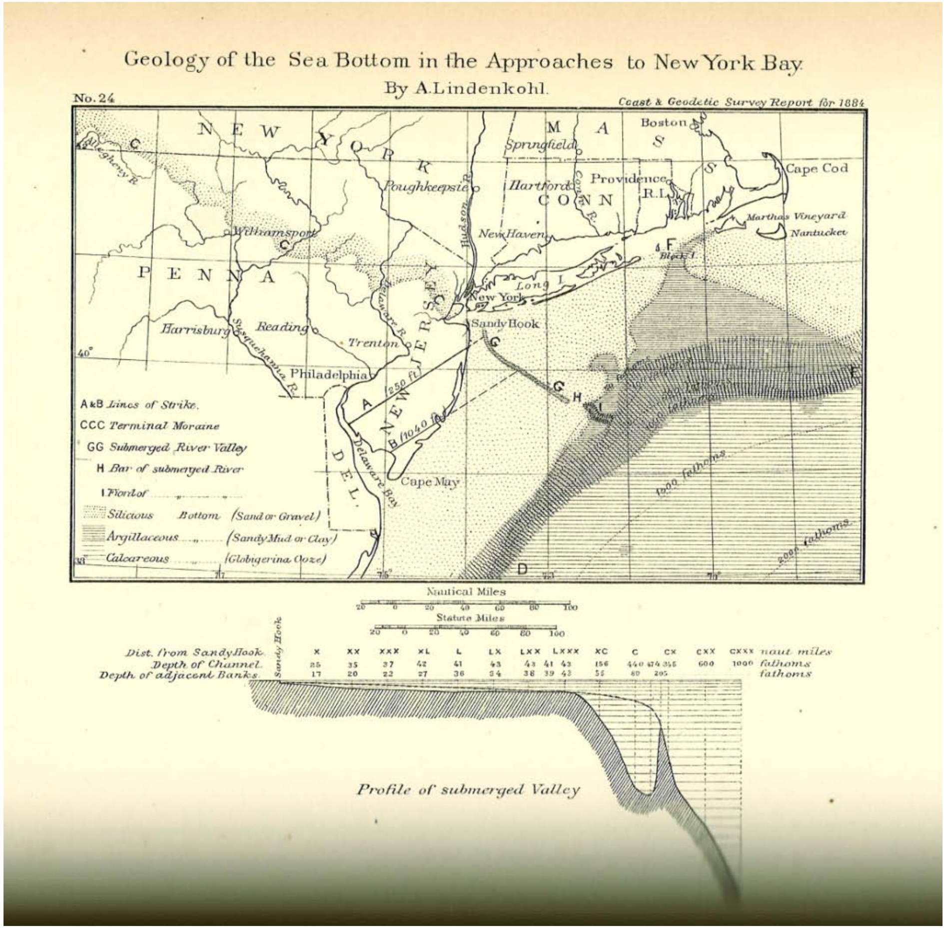


Delaware River from Reedy Island to Liston's Point
showing changes in depth between 1841 and 1881
by Henry Marindin, No 23, 1884

The red letters refer to river profile zones mapped as separate units. The colors of the river bottoms denote changes in the 4 decades between 1840 and 1881. Blue denotes deepening, black denotes shoaling, and the blank areas were substantially unchanged.[32]

Adolf Lindenkohl extended hydrographic and physiographic studies out to the edge of the continental shelf in his investigations of the submarine canyon of the Hudson River and the local geology of the area[33].

[32] See Marindin, 1884.
[33] See Lindenkohl, 1884.



Geology of the Sea Bottom on the Approaches to
New York Bay by Adolf Lindenkohl, 1884

This new sophistication of the Survey and its scientists in description and presentation of their research on deep ocean bathymetry and the functioning of ocean systems reached a certain melancholy finale, in retrospect, with the Survey's large 3-D models of the Gulf of Mexico and the Atlantic coast. The melancholy part is that the modeling of the Gulf of Mexico was particularly associated with Julius Hilgard[34], and the presentation and display of the various iterations of the models was considered to be a great triumph for him. Yet even at that moment dark forces were gathering against him.

But let us allow Hilgard a brief moment, once again, in the light shone by his achievements. Hilgard demonstrated the Gulf of Mexico model and lectured about it at meetings of the National Academy of Sciences and the American Association for the Advancement of Science. And the model was displayed at the Southern Exposition in Louisville, Kentucky in 1883.   As reported later by Assistant Henry Blair of the Survey, the exhibits at the Exposition of a scientific nature were mainly by nine government agencies, including the Survey. "The object which attracted the most attention in the Coast and Geodetic Survey exhibit, Mr.Blair observes, was the model of the Gulf of

[34] See his Hilgard, 1880 in particular and also Hilgard, 1884

Mexico. Several applications for copies of it were received and many special visits were made to it by classes of advanced students, principals of schools, and other interested in geological and geographical studies”[35].

The Gulf of Mexico model, from Gulf Stream Explorations, No. 25, 1884

The model was Hilgard at his best: scientifically grounded on the best research, yet relatively accessible to all, the physical equivalent of Hilgard’s preference, despite being a skilled mathematician, for lecturing and writing on mathematics without the use of mathematical symbols, “preferring to use logical statements of the processes of reasoning”.

All that was about to end.

James Q. Chenowith, Slouching Towards Washington.

What eventually was known as the Allison Commission investigated federal scientific agencies from 1884 to 1886. Although there was some discomfort and some few serious issues raised, for the most part the Survey fared well before the Commission. The Commission was a joint panel of the Congress, so the budget cutting tendencies of the House were counter-balanced by the funds-restoring tendency of the Senate. And in any case, the full implications of the Commission really became realized after the Commission’s work was done, in 1886.

[35] Blair, 1884, p. 489

In the middle of that process, though, Grover Cleveland, a Democrat, was elected President in November, 1884. Ho took office in March, 1885. The next month Cleveland appointed James Q. Chenowith to be the First Auditor of the Treasury Department. "He was an officer in the Confederate army and has served several terms in the State Legislature of Texas. He is a lawyer and a staunch Democrat".[36] Chenowith began his job on May 1, 1885. A month later, the Coast and Geodetic Survey was under his investigation. "The accounts of the Coast Survey for the portion of the last fiscal year which are now before First Auditor Chenowith have been suspended by that official, pending the completion of certain investigations which he has set on foot. The discoveries thus far are said to indicate that there have been many unnecessary expenditures and that in certain branches of the bureau great extravagance prevailed."[37]

The Survey was by no means Chenowith's only target. Scandal arose when Chenowith tried to fire a Civil Service top candidate named Kellar for a Treasury job because he was a Republican. This violation of the nascent Civil Service protocols now in place caused an uproar, known as the Kellar affair. Eventually Chenowith was forced to back down and apologize[38], although the scandal continued and Chenowith acquired a reputation for strong opinions quickly determined.

It is unclear what the next chain of events was, but within a month, headlines blared: "Coast Survey Surprise." "Acting on the recommendation of Judge Chenowith, First Auditor of the treasury, Secretary Manning [Sec. of the treasury] has suspended Prof. Hilgard, superintendent of the coast and geodetic survey; C.O. Boutelle, assistant superintendent; Mr. Morgan, disbursing agent; Mr. Saegmuller, chief mechanician; and Mr. Zumbrock, electrotypist of that bureau, pending an investigation into certain irregularities said to exist in the accounts of that branch of the service…. The Secretary has appointed… Mr. Thorne, chief clerk of the internal revenue bureau [and others] … to inquire into the alleged irregularities… Mr. Thorne… temporarily assumed charge of the office as acting superintendent."[39]

Hilgard protested the accusations, to no avail. "No instances of the alleged irregularities were cited, but Prof. Hilgard replied to the First Auditor indignantly denying the charges in toto, and asking of specific instances. He received no reply until he was informed of his suspension from office yesterday".[40] The news caused no little consternation in the capital. "The development of the case has caused a good deal of surprise, and a further report is awaited for with anxiety".[41] The New York Times published an editorial on the matter: "In the absence of proof the country will not readily believe that the officers of the Coast Survey have been unfaithful to their trust. Auditor Chenowith is not a conspicuous advocate of reform".[42]

[36] New York Times, April 26, 1885.
[37] Ibid, July 2, 1885.
[38] Ibid., July 8, 1885.
[39] Ibid, July 25, 1885.
[40]Ibid, July 26, 1885
[41] Washington National Republican, July 27, 1885.
[42] New York Times, July 28, 1885.

Within the next week, the defenses of Hilgard and the rest of the Survey fell apart. Mr. Thorne was both acting superintendent and chief of the investigating committee examining the practices of the Survey. Whatever they found was determined to be damning. As Chenowith noted: "This branch of the service showed upon a first inspection irregularities which are glaring, and it was like unraveling a ball of twine—when it was started it kept coming out. Of course it is necessary to carry on this important branch of our government service, but one half of the money expended in this survey has been wasted. It may have been carried on according to scientific principles, but it surely was not managed on business principles". [43]

Matters got only worse. The New York Times published a long article only a week after its last reference to the scandal, with the headlines: "Drunk Most of the Time: Scandalous condition of the Coast Survey. Prof. Hilgard and some of his assistants continuously intoxicated—embezzlement, forgery, and frauds."[44] A few days later the committee's report was completed. "[It] reveals a sad state of things, much worse than anything intimated in the complaints of Auditor Chenowith"[45]. Essentially, what the committee discovered was a series of small improprieties and infractions that added up to a generalized disorderly bureau, compounded by a leadership vacuum at the top capable of noticing, let alone dealing with the embezzlement, pilferage and other problems that the committee found. In the end, much of all of it was blamed on Hilgard and his failures and intemperance; Hilgard had been suspended as superintendent, but now he resigned. "The present trouble in that branch of the public service is clearly traceable to an infirmity which has overtaken one man, whose long record of faithful and valuable service ought not to be lost sight of".[46] But whatever Hilgard's responsibilities and faults, as well as his virtues, it was over. He was gone from the Survey, and the Survey would now change. Although, for all that, of the others suspended in the initial scandal, Charles Boutelle was reinstated in the Survey, George Saegmuller insisted on a hearing, which absolved him of all charges against him, and Mr. Zumbrock returned to the Survey as a skilled electrotypist. Only Hilgard was utterly defeated and removed.

Chenowith had had a hot productive summer in the Capitol, and he saw clearly what worked. "When First Auditor Chenowith left for his vacation he gave directions for a thorough examination of the accounts and methods of the Geological Survey. This work was committed to gentlemen who have long been familiar with the subject. Upon his return he finds a full report ready for his inspection and action. It takes the ground that immense sums are wasted by this survey, and that a large proportion of its most costly work is being prosecuted without legal authority. It is likely that there will soon be a stoppage of accounts on an extended scale. There are grounds for the belief that the geodetic, topographic, and geological surveys now in progress in 17 of the older states will be declared wholly unauthorized. The contract with the state of Massachusetts to execute a topographical map of that State on a special scale is likely to be treated as

[43] Washington National Republican, August 4, 1885.
[44] New York Times, August 5, 1885.
[45] Ibid, August 7, 1885.
[46] Washington National Republican, August 11, 1885.

made without proper authority."[47] Of course, the US Geological Survey did not grind to a halt. Nor did Chenowith succeed so easily with his next target.

Chenowith next investigated the US Fish Commission, and specifically its director Spencer Baird, who was simultaneously the second Secretary of the Smithsonian Institution. Again, accusations were made of scandalous waste of funds and extravagances. These were easily rebuffed. Chenowith was summoned before his boss, Secretary of the Treasury Manning, who "scolded" him.[48] As the newspaper noted: "The Auditor means well, and would be a good officer if he had not allowed his head to be turned by his discovery of a bad state of affairs in the Coast Survey. His mistake was made in concluding that as there was one defective branch of the service the entire service must be rotten".[49]

Hilgard was dispatched in the hot summer of 1885. Chenowith's trajectory down was about as fast, ironically. By the winter months of 1886 he was being investigated for questionable expenditures of his own. His reign soon ended, and he returned to Texas.

But the Coast and Geodetic Survey had been disgraced, and Julius Hilgard, one of the ablest members it had ever produced, who had spent his life in the Survey, had resigned as a sick and broken man. As his memorialist Otto Tittman put it: "His retirement took place in 1885, and from that time on his lingering illness entailed great suffering, and several times brought him to the point of death. From each of these attacks he rallied back with less power of resistance until death relieved him of his sufferings, on May 8, 1891"[50].

Hilgard's era, which was the era of Coast Survey personnel who had worked with Bache, who invented the American Method, who fought and won the Civil War, was ending. For the first time in its history, the Survey would be led by a Superintendent who, at the outset, had no real idea what geodesy was about. Chenowith was gone, but the troubles he stirred up would continue for many years to come.

[47] New York Times, September 15, 1885.
[48] New York Times, November 23, 1885.
[49] Ibid.
[50] Tittman, 1895, p. 465.

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Sailing Close to the Wind: Superintendent Thorn Rescues the Coast and Geodetic Survey (1885-1889)

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Frank Manly Thorn (1836-1907)

Frank Manly Thorn was Superintendent of the US Coast and Geodetic Survey from 1885 to 1889. He was the first non-scientist to lead the Survey, and also the Survey's first leader since Benjamin Peirce who didn't leave by death, or by disgrace, in the case of his predecessor, Julius Hilgard. His ascendancy was so closely linked to Hilgard's fall that some summary of events in the years before Thorn's arrival is necessary.

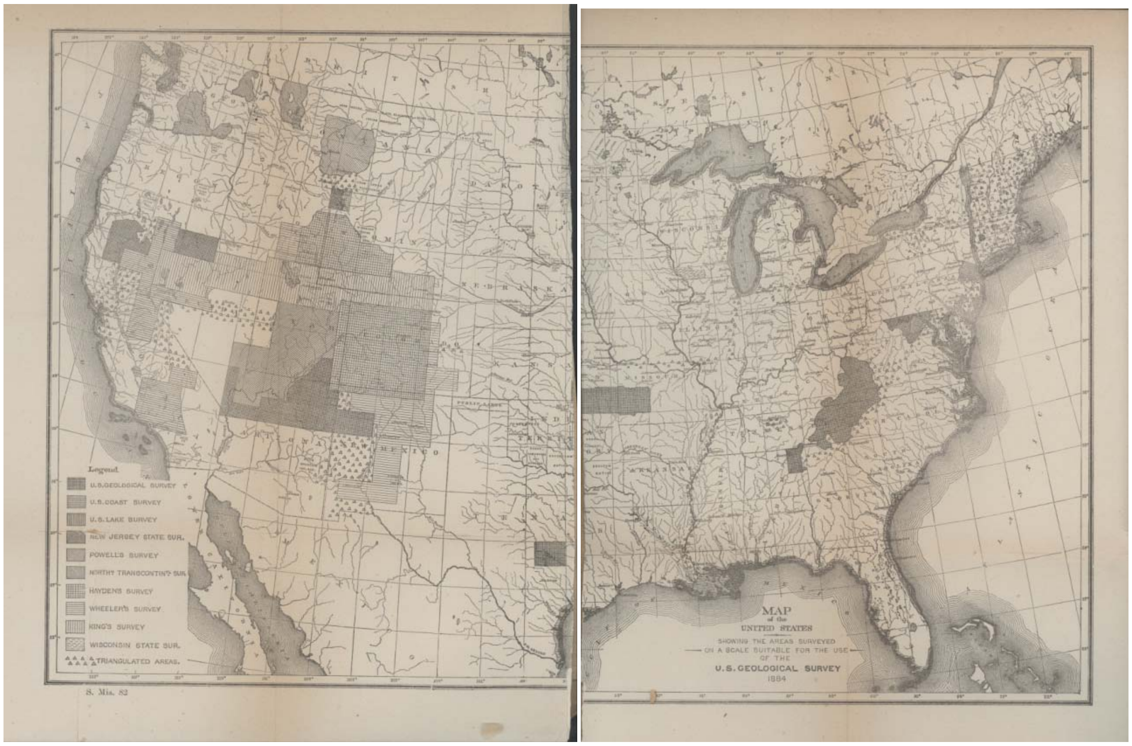
The Allison Commission, Chenowith, the Coast Survey, and American Science

During the tenure of Benjamin Peirce (1867-1874) the budget of the Coast Survey almost doubled from what it had been at the end of A.D. Bache's tenure. The tenures of Carlile Patterson (1874-1881) and Julius Hilgard (1881-1885) were very different. The Panic of 1873 issued in a a period of financial instability and political uncertainty, compounded by labor struggles and strikes and bank failures which eventually engulfed the operations of all agencies in the American government. Patronage and the spoils systems, and efforts to combat them, caused increased scrutiny of federal agencies and their operations and efficiencies.

For the federal scientific agencies, these culminated in the investigations of the Allison Commission (1884-1887), which was a special commission jointly organized by the US Senate and House of Representatives, to investigate the workings and inter-relationships of the US Coast and Geodetic Survey, the US Geological Survey, the Signal Service of the US Army (the predecessor of the Weather Bureau), and the Naval Hydrographic Office. The scale and scope of the hearings and investigations of the Commission were unprecedented in American history, and the voluminous documentation the investigation yielded have made the Allison Commission a signal and much-studied event in the history of American science.[1]

Given the scholarly attention already directed at the Commission, we need only summarize the major issues that impacted the fate of the Coast and Geodetic Survey. Essentially, there were three Venn diagram arenas, two of which enclosed the Coast Survey. The first arena of contention was the Coast and Geodetic Survey and the US Geological Survey and the questions of the place of geodesy in a national science system, the relationship between geodetic networks and topographical mapping, the relationship between coastal oriented mapping and geodesy and the vast interior areas of the US portions of North America, etc. The second arena was inhabited by the US Coast and Geodetic Survey and the Naval Hydrographic Office; and the critical issue was whether or not the Coast Survey should be once again brought into the US Navy or not. Secondary, but also critical issues about the place and significance of geodetic networks in coastal charting and marine hydrography, were related to similar issues in the first arena. The third arena was occupied by the US Army Signal Service and the beginnings of the Weather Bureau. The issues at hand were whether or not such an agency should reside in the military or should become a civilian agency. This arena had little direct relation to the Coast and Geodetic Survey as such, except for the common issue of whether a scientific agency was best run by the military or under civilian control. As a result, the Coast and Geodetic Survey was under scrutiny in all three arenas of the Allison Commission.

[1] See especially Dupree, 1985, Rabbitt, 1980, Manning 1975 and 1988, Kevles 1995.



Areas of the US Suitable for topographic mapping by USGS
map prepared by USGS, 1884 and submitted to the Allison Commission
shaded areas had sufficient geodetic control for mapping

In the middle of the Commission's labors, which occupied portions of two sessions of Congress, in 1884 Grover Cleveland became the first Democrat elected President since 1856. When the Cleveland administration took office in March, 1885, every federal agency and bureau changed, from the top down. As was detailed in the Hilgard chapter, a Texas Democrat and former Confederate officer named James Q. Chenowith became First Auditor of the Department of the Treasury. He proceeded to investigate the workings of the Coast and Geodetic Survey, and then the Geological Survey, and finally the US Fish Commission. Chenowith had little impact in the latter two investigations, as they were by then prepared for his assault, but he had devastating impact on the Coast and Geodetic Survey.

Chenowith's issues revolved closely around money and whether or not agencies spent it correctly, with secondary issues about whether or not certain suites of scientific work were appropriate or not. In the case of the Survey, there were issues of expenditures on equipment and what had happened to the equipment, issues of people being paid whether they worked or not, older people being kept on formally basically as an informal method of providing pensions, which otherwise didn't exist, and so on. And there was a singular set of issues for the Survey concerning a system of per diem money for field expenses that had evolved over time since the Bache administration before the Civil War. Essentially, a system devised to provide extra money for both the extra expenses of field work, and also the lack of banks or other methods to secure money and make purchases while in remote areas, had become a system in which workers throughout the agency received field per diem money whether or not they were out in the field. This had become accepted as augmented income, partially compensating the Survey workers for their notoriously low wages. Where the Survey saw better and fairer compensation, Chenowith saw embezzlement.

The Allison Commission investigations intersected Chenowith's own, and the result was the greatest crisis in the history of the Coast Survey. Superintendent Julius Hilgard was exposed and denounced as a drunkard, although it is still unclear exactly what his mental and physical state was at the time, with many participants in the Survey later on characterizing Hilgard's problems as being caused by some physical disease. But in any case, Hilgard was exposed and disgraced, and quickly forced to resign as Superintendent. In addition, four leading staff members at Survey headquarters were relieved of their posts, leaving the Survey in a perilous state. The immediate leadership was gone, remaining important personnel were paralyzed and frightened, the general corps of the Survey were in disarray, and the Allison Commission hearings had trumpeted positions that questioned and undermined the scientific legitimacy and appropriateness of the foundational work of the Survey.

Whatever else was to happen, it was clear there would not be and could not be another champion to rise from within the ranks of the Survey to take over, right matters, and move the Survey forward. The entire agency had been tainted and compromised, and leadership could only come from without.

In March, 1885, the Cleveland administration began. In late June, a long-time political ally of Cleveland, also a citizen of Erie County, NY, came to Washington as a Cleveland appointee. On July 1, 1885, he began work as a special investigating agent of the Internal Revenue Service, assigned to the on-going investigations of the Survey. He served in that capacity from July1 to July 22, 1885. On July 23, he became the Acting Superintendent of the Coast and Geodetic Survey.

Frank Manly Thorn (Enters, Stage Right)

Frank Manly Thorn was born in Erie County near Buffalo in upstate New York, on December 7, 1836. His father was a lawyer, who became an elected official in various positions in Erie County. His son followed a similar path, at least at the beginning. Frank Thorn attended local schools, and then the Fredonia Academy in Fredonia, NY. He returned to Erie County and served as a clerk in Surrogate's Court, where his father was Surrogate Judge. Afterwards, young Thorn attended law school in Albany, the state capital. He was licensed as a lawyer—and then began to take a very different path in life. He relocated to Pennsylvania in 1860 where he worked in the early petroleum industry. After the Civil War, in 1867, he returned to Erie County, where he once again took up the legal profession—but he also established a productive fruit orchard and farm, and he began to write and publish humorous sketches in local newspapers using pseudonyms such as Hy Slocum, Carl Byng, and Frank Clive. He also performed as a humorist lecturer and after-dinner speaker, apparently with some success. He had less success with his early writings as a result of issues of plagiarism. Samuel Clemens, or Mark Twain, purchased an interest in the *Buffalo Express*, one of the papers Thorn published material in. When evidence emerged that some piece written by Thorn in the *Buffalo Express* had been published elsewhere earlier, Twain himself was accused of the plagiarism. Upon investigation, Twain banned any further contributions from Hy Slocum and Carl Byng, writing characteristically to Thomas B. Aldrich, his original accuser of plagiarism, that he was doing it "for their **own good**—for everything they write is straightway saddled onto *me*".[2] By 1875, Thorn was re-publishing a piece previously published under a pseudonym under his own name in *Scribner's Monthly*.

In 1870, Thorn began his own political career. He was elected to the Erie County Board of Supervisors from 1870 to 1880. He joined the campaign of Grover Cleveland, his fellow local attorney, for Governor of New York in 1882, which was successful. Two years later, Cleveland was the Democratic candidate for US President, with Thorn campaigning actively on his behalf. Cleveland won in November, 1884, and was sworn in as President in March, 1885. He summoned Thorn from Erie County a few months later. And so it was that the man who became the sixth Superintendent of the Coast and Geodetic Survey had prepared for the position by practicing professionally as a lawyer, humorist and after-dinner speaker, and apple and potato farmer. In July, 1885, President Cleveland named him the Acting Superintendent of the Coast and Geodetic Survey

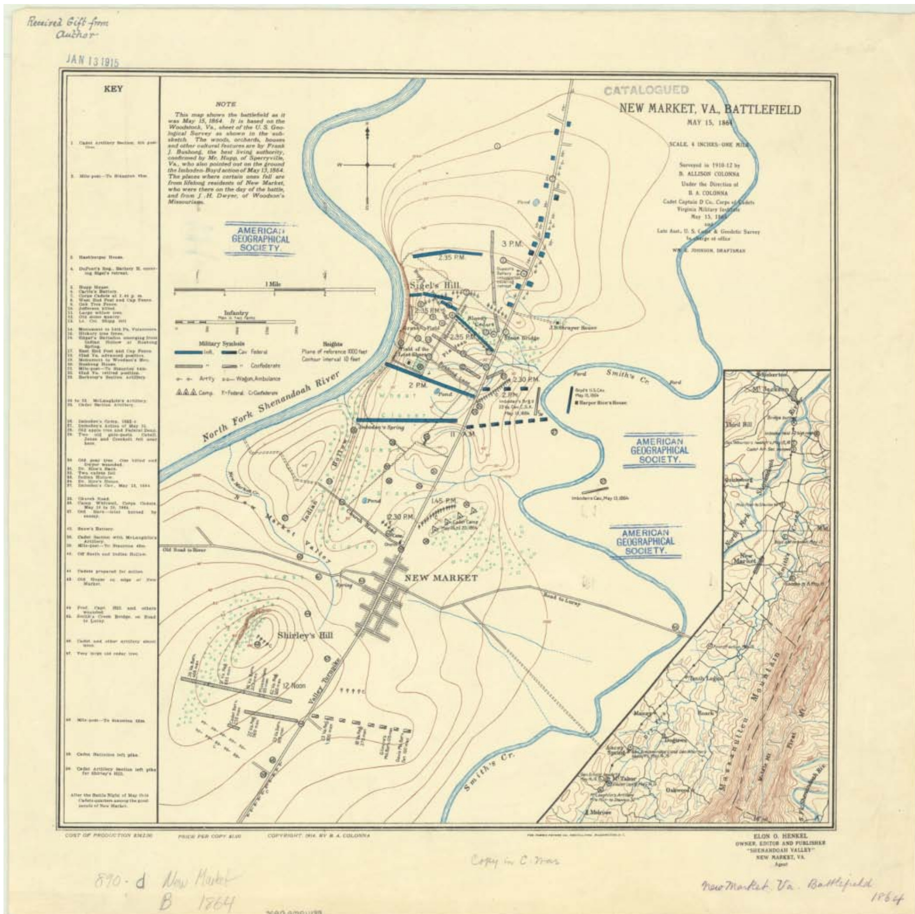
Thorn's very first order of business was to find someone capable of actually directing the Coast and Geodetic Survey. This was not an unfamiliar task; already in its history the Survey had survived the sudden deaths of Superintendents Hassler and Patterson, the long illness and incapacity of Superintendent Bache, and now the disgrace and removal of Superintendent Hilgard. Thorn had already met the headquarters staff—if only for three weeks as an IRS agent—and he made the first of a long string of very good choices. And so it was that Frank M. Thorn chose as Assistant in Charge of the Office a man who really was more of a partner in directing the Survey—Benjamin Azariah Colonna (1843-1925)

Colonna Crosses the Chesapeake from the Eastern Shore to Washington, DC

Benjamin A. Colonna was born October 17, 1843 on a farm in between the villages of Pungoteague and Craddockville, in Accomac County, Virginia, on the Eastern Shore of Chesapeake Bay. His family had emigrated from Europe to that area no later than the 1660s, and had remained there ever since. His grandfather was a farmer and a waterman, an apple brandy distiller, and also a first mate on one of the earliest steamships on Chesapeake Bay. The family owned slaves, and supported the Confederacy. Young Colonna went to Lexington in 1859, to attend the Virginia Military Institute. In May, 1864, Colonna and the other cadets of VMI fought in the battle of New Market, Virginia, causing the Union forces to retreat, although when they returned to VMI they found their barracks burned to the ground. Colonna became a Captain in the Confederate Army at General Johnston's headquarters in Atlanta, Georgia. Colonna was put in charge of two companies of Galvanized Yankees, one French-speaking and the other German-speaking,

[2] Barbara Schmidt and Leslie Myrick of the Mark Twain Project, UC Berkeley. See www.twinquotes.com

who had mutinied and murdered several of their own officers.   He commanded these troops, in both French and German, which he had learned at VMI, in the Confederate retreat from Georgia to South Carolina, to eventual surrender near Charleston, in May 1865.



The Battle of New Market, Virginia in 1862
As re-constructed 1910-12 by Benjamin A. Colonna
And as surveyed by his son B. Allison Colonna

Colonna returned to an Eastern shore landscape decimated by the privations of the Confederacy and the Union blockade. He owed money to the state of Virginia for his VMI education, but there were little prospects for work. He spent several years teaching school, and continuing studies in civil engineering, looking for something better. In 1868, fate intervened. In March of that year, he wrote a letter to a friend, referring to himself in the third person.

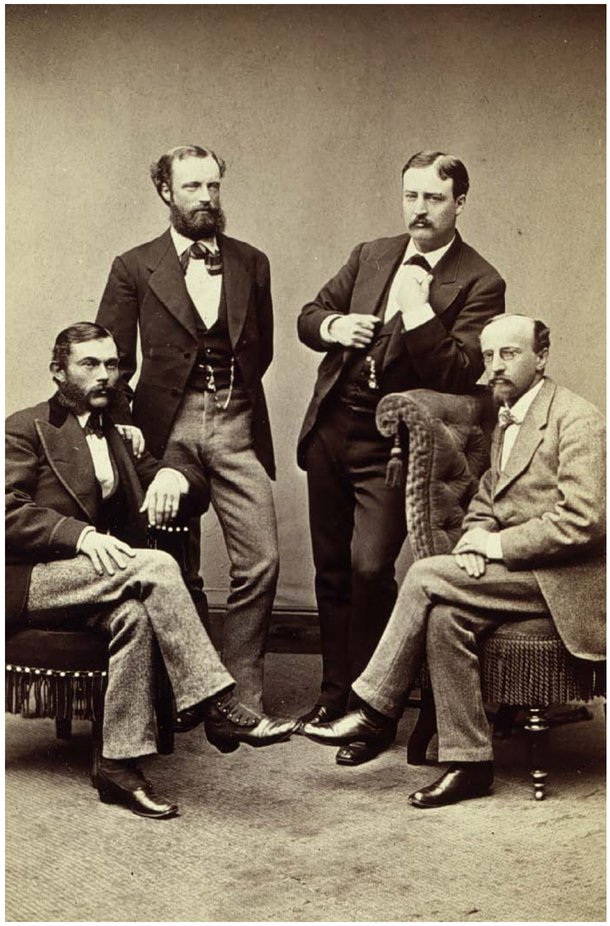
> "Mr. B.A. Colonna, the Village Schoolmaster, was turned over in the middle of the Creek, during the late equinoctial Gale and very unfortunately was bothered with an old man to save. He had to wet himself very thoroughly. Very fortunately for him, there happened to be a detachment of the U.S. Coast Survey on shore who, seeing his fine fix, soon rendered what service to him they could. One, I was glad to find,

> was a friend of the Cleary's and a schoolmate of Jim's. We formed a very agreeable acquaintance and he has almost induced me to enter the service if I can get an appointment as an assistant which he said would not be difficult to do. I believe I would like to do it as it seems to be a life I would like… Will you do me the kindness to inquire whether these appointments as Assistant in the Coast Survey can be obtained by an ex rebel and gain what other information you can on the subject. Wise very kindly offered to give me letters of recommendation and introductions to parties but I'd rather know what I am doing first."[3]

Entry to the Survey proved difficult, as did work in general, so Colonna worked another 2 years teaching school on the Eastern Shore and finding other work. He also fell in love with a 17-year old woman named Julia, for whom he was willing to abandon his life in the Survey, but she rejected his advances, leaving him broken-hearted.[4]

Finally, in the summer of 1870, he was hired as a chain-man on a Coast Survey topographic survey crew. His party chief soon found out how much education he had had, and promoted him to more valuable work. They also urged him to pursue a permanent career with that agency. His real entry into the Survey was under General Richard B. Cutts, surveying in Gloucester, New Jersey, on the Delaware River. He advanced enough to be sent to Washington to learn office work, following the field season. His career for the next decade or so was the classically varied work of the Survey: hydrographic surveying in Pamlico Sound, North Carolina on the steamer Hitchcock, then topography and hydrography on Long Island, NY. In 1876 he worked in Louisiana at the mouth of the Mississippi River on the Survey's series of Mississippi River charts. In 1877, he was detailed to San Francisco where he worked under George Davidson, who became a major friend and mentor. For the next few years he worked on the epic triangulation work of the Arc of the 39th Parallel triangulation system and the Davidson quadrilaterals. In 1879 he participated in the heliotrope signaling and angle measurements between high California mountain peaks that set a world record for line of sight distances in geodetic surveying. He published an article about his nine rigorous days on the summit of Mount Shasta which received wide distribution.[5] In 1882 he was surveying deep in Wyoming territory, and he participated in the second Transit of Venus experiments. 1883 found him on the east coast of Florida. In 1884, he returned to the Pacific coast for surveys in the straits of Juan de Fuca. It was there that his life changed.

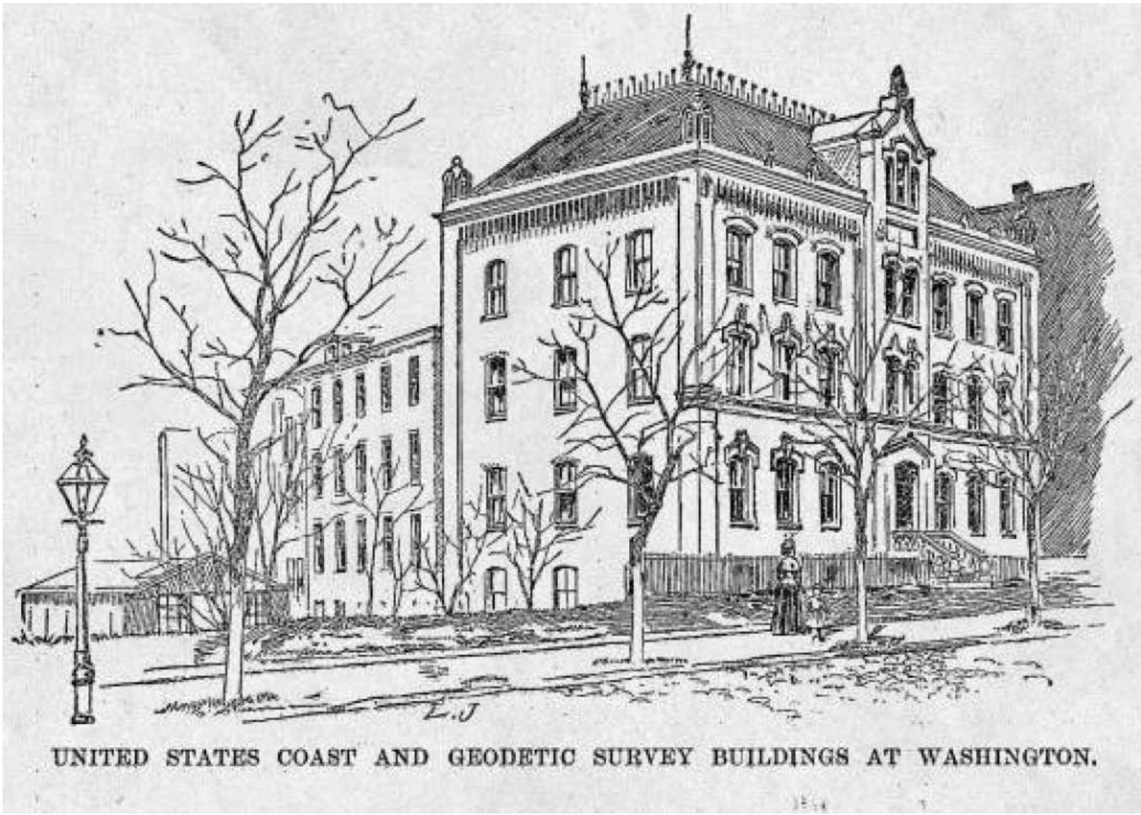
[3] Letter Colonna to John Hanna, March 18, 1868. In Autobiography of Benjamin A. Colonna, 1903, Vol. 2, pp.13-14.
[4] Ibid., p. 18.
[5] Colonna, 1880.



Louis Sengteller, E.L. Dickins, **Benjamin Colonna**, and unidentified man photographed in a studio in San Francisco, 1877 or later

On August 4, 1884, Colonna and a Survey party were skirting glaciers on the slopes of Mount Olympia, as part of a triangulation tie between Whidbey Island and Cape Flattery. Colonna slipped on loose scree, which precipitated an avalanche that carried him tumbling down the face of the mountain and partially buried him in rock and volcanic ash. As he related later, by chance he was wearing a very large Mexican straw hat that day. The other members of the party located him only because part of the hat was protruding from the rock rubble. Colonna was severely injured. He was rushed off the mountain and ferried to Vancouver, BC, to an excellent Catholic hospital, which probably saved his life. Colonna was paralyzed, losing all use of his arms and legs. Over a period of many months, he made a gradual and partial recovery from his injuries. He regained much mobility, but for the rest of his life he walked with a cane. His field work days were over.

And so it happened, in the fateful year of 1885, in the midst of the Allison Commission hearings, and immediately before Superintendent Hilgard's disgrace, Benjamin Colonna was ordered to Washington to take charge of the office work. The Survey headquarters on New Jersey Avenue were only a block from the Capitol, close enough that even a partially disabled man with a cane could walk to give testimony before the Allison Commission.



The Survey's headquarters on New Jersey Avenue,
Harpers Weekly, October, 1888.

The Partnership of Thorn and Colonna

Thorn was briefly employed investigating the agency he was to lead. There are some indications that the stories he had heard about the disarray at the Survey caused him to display an initial hostility to many Survey personnel.[6] However it appears that he soon concluded that the problem personnel at the Survey were few and could be dealt with, while the majority of the agency's people were innocent of any of the charges thrown at them. At the same time, the agency had been in continuous operation for half a century at that point, spanning Hassler to Hilgard and the Civil War, and it had accumulated a large set of customs and procedures which could easily be considered questionable if scrutinized. Further, the outcry over questionable expenditures, whether justified or not, meant that money would become necessarily tighter, and all expenditures would be subject to much more rigorous auditing than ever before. In short, the Survey, to survive, would have to do more with less.

[6] Manning, especially 1975, takes this position.

Thorn was ignorant of almost every aspect of Survey operations, but he was capable and intelligent, and he was also a very trusted political ally of the President. Thorn chose Colonna, out of all the Survey staff, to become essentially the "real" leader of the Survey, at least initially. Clearly Colonna couldn't work outside the office, but it appears Thorn chose him for many other reasons. He was enthusiastic and smart, he had in little more than a decade worked in almost every scientific domain of the Survey, and he appeared to have the kind of management skills necessary to keep the staff satisfied and productive. And he was as different from Julius Hilgard as could be found in the Survey—a thoroughly native American scientist, and even an ex-Confederate, which could diffuse opposition in some quarter and enlist support in others.

Benjamin A. Colonna
Assistant in Charge of the Office

The partnership of Thorn and Colonna fell in place in the middle of the Allison Commission hearings. In the remaining year, various senior Survey scientists and others who had begun their scientific careers in the Survey, such as Cleveland Abbe, Alexander Agassiz, Marcus Baker, George Davidson, William Ferrel, Julius Hilgard Henry Mitchell, Charles S. Peirce, Charles Schott, as well as Benjamin Colonna, testified before the Commission. Superintendent Thorn never appeared once before the Commission. Assistant in Charge Colonna became the de facto spokesman to Congress, probably because he could not be tripped up by ignorance of the Survey's affairs, and his testimony wouldn't have to be corrected.

At the end of the Commission's time, it prepared a final report with recommendations to the Congress and the Executive Branch. There were two dangers the Coast and Geodetic Survey wanted to avoid: transfer of the Survey to the Navy one more time, or to be deposed geodetically, as it were, relative to the work of the US Geological Survey. The Survey won, on both issues. The Allison Commission advised against the transfer to the Navy, and they laid out a strong set of scientific reasons why the Coast and Geodetic Survey should continue essentially its entire plan of scientific research and publishing, although henceforth the major domain of topographic mapping in all non-coastal areas would be the responsibility of USGS. It helped that the USGS' leader John Wesley Powell, who was a close person friend of Julius Hilgard, had strongly supported the Coast and Geodetic Survey and its geodetic network as the foundation for USGS' mapping.

Thus, the Coast and Geodetic Survey survived the crisis year of 1885, and the Allison Commission finale of 1886. In 1887, the oldest threat to the Survey's existence came back in force: yet another maneuver by Congressmen on the House Committee on Naval Affairs to fold the Survey into the Naval Hydrographic Office.

The Survey Sails Close to the Wind

Colonna knew the Survey's work and he knew Congress; Thorn knew President Cleveland. Their strategic partnership was to work together in those disparate realms. What they did and how it worked is revealed in a unique document written by Thorn in 1903 in response to a query by Otto Tittmann, then the current Superintendent of the Survey. Tittmann was inquiring about a somewhat mysterious document, called "Historical Compilation U.S. Coast and Geodetic Survey". It was 16 pages long, listed no author, date, or publisher, and yet it had apparently served some vital purpose decades before. Frank Thorn replied from his orchard farm in Erie County, New York. His reply constitutes the very first memoir of any Superintendent of the Coast Survey and Coast and Geodetic Survey. Every previous Superintendent in history had died in office, except for Peirce and Hilgard, who resigned voluntarily and involuntarily, respectively. But neither of them ever wrote a memoir. Thorn's account is worth quoting in full. He had been a successful author, newspaperman, and speaker, and he could write a clear letter.

Orchard Park, NY
Jan. 31st 1903

Mr. O.H. Tittmann
Sup't U.S. Coast Survey
Washington, D.C.

Dear Mr. Tittmann:

The sixteen-page "Historical Compilation U.S. Coast and Geodetic Survey [1887?]" mentioned on pp. 86-138 of the "List and Catalogue of Publications" kindly sent to me, and a copy of which compilation I enclose herewith, was my work, prepared and used for a special purpose, I think early in 1888 instead of 1887. Notwithstanding its comparative and apparent insignificance, it was quite a factor in disarming executive prejudices and preventing the transfer of the Survey to the Navy Department.

When Hon. Hilary A. Herbert[7] was Chairman of the House Com. on Naval Affairs, he introduced and had referred to his own committee, a bill to accomplish that transfer, in perseverance of a long cherished plan of himself and President Cleveland. I promptly called at the Executive Mansion and asked the President if he favored Mr. Herbert's measure. "Yes" he replied; "You remember that I recommended the transfer in one of my first messages." When I told him that I believed the transfer would be injurious, he asked why and I told him that the experiment of Naval control of the Survey had been tried two or three times and always with unsatisfactory results. He was quite surprised and asked me if there was any published history of the matter. I told him that there was. He asked me to get it for him as he was liable to be called on or to act officially in the matter and he desired to act with full information. I told him that the history of that phase of the Survey's experience was scattered through various public documents from which I would compile the pertinent facts and submit them to him, in a sort of brief, together with copies of the documents from which the facts were compiled.

I had long known that the President had been predisposed to the transfer, not only by the shallow plausibilities of Sam. Randall[8], Mr. Herbert, Lt. Dyer U.S.N[9]. and others but by the fact that the Treasury Department was apparently acquiescing in the effort of the Department of his close friend, Sec'y Whitney[10] to capture our bureau. It seemed to me vitally necessary therefore, to correct his prejudice, not only by submitting a brief history of the Survey's experience with the Navy Dept. but by giving him an insight into its place of organization and the character, subdivision, variety and scope of its work succinctly stated and all fortified and supplemented by an argument as terse and emphatic as I could make it (with due regard to the official proprieties) in refutation of the sophistries with which our foes had, for three years, been filling the air. I paid for the edition of several hundred copies, one of which, accompanied by the original authorities, I sent to the President, who returned them to me about a year afterwards. It is, perhaps, worth noting that he did not, during his second term, renew his recommendation for the transfer of the Survey.

Mr. Colonna and I decided, in the meantime, not to await the President's conclusion. Copies of the compilation were sent to several of the Senators and Representatives, and Colonna read it to various members of Mr. Herbert's Committee on Naval Affairs, and the result of that form of missionary work, was the smothering of

[7] 2nd District of Alabama (Democrat)
[8] 3rd District of Pennsylvania (Democrat)
[9] An officer in the Hydrographic Office of the Navy
[10] Secretary of the Navy

Chairman Herbert's measure by his own Committee, as several of its members promised in their interviews with Colonna.

That was one of several occasions when Colonna's service to the Survey, in preserving its autonomy, was inestimable. The friendship and unquestioning confidence of certain Senators and Representatives enabled him to accomplish more at the Capitol, than any other member of the Survey, to prevent its dismemberment or transfer. At the White House end of the line the man closest to the President was an advocate of the appointment of a certain unsparing and unscrupulous naval critic of the Survey, to its Superintendency as my successor.

I doubt if anybody but Colonna and myself knew how close to the wind the Survey sometimes sailed, or how desperately vicious, and even villainous, were some of the agencies employed to wreck it—and all those agencies could have been placated at any time by my consent to debauch the service by the appointment or promotion of certain rascally parasites of Randall, Chenowith[11] and Co.[12]

As you will observe, probably not more than one fourth of the pamphlet is a compilation—the residue being such a statement and argument as seemed to me best calculated to appeal to the layman instead of the scientist.

Yours truly,
F.M. Thorn

"…it was in fact a Geodetic Survey"

If Thorn's memoir was unique, so also was his Historical Compilation. In a short publication, he collated and described a number of difficult and confusing campaigns to transfer the Survey to the Navy, the dismal outcomes of the transfers that succeeded, along with Thorn's understanding of the work of the Survey, with particular reference to publishing what he called "a perfect map". That that was the arena of contention about which agency should produce hydrographic charts, and also, I would submit, the objective of "a perfect map" is an apt descriptor for the tenure of Superintendent Thorn. In many ways, his short tenure can now be seen as another golden age of Survey cartography, akin to those under Bache and Patterson.

Thorn situates the entire enterprise of the Survey in its fundamental geodetic foundations:

"In pursuit of the original plan of 1807 and of the completer plan of 1843, and to avoid disgraceful inferiority and imperfection of its results, the operations of the Survey were always—except when withdrawn from civilian control—conducted in conformity

[11] James Q. Chenowith, 1st Auditor of the Department of the Treasury. His actions are described in the chapter on Superintendent Julius Hilgard.
[12] See Manning, 1975 and 1988, for accounts of these initiatives—although Manning's analysis and conclusions depart significantly from my own.

with the requirements of geodesy—it was in fact a Geodetic Survey. The transcontinental operations were not only strictly related to the survey of the coasts, (as essential to the harmony of the measurements along the Eastern and Western shores, and as affording a most valuable contribution to that knowledge of the form of the earth and its local variations which is essential to the accuracies of the survey of the coast), but incidentally they supply to the traversed states accurately located points—otherwise practically unobtainable by them—upon which to base their own topographical or geological surveys, for the construction of accurate County or State maps. It will also provide part of that framework without which no accurate map of the United States is possible. Upon that arc has already been achieved some of the best work ever done in accuracy of base-measurement, accuracy and range of observations and area of geometrical figures, and at much less than the cost of similar, but less notable, work abroad. That the enterprise is either premature or extravagant will hardly be urged in face of the fact that Europe presents not a single transcontinental arc of triangulation, but a complete net-work covering every country except Turkey and a portion of Russia, and that even in remote and mainly uncivilized India, a superb work of triangulation ten times as extensive as our transcontinental arc has already been completed".[13]

The Compilation is a combination of excerpted text from a variety of historic documents, Thorn's own commentary, such as the passage just quoted, and finally, materials submitted by Colonna or other Survey personnel to the Allison Commission. One key passage, from one of Colonna's sessions before the Commission, summarizes the kinds of field work underway in Thorn's era.

"The field work of the Geodetic Survey is in eight different lines, all but one (the fifth) of which are necessary to the production of a perfect map. These divisions are:

"First. *Triangulation*, including base measurements, by means of which distances between prominent points are made known.

"Second. *Astronomical observations*, by means of which directions of all measured lines are made known, and also the locations of points on the earth are made known…

"Third. *Leveling*, by means of which the heights of objects above mean level of the sea are made known.

"Fourth. *Tidal observations*, for determining the mean level of the sea, from which heights are reckoned; also for predicting the rise and fall of tides for the use of navigators and others, and also for the reduction of soundings taken at any time to what they would have been if made at low water.

"Fifth. *Gravity observations*, for determining the density of the earth.

[13] Thorn, Historical Compilation (1887), p. 8.

Sixth. *Topography*, or the picturing by conventional signs of all the surface features of the land, its elevations and depressions, its streams, roads, canals, its forests, plains and mountains, its towns, fields, etc.

"Seventh. *Hydrography*, by means of which the configuration of the bottom of the sea, lakes, and rivers become known; also physical hydrography which makes known the character of rivers, tidal, and ocean currents, their effects in producing progressive or periodic changes in the configuration of the bottom.

"Eighth. *Magnetic observations*, from which we learn the direction in which the compass needle points, the changes in the direction, the intensity of the magnetic force, which directs the needle and the variations of this force, and thus get material to foretell the changes of direction to which the compass needle is subject, and the variations of the force directing it.

"The order in which these operations are carried out is not an arbitrary but a logical one, and in this logical order the hydrography comes last."[14]

In fact, although the progression from triangulation to publication ready material is generally as Colonna stated, hydrography as such didn't necessarily come last, but making hydrography appear last was a key argument of the Survey to deflect the latest initiative of the Naval Hydrographic Office to take over the Survey. The Navy stressed that they were capable of hydrography; the Survey countered that hydrography was dependent on the full array of geodetic sciences that necessarily preceded the hydrography.

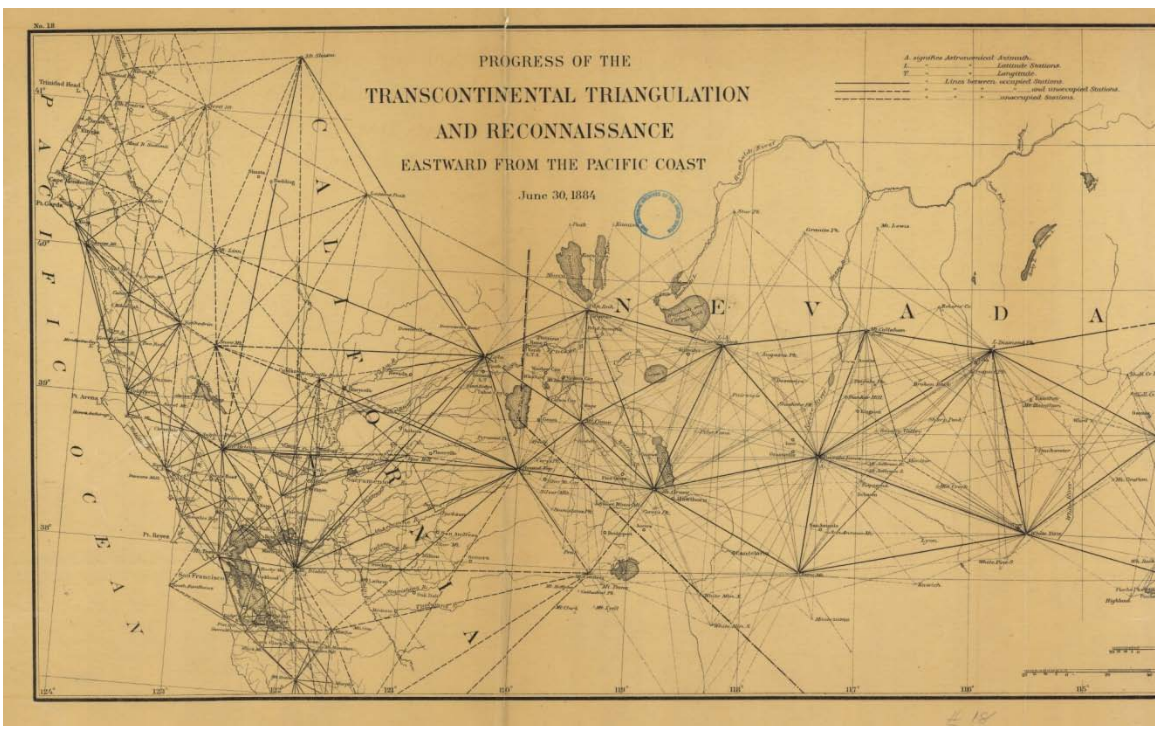
But in any case, Colonna's progression of the disciplines and their timing in the map production process can provide a useful framework to discuss the actual achievements of the Survey during Thorn's tenure, as opposed to discussing the work accomplished division by division, as had been done in earlier chapters. The Hilgard/Thorn era of the Survey was unparalleled for the turmoil within the agency, with the Superintendent forced out, several key officers fired and then re-instated, retrenchment of budgets, outside scrutiny of expenditures, significant losses of salary to Survey personnel, and so on. It is a wonder that the Survey was able to accomplish as much as it did.

Triangulation

It may be argued that the Arc of the 39th Parallel triangulation network exercise in the west brought Survey geodesy to a whole new level, literally and figuratively. The combination of basin and range topography, the existence of isolated peaks visible at great distances, and the occasional atmospheric clarity that allowed those observations, led the Survey to triangulation observations at distances never before accomplished anywhere. Assistant Colonna had himself been a participant in the great triangles in

[14]Ibid., pp. 11-12.

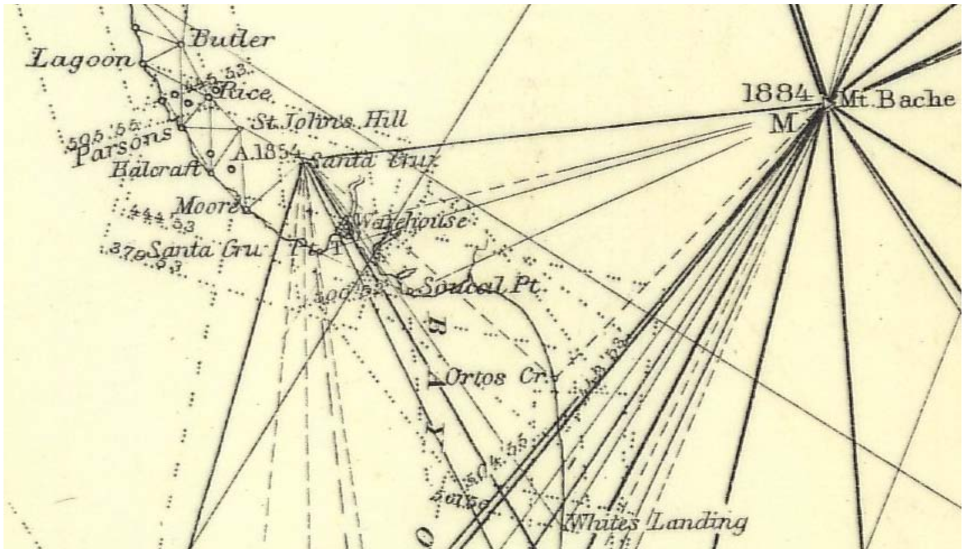
California. But the potential of great distances and areas positioned also made it paramount that stations were chosen well. Much thought and experimentation on this matter was condensed in Charles Boutelle's treatise "On Geodetic Reconnaissance", which was published, ironically, at the same time that Boutelle was first relieved of his post, and then later on, after he petitioned for a Congressional hearing, cleared and restored to his position in the Survey.   His treatise summarized what the Survey had learned in the west. "It is not intended to supercede any portion of Appendix No. 9, Report of 1882, on the field work of the triangulation, but rather to enlarge and illustrate that portion of it which treats of Reconnaissance, by examples drawn from actual cases occurring in the usual routine, and by bringing out very fully the principles, theoretical and practical, which should govern in carrying on this very difficult, responsible, and laborious portion of Coast and Geodetic Survey duty. No department of professional labor calls for the exercise of a higher order of ability, or better repays thorough execution."[15]



A portion of Sketch No. 18, Annual Report for 1884,
Show the combination of reconnaissance triangulation and
primary triangulation along the 39th Arc Transcontinental Survey

Once the primary network was well established, Survey crews could return for secondary and tertiary triangulation of smaller areas, generally in close conjunction with topographic and hydrographic mapping. An example of the latter was the triangulation in the vicinity of Santa Cruz, California, in 1884 and 1885.

[15] Boutelle, 1885, App. No. 10, P. 469.



A portion of Sketch No. 10, Annual Report for 1885,
showing secondary and tertiary stations in the vicinity of Santa Cruz California

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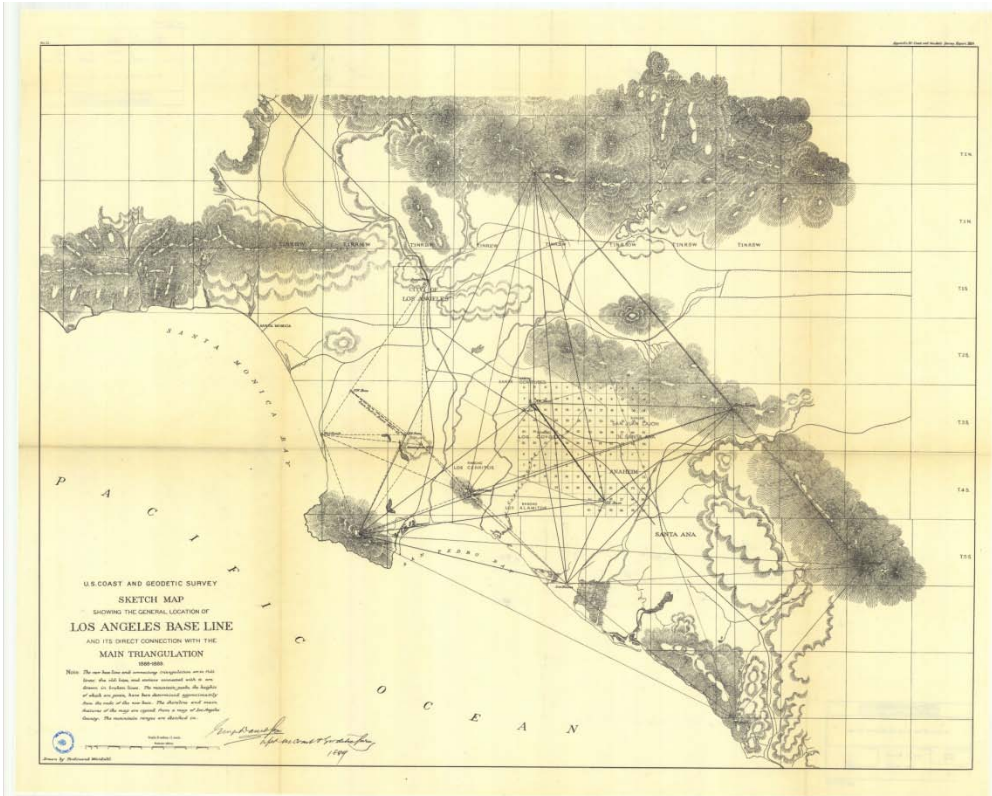
George Davidson's camp by the San Lorenzo River, outside Santa Cruz
in a grove of California live oaks
From Benjamin Colonna's Photo Album

The other essential exercise in triangulation is the measurement of highly accurate base lines, at appropriate places and intervals. George Davidson organized the enterprise of the Los Angeles base line, which set new standards for precision in measurement in the Survey.[16]

[16] Davidson, 1889, App. No. 9, pp. 217-231.



The Los Angeles Base Line, 1889

As usual, the baseline was measured on the flattest place possible, and then tied in to triangulations of surrounding high peaks.

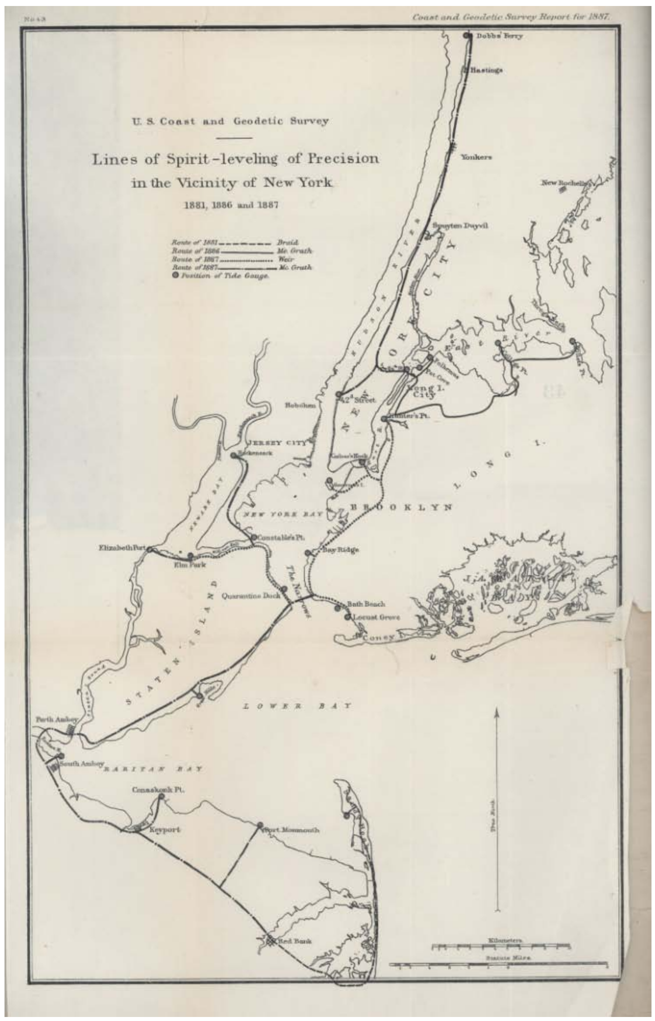
Astronomical Observations

During Thorn's tenure the Survey certainly continued making observations, but the more important development was the ways in which the Survey's work in astronomical positioning and deflections of the vertical and other aspects of geodesy were increasingly situated in larger international scientific context. Charles S. Peirce's gravity research was noted in Europe, and that fact was noted in the United States. The Survey had joined the International Geodetic Association, headquartered in Berlin, and George Davidson had attended the Association's annual meeting in 1888, possibly at his own expense, due to the difficulties with Survey funding and audits for improper expenditures. Finally, as one of many indexed publications the Survey published under Thorn, J. Howard Gore published his massive Bibliography of Geodesy as an appendix in the annual report. As Thorn noted, strategically, in his introduction:

"My own conviction of the propriety of Professor Gore's attitude was so clear that I could not, without a conscious disregard of duty, have declined the proffer of his manuscript to this Survey, for preservation and publication among the scientific appendices to its Annual Report, and so assuring, without cost for preparation or compilation, appropriate association of the recognized American Bureau of Geodesy with a complete Bibliography of Geodesy, American, in inception and authorship and the first work of its kind".[17]

Leveling

The Survey created various new networks of "spirit leveling of precision" which were tied into tide station networks and the triangulation networks to allow characterization of the movements of water in tides and currents at a scale and precision never before achieved. One of the most signal exercises in Thorn's era were the tide station and spirit levels of precision networks around New York Bay and Harbor.



The network of tide stations and lines of spirit-leveling of precision in the Vicinity of New York, 1887

[17] Thorn, 1887, App. No. 16, Intro., p. 313.

Many of the tide stations had been in place since Bache's day, others were installed under Thorn. But the lines of leveling of precision allowed heights of the tide stations to be determined with much greater accuracy relative to the Survey's sea level datum for New York Bay and Harbor.[18]

The much more accurate data resulting from the more precisely situated tide stations then, in turn, allowed Henry Mitchell, and later his assistant Henry Marindin, to characterize the tide and current flows in and out of the harbor as had never before been possible. This allowed Mitchell to establish the critical roles of the ebb tide flows of the East River, bringing great quantities of sea water from Long Island Sound into the Bay, and the roles of these ebb flows in keeping open navigation channels in the Bay. His research had dramatic impact on the receptions of major alterations that had been proposed for the Bay. The story is summarized in Henry B. Well's unique lauding of the imperiled Survey, published in 1888 as a special four-page Supplement to the journal Harper's Weekly.

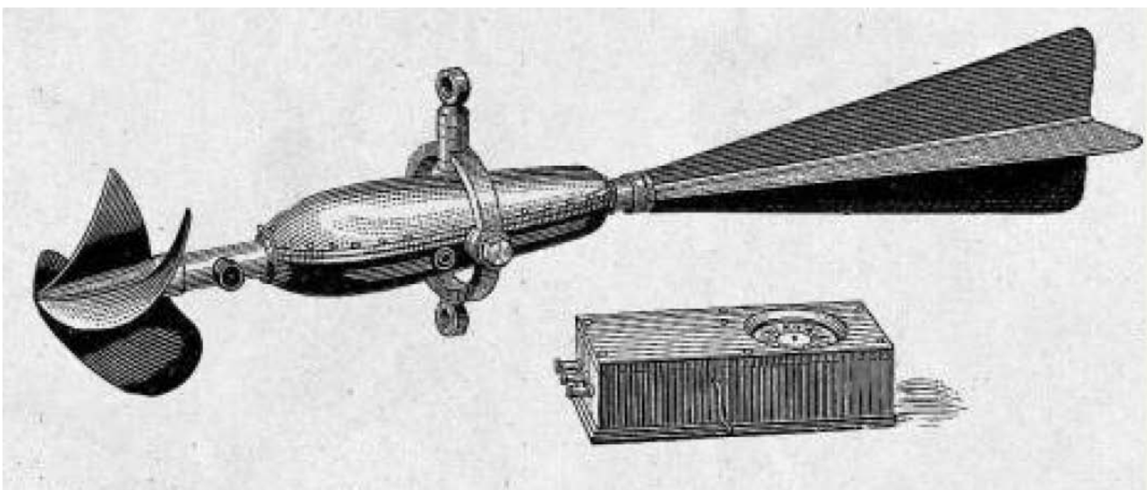
"Another interesting feature of the work is the observation and study of currents in relation to channel-scouring, shoal-building, and the like, under the immediate supervision of Professor Henry Mitchell, a veteran assistant in the Coast Survey, and at the same time one of the Mississippi River Commission. Few indeed are the men who are engaged in our foreign trade, whether as merchants or sailors, who are not indebted to Professor Mitchell. Again and again has his wise counsel prevented irreparable harm to our ports. Take a case in point. Some time before the Brooklyn Bridge was projected it was proposed to close East River by a broad dike, and thus unite New York and Brooklyn. The New York Chamber of Commerce, wise in its generation, submitted the matter to the Coast Survey. Professor Mitchell informed them that if this were done the depth on the bar at Sandy Hook would diminish some four feet. The project was abandoned in consequence. The damage which would have resulted to the prosperity of New York and the adjacent cities in one year, from such a mistake, would have exceeded the entire cost of the Coast Survey from its inception to the present day.

"Professor Mitchell answered this question as he did on theoretical grounds. The entrance to New York Bay is but an inlet, a break in the littoral cordon which reaches from the end of Long Island down to Florida, and of which Coney Island and Sandy Hook are dry parts. Why is it that entrance has and maintains a depth almost unique among such harbors the world over? Why is it that New York Harbor is prone to remain open to commerce when harbors far to the south are closed by ice? If the rivers which flow into it were the only scouring cause, New York would be a barred harbor with comparatively little water on the bar. Rivers aid little in this work. The lighter fresh-water flows over the denser salt-water, and does not reach the bottom. It is like trying to dig a hole in the ground by shoveling in the air. The heavier salt-water is the shovel that reaches the bottom and does the work. More salt-water must pass out over Sandy Hook bar on the ebb tide than entered it on the flood tide, and from Long Island Sound through

[18] Before the vertical networks of the early 20th century, there never was a uniform "seal level datum" fo the Atlantic coast. Sea level datums were established for major ports separately. Dave Doyle, Chief Geodetci Surveyor, National Geodetic Survey, pers. comm.. 2009.

East River this surplus must come. It is the low freezing-point of this excess of salt-water, and the rapid change of water it produces, which kept the port from being closed in by ice. What an escape was it that that dike between New York and Brooklyn was not built!

"Not very long since one of the employés in his field party, Mr. Eugene E. Haskell, invented, in conjunction with Mr. Edward S. Ritchie of compass fame, a wonderful machine. It could be placed in any reasonable depth of water, and would record at any place with which it was connected the exact velocity and direction of any current which might exist where the machine was. A careful series of experiments with this machine showed that the ebb-tide exceeded the flood-tide through East River by 448 millions of cubic feet. Every position taken by Professor Mitchell on theoretical grounds was confirmed by direct experiment."[19]



Haskell and Ritchie's Current Meter
Harper's Weekly, Supplement, October 20, 1888

Mitchell's triumphant success in defeating a plan to dike the East River was the legacy of many years of data accumulation and much pondering about dynamic tidal systems of the Bay.[20]

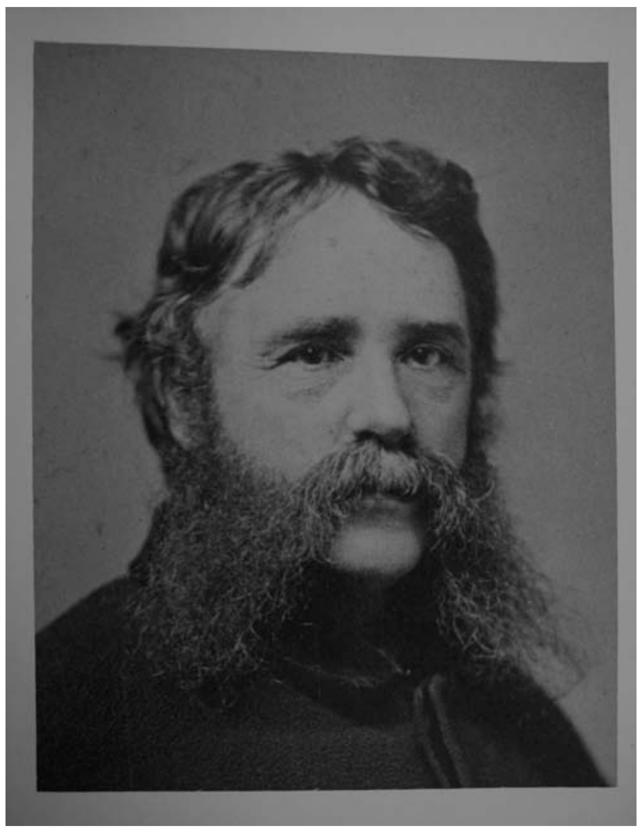
Tidal Observations

As the previous example made clear, it is hard to separate tidal observations from many other elements of topography, hydrography and leveling and, for that matter, from geodesy in general, as all these matters are closely connected to the determination of the geoid and evaluation of other phenomena in relation to that. The major developments in

[19] Henry Well,s 1888, p. 806.
[20] See Mitchell, 1886, App. No. 13, and 1887, App. No. 15.

Thorn’s tenure were continuation of major initiatives combined with the departure of major Survey scientists closely associated with those same initiatives.

Some time during Thorn’s era, Henry Mitchell departed the Survey and his role as Chief of Physical Hydrography. It is not entirely clear when this happened, but the fact that he is listed in the Alphabetical Index for the annual report of 1888, and is missing from the same index for 1889, is suggestive. It is also unclear why he left. Manning says he was driven out by Thorn: “When Henry Mitchell, the hydrographer and harbor expert, showed obvious unhappiness at Thorn’s presence in the Coast Survey, the superintendent mocked both Mitchell’s technical learning and his personal mannerisms. Mitchell soon resigned”.[21] However, Manning cites no source for this story, and many elements of his discussion of both Thorn and Colonna do not ring true.

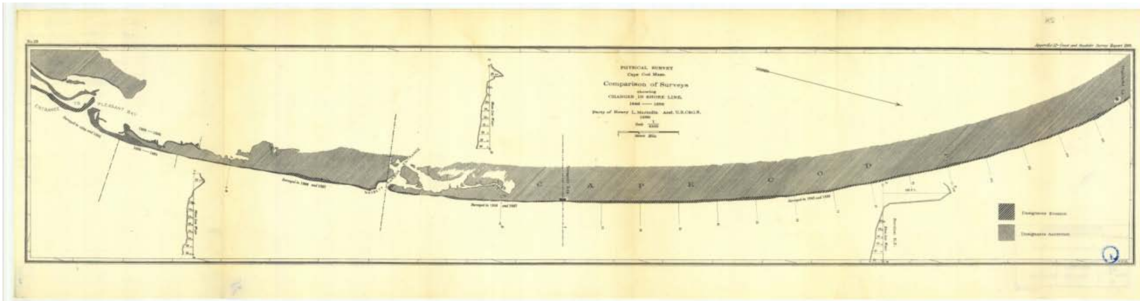


Henry Mitchell, Chief of Physical Hydrography
an undated photograph

In any case, Henry Marindin, Mitchell’s assistant, now became Mitchell’s successor, in completing comparative studies of hydrographic changes in areas pioneered by Mitchell. Hence, in 1889, Marindin analyzed “Encroachment of the sea upon the coast of Cape Cod, Massachusetts, as shown by comparative surveys”. As he noted: “with the data obtained by the party of Physical hydrography in my charge during the

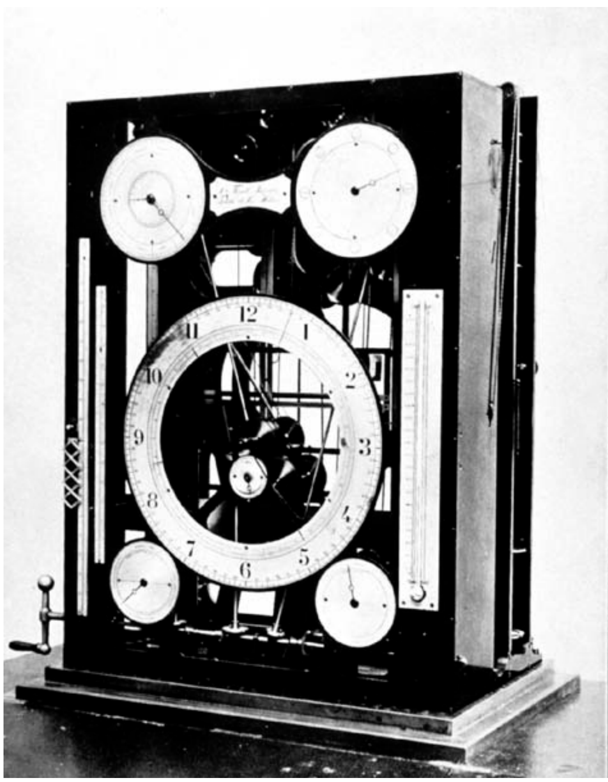
[21] Manning, 1875, p. 190.

season of 1887 and 1888 on Cape Cod, we are now able to make comparisons and show the changes which have taken place in the shore and bluff lines on this part of the Cape since previous surveys, and thus add to our knowledge of the physical history of the Cape, the study of which was initiated by Assistant Henry Mitchell in 1871." [22]



Changes in Shore Line, Cape Cod, by Henry Marindin
Figure No. 28, Annual Report for 1889

The other major change in the Survey related to tidal observations and related matters was the long-delayed completion of William Ferrel's Tide Prediction Machine. Ferrel had completed the fundamental concept and design of the machine in 1881-1882.[23] The machine was built almost entirely by Ernst Fischer and his staff in the Instrument Division, a process that took half a decade.



[22] Marindin, 1889, App. No. 12, p. 403.
[23] Ferrel, 1883, App. No. 10, pp. 253-272.

William Ferrel's Tide-Predicting Machine

Gravity Observations

Colonna noted gravity observation as the one type of field activity not necessary to the production of "a perfect map". Nevertheless, gravity work continued and expanded under Thorn. This was at no little risk, as Charles S. Peirce's gravity research had been singled out for scrutiny as "impractical science" both by the Treasury department auditor Chenowith, and various members of the Allison Commission. Peirce was a target in part for his idiosyncratic personal behavior, and also for his refusal to back down or become submissive in response to the serious charges leveled against both him and his research. Peirce had already acquired an international reputation for his research in gravity, several branches of mathematics, and logic. He was also acquiring a national reputation based on his eccentricities, particularly in relation to the ostensible duties of federal employees. At the nadir of the Chenowoth[24]/Allison Commission scandals for the Survey, Peirce actually wrote a letter of resignation to the Secretary of the Treasury, which he gave to Thorn. Thorn saved Peirce's career at the Survey by refusing to pass the letter on to the Secretary. Thorn also expressed a certain understanding and appreciation for Peirce in a letter in which he paid him a high compliment, given his career as a successful writer of humor. Thorn noted that Peirce was good at turning "the humdrum routine of official intercourse into a series of lively episodes".[25]

Peirce's reputation concerning gravity research was based on his rigorous research in the imperfections in the mechanisms of swinging pendulums and their impacts on the resultant data on gravitational attraction at the instrument's site. His greatest problem in extending his research was that he was unable to design and acquire pendulums and their mechanisms that were sufficiently accurate for his rigorous purposes. Nevertheless, his conceptual schema for the kinds of research he thought useful and necessary was as big as the country. As an anonymous contributor to Science noted after interviewing Peirce:

"Mr. C. S. Peirce explained some of the errors still needing correction in pendulum observations, particularly such as were due to the flexure of the pendulum. He presented the outline of a scheme for a gravitation survey of the entire country, indicating the position of points in the eastern portion of the country which he thought most desirable to occupy, in which the stations would be about two hundred miles apart, regions of geological disturbance avoided, but their sides occupied, together with the summits of the higher mountains. Seven or eight stations could be occupied in a year, and

[24] The Treasury Department Auditor referred to previously
[25] F.M. Thonr to C.S. Peirce, March 3, 1887, in C.S. Peirce Papers, Houghton Library, Harvard University. Described in Manning, 1975, p. 189.

thus a series of curves secured which would give us the form of the geoid; i.e., of the surface beneath the continent where the force of gravity was uniform."[26]

Peirce's schema for a network of gravity stations echoes and extends notions within the Survey, going back at least as far as 1871, with Charles A. Schott, to create a networked system of observatory sites at relatively evenly spaced intervals, in order to determine magnetic declinations for the nation.

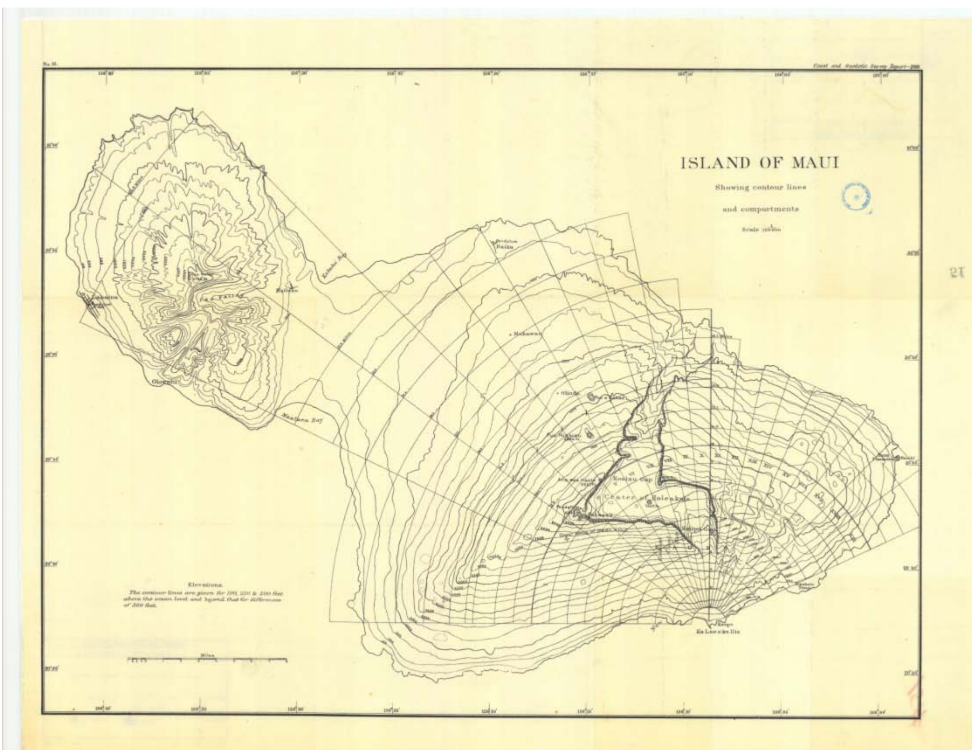
Charles A. Schott's schema for magnetic observatories
From his Smithsonian workbook, dated 1871
LOC Manuscripts Division

In the early stages of Peirce's gravity research, he utilized the unique situation of Hoosac Mountain in western Massachusetts, which has a railroad tunnel running through it, to swing his pendulums at the top of the mountain and deep inside it. Peirce's experiment posited the tiny difference between gravitational attraction between the two sites, allowing for compensation for the mass of the mountain, would allow Peirce to "weigh" the earth. Unfortunately, the imperfections in the pendulums precluded the accuracies Peirce needed to accomplish this. Nevertheless, Peirce's concepts for measuring gravitation relative to mountain masses were extended in other research within the Survey.

The second major gravity researcher in the Survey was Erasmus Darwin Preston. During the Thorn tenure, Preston made a long and productive research trip to the

[26] Science, October 24, 1884, P. 397.

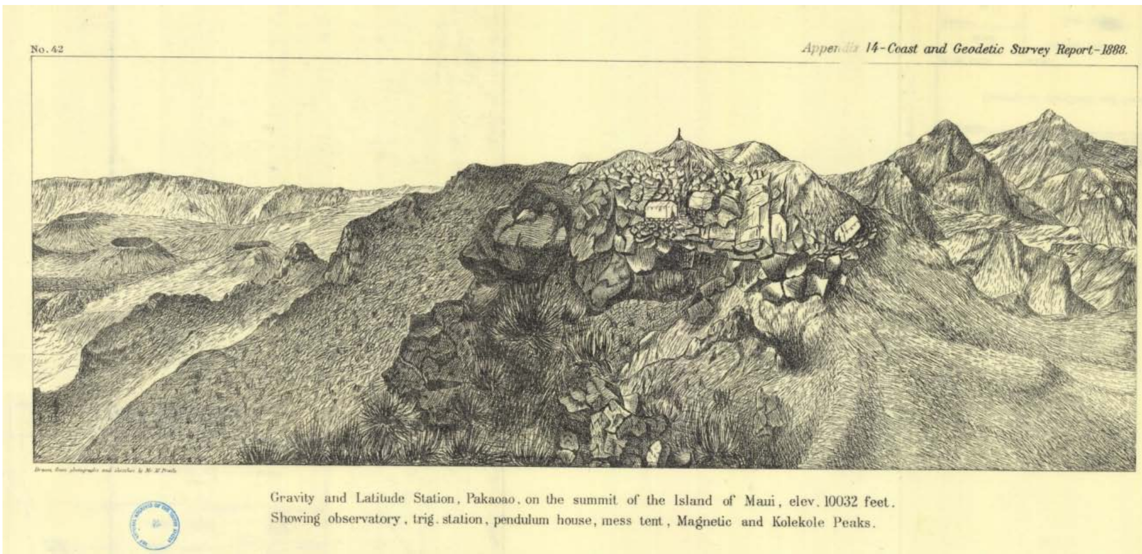
Hawaiian Islands, entirely funded by the Kingdom of Hawai'i. As Preston noted, his journey to make latitude and gravity measurements really had its origin in 1883, when two members of the United States Solar Eclipse Expedition stopped in Hawai'I to determine the force of gravity at a station established by a French scientist, De Freycinet, in 1819. However, their determination of latitude at the station differed significantly enough from other determinations nearby, that the scientists considered the reason for this to be deflection of the vertical by the volcanic mountain masses of the island. "Professor W.D. Alexander, the Surveyor General of the islands, at once conceived the project of having a number of latitudes of precision determined, which should not only include Maui, but all the larger islands.. The scheme proposed by Professor Alexander contemplated the occupation of fourteen latitude stations, of which three were on Kauai, four on Maui, and four on Hawaii. But as the object of the observations was the determination of the deflections of the plumb-line, and this depends on the density of the mountains, it was thought advisable to supplement the latitude work by some measurement of the force of gravity. Therefore the original plan was extended so as to include pendulum observations on the summit of Haleakala, Maui, at a station near the sea-level of the same island and at Honolulu."[27]



The Island of Maui Figure 51, Annual report for 1888
Pendulum stations were at Lahaina, extreme west of the island,
and adjacent to the summit caldera on Haleakala

[27] Preston, 1888, App. No. 14, p. 472.

Preston's research extended and enlarged the cooperation between the Coast and Geodetic Survey and the Kingdom of Hawai'i, which actually began in 1871, when the Survey had loaned a baseline measuring apparatus and other geodetic instruments to the newly formed Hawaiian Government Survey. The Hawaiian Survey used the equipment to establish the first baseline, on the island of Maui[28]. Collaboration between these two Surveys continued after American annexation of the islands, including the geographic and linguistic research of W.D. Alexander's important gazetteer of Hawaiian place names published in the Survey's Annual Report for 1902[29]. Further, Preston's photography and engravings of his stations and different locations on the journeys to them still serve as critical data for environmental changes in the Hawaiian Islands.

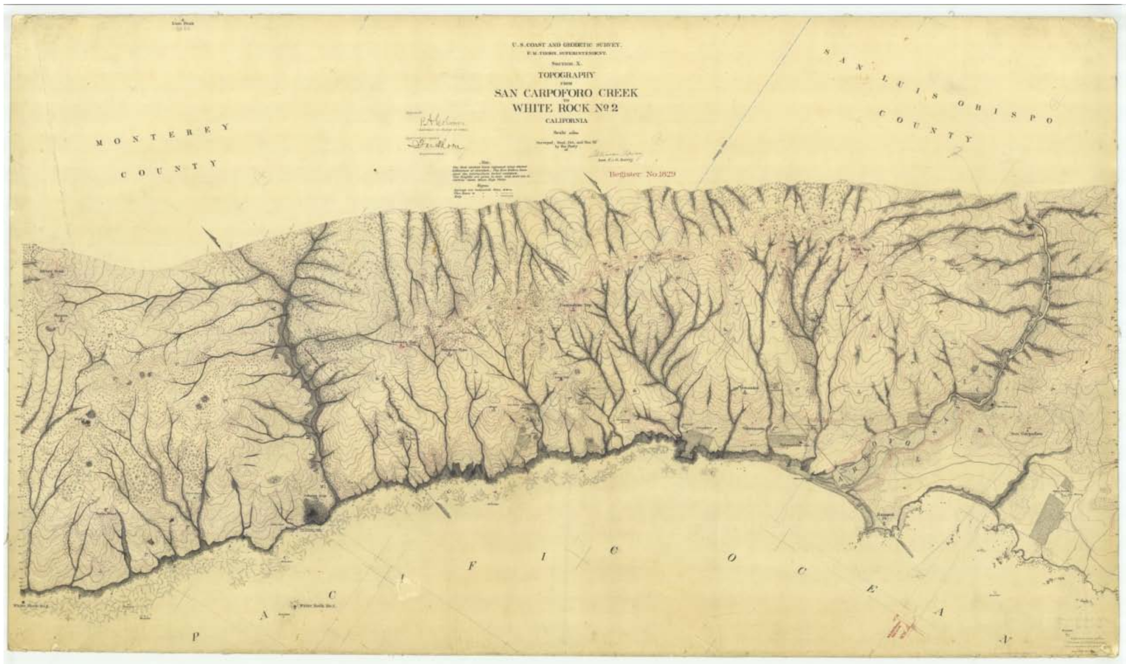


Gravity and Latitude Station at Pakaoao, on Haleakala
Figure No. 42, Annual Report for 1888

Topography

Certainly the greatest impediment to progress in topography (and also hydrography) during Thorn's tenure was the financial and budgetary scandals that engulfed the Survey under Hilgard. Scrutiny of the field work per diem salaries, and the funding of field work in general exacted a heavy toll. Since Survey personnel spent so much time in extremely isolated areas, and since they needed great quantities of specific and often expensive supplies, the only realistic way to secure their supplies was to give personnel the funding they needed in advance. This situation could lead to embezzlement and inappropriate purchases, but at the same time there wasn't any realistic alternative, although the Allison Commmission and Chenowith both demanded changes. But Thorn did what he could, and what was necessary to hold down expenses and produce more with less, and so field work revived, and even flourished.

[28] Lyons, 1903, p. 9.
[29] Alexander, 1902, App. No. 7: 367-



T-1829 Big Sur Coast of California, San Carpoforo Creek to White Rock No. 2
Surveyed by Assistant Stehman Forney, approved by Colonna and Thorn 1887

Possibly in response to the upheavals in field work, although this is not certain, the Survey under Thorn prepared a remarkable document, “Instructions and Memoranda for Descriptive Reports to Accompany Original Sheets”. It is one of the summary intellectual achievements of the Survey, a paragon of the state of geographic, ethnographic, and ecological literacy of Survey scientists in the era. It was organized by the finest field scientists in the Survey: “Pursuant to the recommendations made in the report of C.O. Boutelle, B.A. Colonna, Henry Mitchell, Lieut. Commander W.H. Brownson, U.S.N., E. Hergesheimer, and H.G. Ogden, Assistants, U.S. Coast and Geodetic Survey—a board to whom the subject matter was referred—each topographic or hydrographic sheet hereafter deposited in this office will be accompanied by a descriptive report relating to the locality surveyed, and embrace such topics relative to that locality as are mentioned or suggested in the subjoined schedules of topics, to the compilation of which the members of the board above mentioned and Assistants Davidson, Rodgers, Lawson, Lieut. J.W. Hawley, U.S.N., and Lieut. G.H. Peters, U.S.N., have contributed.”[30]

The basic point of the Instructions and Memoranda is to induce its users to notice *everything important* in the landscape and seascape as regards to the place, and to crystallize that knowledge in a narrative that best presents the information in a way conducive to preparing charts and coast pilots and sailing directions as the best aids to

[30] Thorn, 1887, App. No. 11, p. 211.

navigation possible. There are long lists of specific types of questions that can be asked and answered, differentiated for topographic or hydrographic sheets. One example each from each domain will give the flavor and rigor of the questions asked, and the rigorous understanding of the landscape and seascape necessary to answer the questions.

Schedule of Topographic and Physical Subjects

7. Does the coast recede, and at about what rate? State authority for rate given. What becomes of eroded material? Are there evidences of emergence or subsidence of shores, and what are they? If there are salt marshes, are they reclaimable? What would be the length of dike needed, and what is the ratio of dike to drainable area? Can the water be sunk by sluices, and how much?

Schedule of Hydrographic Subjects

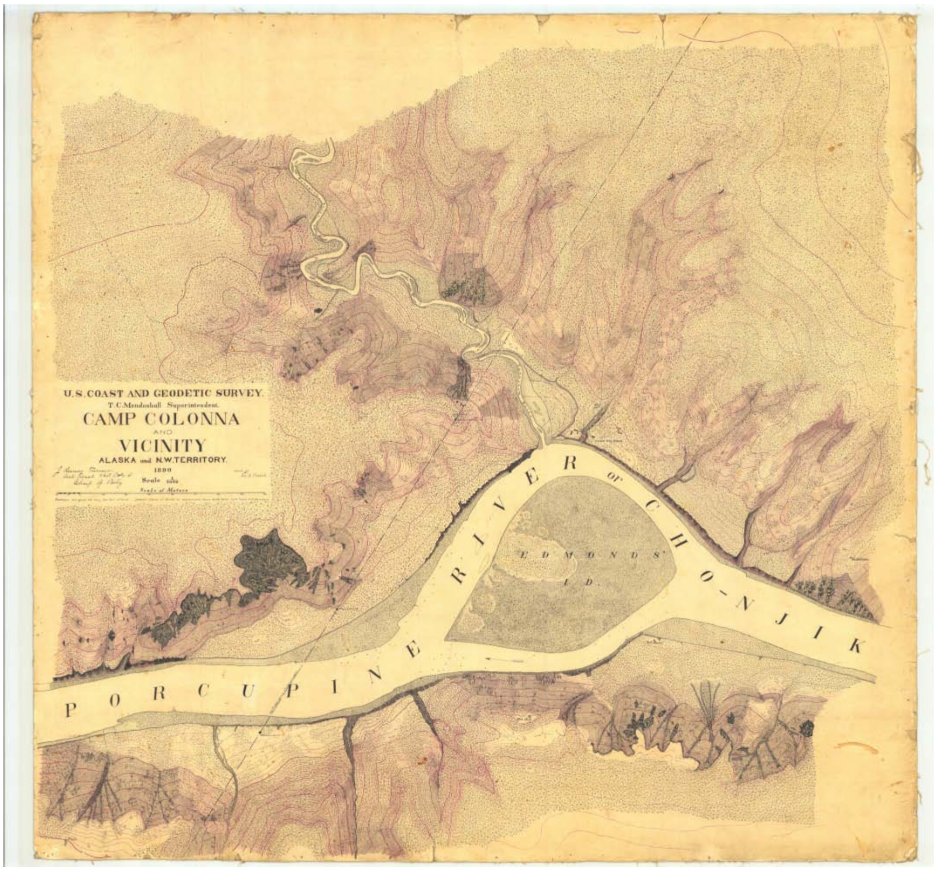
30. Wrecks; where usually occurring; do wrecked vessels usually go to pieces in first storm? There are places where to remain on board is safest, on others the only hope is in reaching shore, as vessel goes to pieces. Give this outline in full.

The final section is the Schedule of Statistical Subjects. It concludes with a final paragraph, which in many ways can be considered an ethnographic and cartographic apex of the U.S. Coast and Geodetic Survey and the U.S. Government in general, in that era. It states in full:

9. Special attention is called to the nomenclature of all points named, especially Indian names. Where the orthography is doubtful, care should be taken to obtain the best authority for the name and spelling used, that confusion and correction upon our printed charts may be avoided and the charts themselves may become the best future historical authority. Where different and doubtful spellings of apparently equal weight are found, all such should be used in the report. All changes in nomenclature, where known, should be noted."

F.M. Thorn
Superintendent

The Survey's attention to the Instructions, and specifically relative to Indian names, is exemplified in the t-sheet prepared as part of the Survey's occupation of an observatory above the Arctic Circle in 1889, as part of a more or less cooperative effort by the United States and Great Britain to more accurately locate the 141st meridian, which is the largest single section of the boundary between Canada and Alaska. It had been roughly determined previously, but the advent of the Canadian and Alaskan gold rushes made it imperative to both nations that the meridian be determined with far more accuracy. The Survey crew that did the work established Camp Colonna, to honor their colleague whose field work days were over. Camp Colonna was located on a bend of the Porcupine River, or, as noted, is Cho-Njik, its name in Gwich'In, an Athabascan language of the Yukon,.



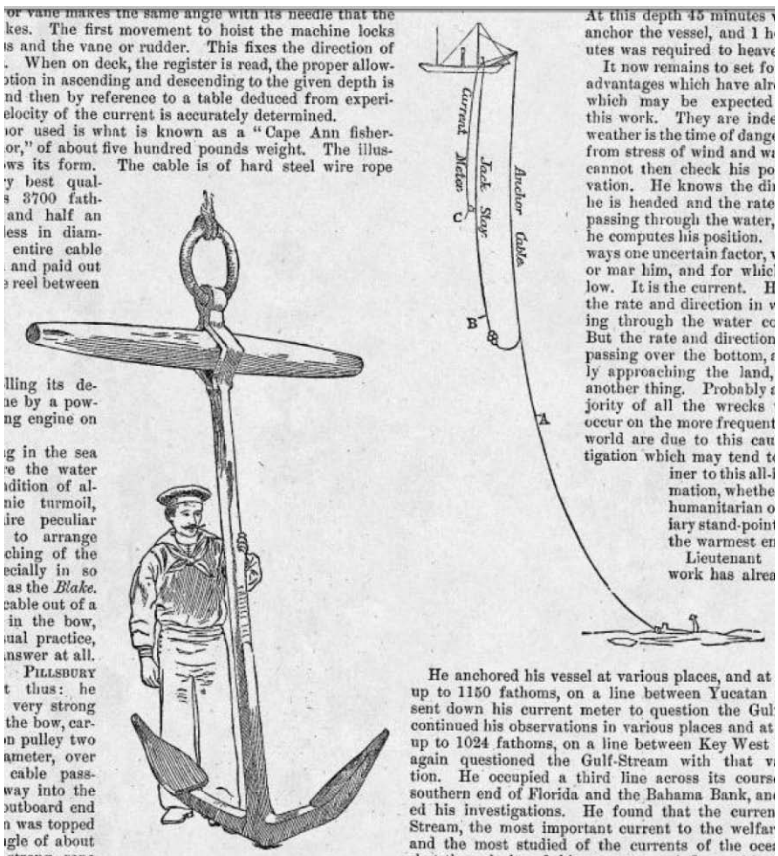
T- 2066 Camp Colonna and Vicinity
On the Porcupine River, or Cho-Njik
Field work and observations in 1888-89, but the map
was not returned and registered until 1890.

Hydrography

"…and in this logical order hydrography comes last" was really phrased in the arena of political logic. Hydrography has already come up repeatedly in discussion of Survey work in the Thorn era. Beyond matters like Henry Mitchell's celebrated analysis of the tidal regimes of New York harbor, aided by William Ferrel's harmonic analysis of the tides at Governor's Island in the harbor,[31] and allied work, the major arena left untreated thus far is the Survey's continued oceanographic explorations of the Gulf Stream and the Gulf of Mexico. The research included the deployment of increasing

[31] Ferrel, 1885, App. No 13, pp. 489-493.

sophisticated equipment that could record current speed and direction data reliably at great depths.



or vane makes the same angle with its needle that the kes. The first movement to hoist the machine locks ıs and the vane or rudder. This fixes the direction of . When on deck, the register is read, the proper allow- ıtion in ascending and descending to the given depth is nd then by reference to a table deduced from experi- elocity of the current is accurately determined.
ıor used is what is known as a "Cape Ann fisher- or," of about five hundred pounds weight. The illus- ıws its form. The cable is of hard steel wire rope y best qual- s 3700 fath- and half an less in diam- entire cable and paid out reel between

lling its de- ıe by a pow- ng engine on

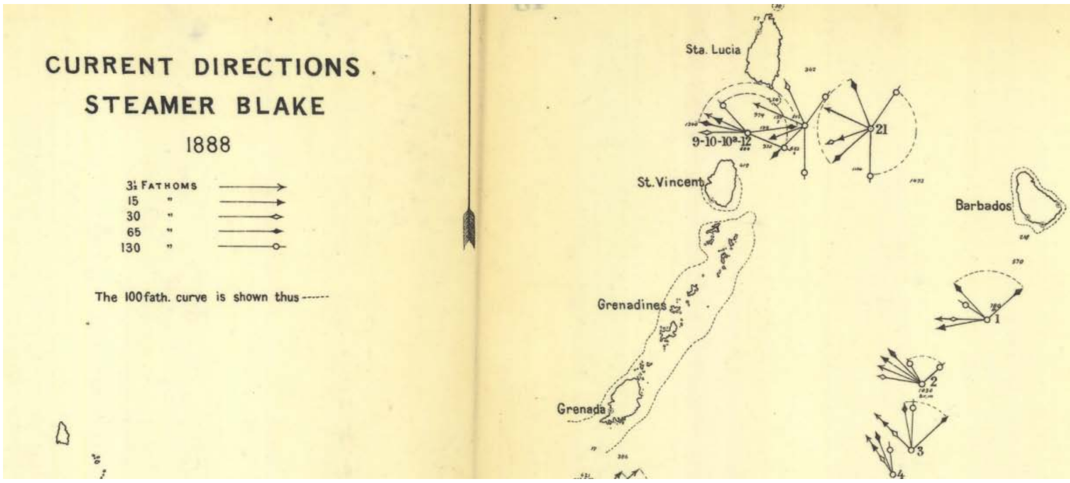
g in the sea e the water dition of al- nic turmoil, ire peculiar to arrange ching of the ecially in so as the *Blake.* cable out of a in the bow, ual practice, nswer at all. PILLSBURY t thus: he very strong the bow, car- n pulley two ameter, over cable pass- way into the ıutboard end n was topped ıgle of about

At this depth 45 minutes anchor the vessel, and 1 h utes was required to heave
It now remains to set fo advantages which have alr which may be expected this work. They are inde weather is the time of dange from stress of wind and wa cannot then check his po vation. He knows the di he is headed and the rate passing through the water, he computes his position. ways one uncertain factor, or mar him, and for whic low. It is the current. H the rate and direction in v ing through the water cc But the rate and direction passing over the bottom, a ly approaching the land, another thing. Probably a jority of all the wrecks occur on the more frequent world are due to this cau tigation which may tend t iner to this all-i mation, whethe humanitarian o iary stand-point the warmest en Lieutenant work has alrea

He anchored his vessel at various places, and at up to 1150 fathoms, on a line between Yucatan sent down his current meter to question the Gul continued his observations in various places and at up to 1024 fathoms, on a line between Key West again questioned the Gulf-Stream with that v tion. He occupied a third line across its cours southern end of Florida and the Bahama Bank, an ed his investigations. He found that the curren Stream, the most important current to the welfar and the most studied of the currents of the oce

The Cape Anne's Fisherman's Anchor adapted to use in the Survey's current meter system, shown on the right, in Henry B. Well's Supplement to Harper's Weekly, October 20, 1888

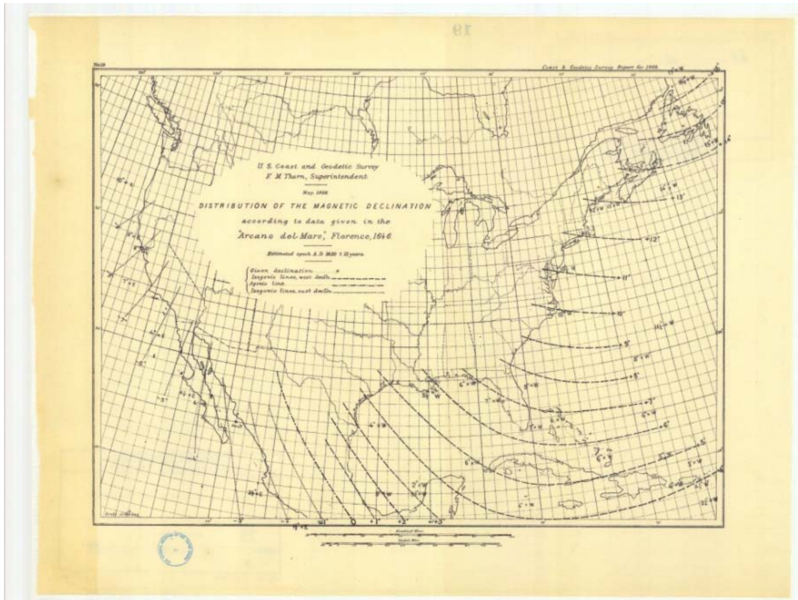
The new system could be used to acquire current data at specific places and at specific depths, so that the flow structure of water in the entire water volume could be more readily apprehended.



Current Directions and depths in the Caribbean (crop)
From Figure No. 43, Annual Report for 1889

Magnetic Observations

This field was listed last in Colonna's description of Survey field work, in the context of producing "the perfect map". That would be literally true, in that the diagram of true and magnetic north with its estimate of anticipated yearly changes in the direction of magnetic north at that point (the annual secular variation) was always calculated and engraved last in the map production process. But by the nature of terrestrial magnetism, observations and their analysis were pursued constantly, in every area the Survey worked in. One relatively new endeavor in the field of the magnetic elements in the Thorn era was the development of major projects to reconstruct the configurations of magnetic declination in and around North American for specific epochs going back centuries into the past. These reconstructed magnetic epochs could then be used to correlate historic azimuthal bearings and correct them to true north.



Historic Magnetic Declination in the Epoch of 1646
Reconstructed from the "Arcano del Mare" in Florence
By Charles A. Schott Sketch No. 19,
Annual Report for 1888

These maps and data of epochs of historic magnetic declination were closely associated with an intense period of analysis of historic maps and charts related to the entire history of western exploration of the New World. Much of this, in turn, had been triggered by popular and scholarly attention to the Survey's re-publication, in 1884, of much of the body of Dr. Johann G. Kohl's reconstructed maps related to the history of the discovery and exploration in the western hemisphere, a project that began under Superintendent Bache in the 1850s.[32] George Davidson conducted his own research on historic magnetic declinations on the northwest Pacific coast, as well as examinations of many of the early voyages there between 1539 and 1603.[33] Finally, Charles A. Schott, the Survey's great computer, wrote both a massive compendium on the geographic variation and secular variation in magnetic dip and intensity (as opposed to magnetic variation) in the United States, and also wrote an analysis of the complex magnetic work of Greely's Expedition above the Arctic Circle. For a finale, he wrote an appendix detailing the entire history of magnetic research in the Survey.[34]

"…the production of a perfect map"

Assistant Colonna's sequence of different types of field work prosecuted in a logical order to end with "a perfect map" was accurate, although the purposes of each specific discipline were much broader than map production alone. Nevertheless, it must

[32] Kohl, 1855, 1856, 1857, and 1884.
[33] Davidson, 1885, 1886.
[34] Schott, 1885, 1887, 1888.

be noted that the Thorn tenure, however tenuous and doubtful it might have seemed at the beginning, by the end had become another golden age of cartographic production in the history of the Survey. This reflected Thorn and Colonna's efficient management, and possibly as well the knowledge by all who remained with the Survey that they had to do substantially better or the Survey's prospects were very dim.

The amount and quality of the maps produced under Thorn led to a series of systemic improvements, culminating with the creation in 1887of a Chart Division, formed out of operations that had been lumped with many other activities and products in the Miscellaneous Division. As the Annual Report explained:

"In December, 1887, the Chart Division was organized, and Assistant W.H. Dennis was instructed to take charge of it, his special duty being to have the custody of the charts and to direct their correction and issue. He reports that the total number of charts disposed of during the year was forty-four thousand five hundred and ninety-five, which was an increase of nearly 30 per cent, over the issue of the year before. Of this number, twenty-five thousand two hundred and seventy-three were sent to agents for sale; eleven thousand six hundred and eight issued to meet demands from the Executive Departments, and two thousand four hundred and eighty-three in response to requests from members of Congress.

"Mr. Dennis calls attention to the fact that during the last six months of the year upwards of three thousand one hundred corrected charts were sent to the Hydrographic Office of the Navy, where, notwithstanding the very critical examination to which they were subjected, not a single error was found for which the Chart Division was responsible."[35]

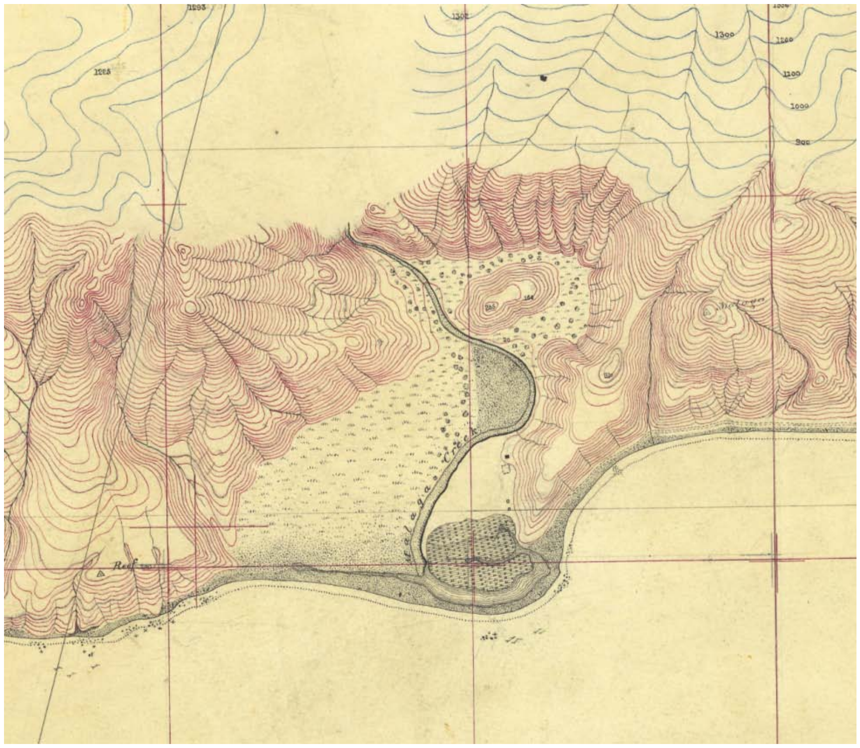
The recurrent theme of the Thorn tenure as Superintendent was how the Survey could not only make do with less funding, but also do more with less. One example of the latter is exhibited in Thorn's letter of January 20, 1888 to the House Committee on Appropriations, subtitled "An estimate from the Superintendent of the Coast and Geodetic Survey to supply deficiency for expenses of the Bureau for the current fiscal year". The letter opens a revealing window into the heart of the Survey's cartography of the era. Thorn contrasts the cartographic regime under the later Superintendent Patterson to the new realities imposed on the Survey as a result of the many Congressional and Executive investigations of the Survey and the fall of Hilgard. He notes:

" For the purpose of promoting excellence and uniformity in the quality of the field sheets [i.e., the topographic sheets, or t-sheets] the late Superintendent Patterson several years ago established the practice of having the professional draughtsmen in this office ink the sheets which had been originally drawn with pencil by the field officers.

"The inevitable effect of this practice was to divert a number of the draughtsmen from the business of reducing the drawings of the field sheets to the scale of the charts, thereby relaxing the production of the charts. The resulting improvement in the sheets

[35] Thorn, Report of the Superintendent, 1888, pp. 90-91.

was not only open to dispute, but it afforded no compensation for the delay in publication of charts consequent upon such diversion of the labor of the draughtsmen"[36]



A section of T-1432A Johnson Station to Point Dume, California (1877)
from the Patterson era showing the draughtsmen's inking
over partially erased pencil lines

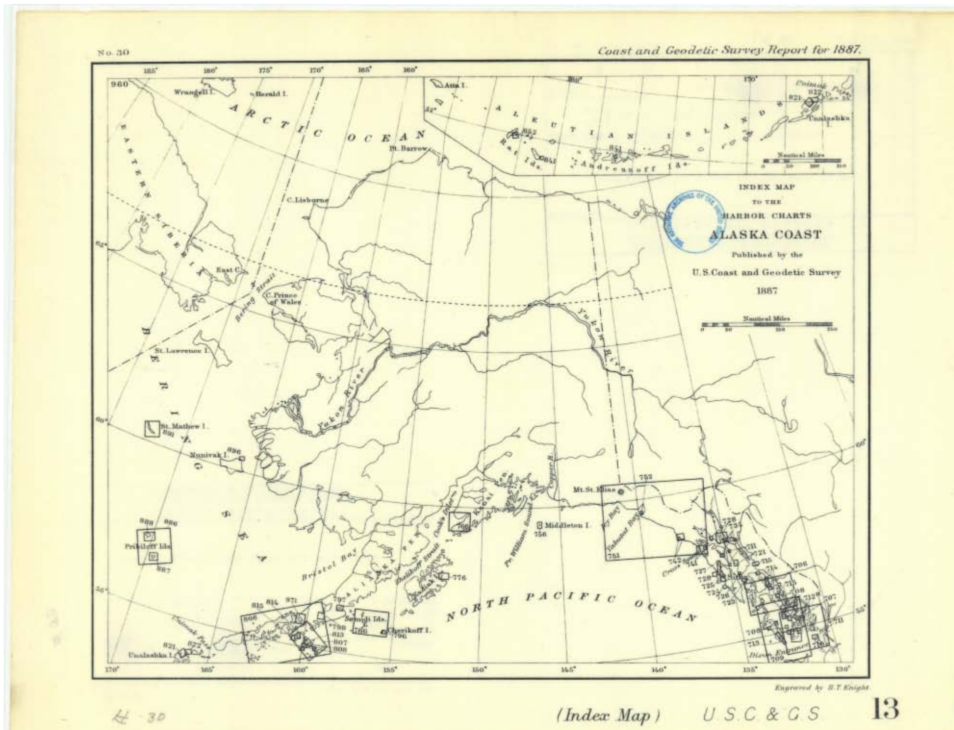
Thorn goes on:

"Accordingly, several months ago we suspended the practice referred to, directing the field officers to ink their own sheets, and were thereby enabled to render available directly, in drawings for charts, the services of several draughtsmen whose time had theretofore been occupied in the inking of topographic sheets. The consequence is, that since the 1st of July last, a period of substantially six months, we have been able to place in the hands of the photolithographer drawings of twenty-one new charts—double the usual number for such a period—besides thirteen index maps and three new editions of charts, all of which are substantially published at this date. … This large number of photolithographic charts and ten additional charts now engraved on copperplate, and awaiting only the engraving of the titles and notes, we are reasonably sure of being able to issue by the 1st of July next, if the appropriation for which I now estimate can be obtained… Without such additional appropriation the issue of the twenty-eight charts mentioned is liable to a delay of a year or more. Such delay in the production of charts in the past has not only been the occasion of annoyance to the management of the Survey

[36] Thorn, 1888, in 50th Congress, 1st Session, Executive Document No. 111, p.2.

and of criticism by others, but it always largely impairs the value of the chart and of the survey and all the work which it represents. "[37]

Thorn's appeal for extra funding was successful, and the new charts were soon published, including the first set of chart index maps ever produced and included in the annual report.



Index Map to the Harbor Charts Alaska Coast
Figure No. 30, Annual Report for 1887

The chart publishing process that Thorn directed had evolved considerably from the days of Hassler. During his tenure, Henry Wells, a writer and editor of Harper's Weekly, produced an extensive report on the functioning of the many branches of the Survey. His description of the inter-relations between the finished topographic and hydrographic sheets, the Survey's photographic transfer process, plate engraving and the use of the charts derived from the original plates is as comprehensive a description as exists for the era.

"Great judgment and skill are requisite that no useful detail be omitted on the one hand, while on the other the drawing is not made obscure by needless repetition. This done, the original sheet, bearing the signature and approval of every officer who has had a hand in its production, is filed away in the archives of the bureau. Not a single mark is

[37] Ibid, p. 2.

permitted on any chart of the Coast Survey the authority and responsibility for which cannot be fixed at a moment's notice.

"The new drawing is then traced on another paper with a peculiar ink. A plate of copper is then provided, except in point of size and thickness, exactly like a visiting card plate. The polished surface of the copper is covered with a solution of wax in turpentine, the tracing is inverted upon it and rubbed, and upon removal of the tracing every line is found printed on the copper plate just as it is to be engraved. The engraving is like that on a visiting-card plate, all lines being below the surface.

"The engraving completed, a proof is taken. This proof is examined by every officer who has had to do with the production of the drawing. Every mistake in his department must be indicated, and he must certify upon its margin in writing that there are no others. On the chart of Delaware Bay are 18,000 figures of soundings. Every one of these is verified individually. The plate is then corrected and a new proof struck off. The same routine of verification is had, and if no further errors are found, an edition of seventy-five copies, and no more, are struck off for immediate use. All subsequent copies are printed from an electro-plate duplicate of the original plate.

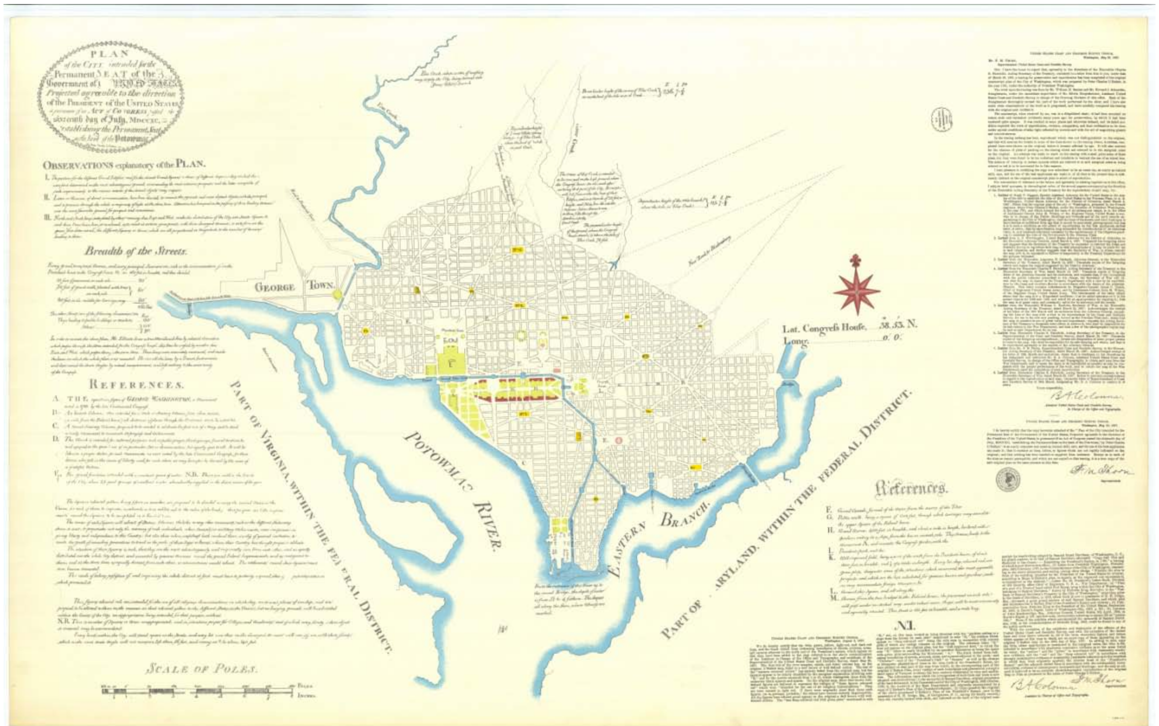
"The mechanical and artistic work on these charts is simply superb—we have already spoken of the intellectual work they embody. The writer has compared them with English, French, German, Dutch, Spanish, and Italian charts, and they are almost as superior in execution to the best as the mechanical execution of a greenback was superior to that of a Confederate note."[38]

The profusion of new maps, and maps of newer subjects, and especially maps outside the usual array of nautical charts and harbor charts, etc., was eventually formalized in 1886 by the creation of the 3000 map series, which was a block of chart numbers starting with 3000, which was the 1886 republication, for whatever reason, of an 1853 harbor chart of Plymouth, Massachusetts, as opposed to a contemporary revised edition of chart 338, the Plymouth harbor chart. In addition to republishing historic nautical and harbor charts, the 3000 series was used to re-publish a sub-set of the Survey's maps created during the Civil War, and many one-of-a-kind maps, such as the republished 1874 topographic map of Hoosac Mountain by Charles S. Peirce, which was an integral part of his gravity station work at and inside the mountain.

In keeping with the systematic work on historic magnetic declination epochs and the revived cartography of discovery and exploration by Johann Kohl and George Davidson, Assistant Colonna discovered a very rare copy of Pierre de l'Enfant's original schema for the development of the Capital of Washington, rolled up behind a desk in the Survey's headquarters, or at least that was the story It must be said that this was a providential moment for the map to show up, as the Survey was in the midst of topographic surveying, at the behest of Congress, the area of the District of Columbia formerly called the County of Washington, outside the City of Washington. The distinction between City and County had been erased in the early 1880s, so the Survey's

[38] Henry Wells, 1888, p. 806

task was to prepare detailed topographic maps of the major area of the District, which now was to be developed in some accordance with the ever evolving Plan of L'Enfant.



Plan of the City intended for the Permanent Seat of the Government of
The United States, etc. 1790 by Peter Charles L'Enfant
Chart 3035A, 1887

The extensive commentary by Thorn and Colonna, printed on the map, in addition to descriptions in the annual report, indicate that the map original was considered historically significant and critically detailed, but it had aged so badly that no literal reproduction of it would serve. So the artists of the Survey re-constructed the map in a mock-archaic cartographic style faithful to the original, but using different and much more vibrant colors than L'Enfant has used originally. At the same time, the extensive commentary described every change they had made. At the same time, the Survey re-published in a similar way Dermott's 1798 map of the City of Washington as Chart 3034B, and W.J. Stone's 1839 Washington City map, now Chart 3036.

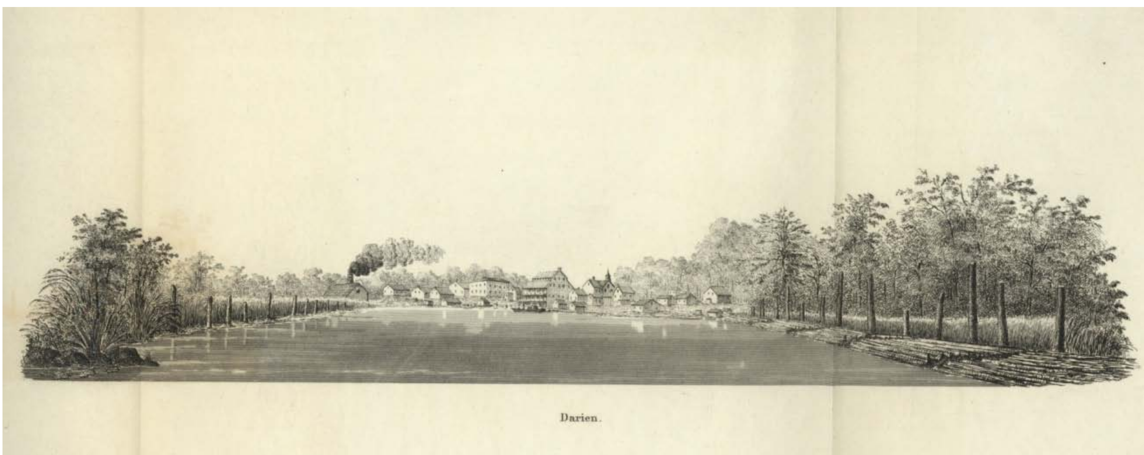
In keeping with the new series of index maps to the regular series of Survey nautical charts, the Survey also prepared an extensive and comprehensive index to all figures and sketches ever published in the Annual Reports, from 1844 through 1885.[39]

The Coast Pilots, Atlantic and Pacific

[39] Goodfellow, App. No. 12, 1887.

The Survey had long produced coastal guides and sailing directions, beginning with George Davidson's 1858 Directory of the Pacific Coast. After the Survey acquired the Blunt's Coast Pilot series in 1867, they were called Coast Pilots, in various editions. Significant revisions and new material on both sides of the continent culminated in Thorns' tenure in two landmark publication series in the history of the Survey.

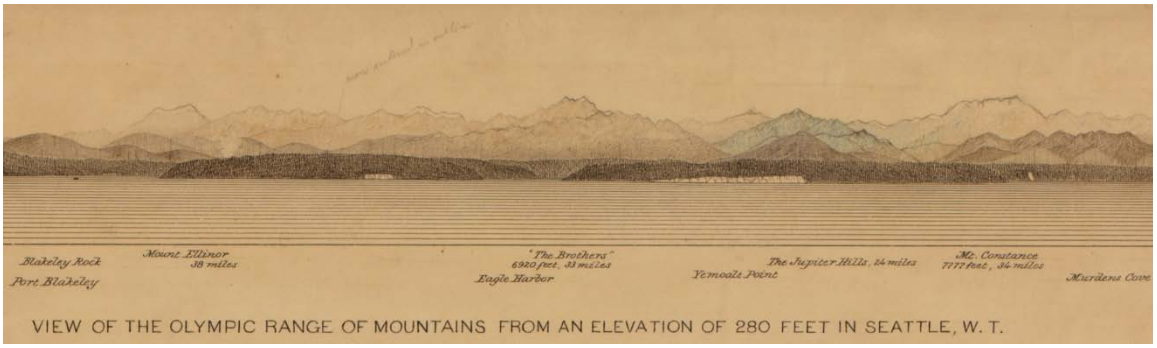
On the Atlantic coast, previous editions of the Atlantic Coast Pilots were revised and completed, to create in 1887 and 1888 the unified series of Atlantic Local Coast Pilots, in 22 sub-divisions, from the Bay of Fundy to the Florida keys. The revised series featured, in all but sub-division 22, the extraordinary coastal views of John Barker, who began work for the Survey in the Peirce tenure, and worked until his death in Patterson's tenure.



Darien, Georgia by John Barker, 1887
Atlantic Local Coast Pilot Sub-Division 21
Tybee Roads to Jupiter Inlet

Barker's work began in the North Atlantic as visual aids to navigation, but as he worked his way south, his drawings and his own engravings derived from them became primary records of American maritime history and technology as Barker had found them. These were both the culmination, and the finale, of Survey coastal views on the Atlantic coast.

The Pacific equivalents to the Atlantic Coast Pilots had begun under George Davidson in 1858. Especially after the work expanded to include Alaska, more specialists were recruited to the work, including William Dall and Marcus Baker. In 1880, at the request of Superintendent Patterson, Davidson started work on what would become the 4th revised edition of the Pacific Coast Pilot. In 1883, he inducted the superbly talented draughtsman and hydrographer Ferdinand Westdahl to the task of preparing coastal views, in addition to views by Davidson himself. Westdahl worked from San Diego to Vancouver Island during 1884-86 on the views. Davidson also brought in Cleveland Rockwell, and Assistant Gilbert to draw views. Rockwell then transferred and revised the views for engraving. These were combined with Davidson's text, which had been completed in 1886 but then revised and edited. These culminated, in 1889, with the Pacific Coast Pilot, George Davidson's *magnum opus*.



View of the Olympic Range (and "the Fauntleroys") from Seattle
Original view by Ferdinand Westdahl 1884-86

1889 marked the completion of the Pacific Coast Pilot, and the end of Thorn's tenure as Superintendent. During his tenure, the Survey assisted other government agencies and institutions in graphic projects as well as scientific research. One such collaboration involved the Smithsonian Institution. They were attempting to renew or republish an engraving by the celebrated American painter Asher Durand. In 1835, Durand had completed a celebrated painting, his copy of John Vanderly's "Ariadne Asleep on the Island of Naxos". He then made and published a copper engraving based on his painting. It was this engraving that the Smithsonian wanted to revive. Survey specialists were recruited to guide making a new copper plate derived from a photographic transfer from an original print, a process previously described by Henry Wells in the *Harper's Weekly* Supplement. The engraving displays the classic Mediterranean Sea in the background. Therefore, the engraving might be considered a final sly gift of the Superintendent, who had been a professional humorist for most of his life. "Ariadne Asleep on the Island of Naxos" was, in a sense, the Survey's last published coastal view.

"Ariadne Asleep on the Island of Naxos" by Asher B. Durand, 1835
As republished by the Smithsonian Institution, 1889.

The End of (the First) Cleveland Administration and Superintendent Thorn

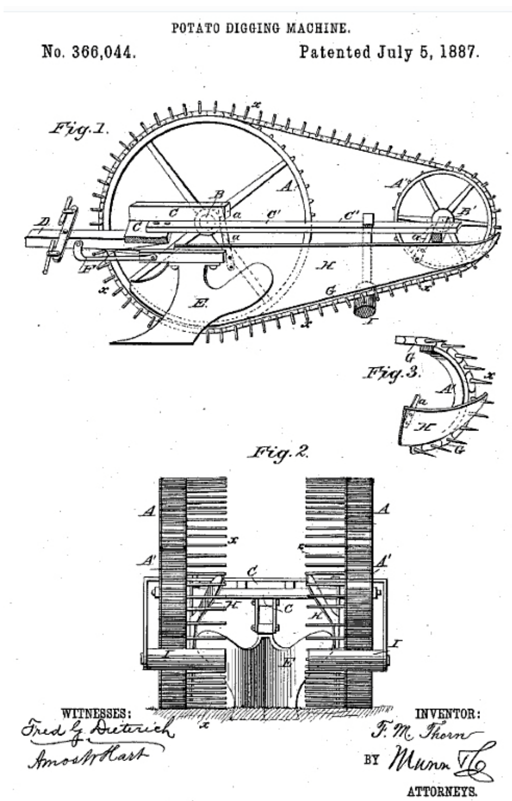
The same tide whose flood had brought in Frank Manly Thorn as Superintendent washed him out on its ebb. It was clear to all, particularly to him, that his tenure would be limited, regardless of the results of the 1888 election which President Cleveland lost. The Survey had been so compromised by scandal under Hilgard that it was impossible for his successor to rise from within the Survey itself. The next Superintendent had to come from without. Thorn was selected by Cleveland because he was an intelligent, competent public servant and, of course, in the retinue of Cleveland—but he was not a scientist. Much of the Survey's prestige, if not its competence, had always come from its status as the premiere scientific agency in the government, and that requires scientific leadership, however competent Thorn was. And he had succeeded quite well. As the *New York Times* headline put it: "Not So Bad for Layman. Three Years' Management of the Coast Survey. President Cleveland's Appointment of Superintendent Thorn Fully Justified by Results."[40]

Yet it wasn't Cleveland's defeat in 1888 that brought an end to Thorn's tenure. It was, instead, the continuation of the same kinds of actions by Congress which had

[40] New York Times, April 14, 1889, p. 1

brought down Superintendent Hilgard. Throughout the previous history of the Survey, the Superintendent had been appointed by the Secretary of the Treasury. President Cleveland appointed Thorn to his post. That gave the Congress the opportunity to have a role in choosing the Superintendent, under the clause allowing the Senate to "advise and consent" to Presidential appointments. In between Cleveland's defeat in November, 1888, and President Harrison's swearing-in in March, 1889, the Senate added an amendment to the Sundry Civil Bill, requiring the Superintendent of the Coast and Geodetic Survey to be appointed by the President with the consent of the Senate. As soon as the full Congress passed the bill[41], Thorn's days were numbered, as he had not received Senate confirmation or even a hearing, nor had he even participated in the Allison Commission hearings. Thorn stayed on into President Harrison's term as a placeholder and leader of the Survey, pending the appointment—and Congressional investigations of—his successor, Thomas C. Mendenhall. He then returned to the farm and estate in Orchard Park, New York, outside Buffalo, and resumed his former life as a gentleman farmer and public figure.

Frank Thorn eventually held three U.S. Patents on his designs for improved potato diggers.[42] His second patent, shown here, he designed, applied for, and received while serving as the Superintendent of the U.S. Coast and Geodetic Survey. One can say Thorn himself resumed a life in Orchard Park that was "new and improved".



[41] Congressional Record, 50th Congress, 2nd Session, February 19, 1889, p. 2044.
[42] Patent No. 327,357, granted September 29, 1885; Patent No. 366,044, granted July 5, 1887, and Patent No. 437, 528, granted September 30, 1890.

Potato Digging Machine Patent No. 366,044
F.M. Thorn, Inventor

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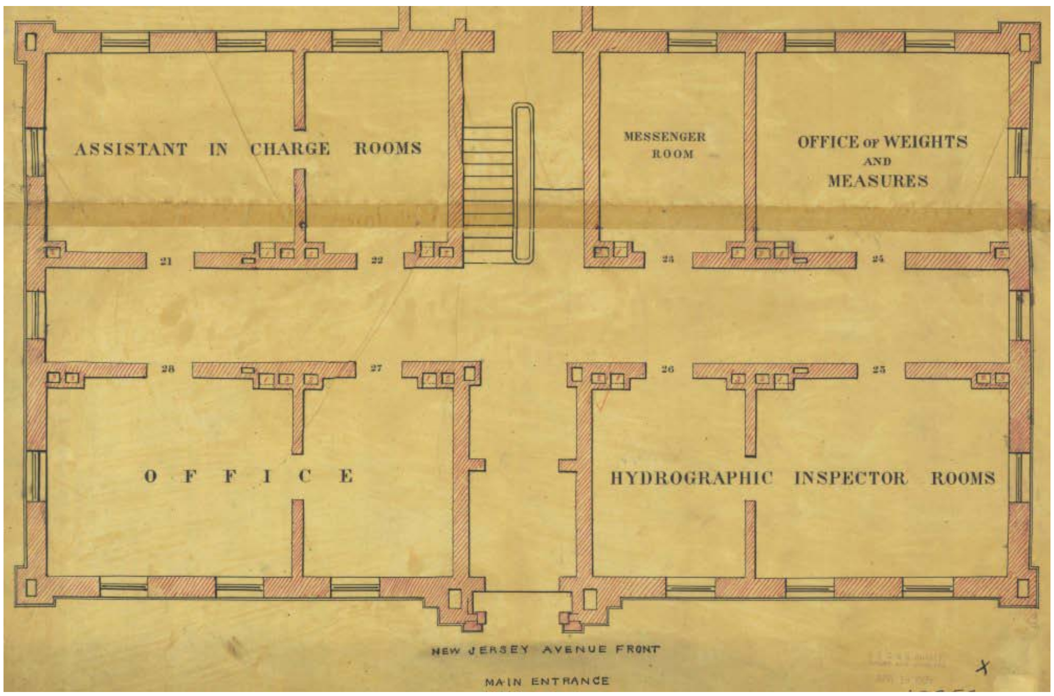
Carlile Patterson, the Great Captain of the Coast and Geodetic Survey (1874-1881)



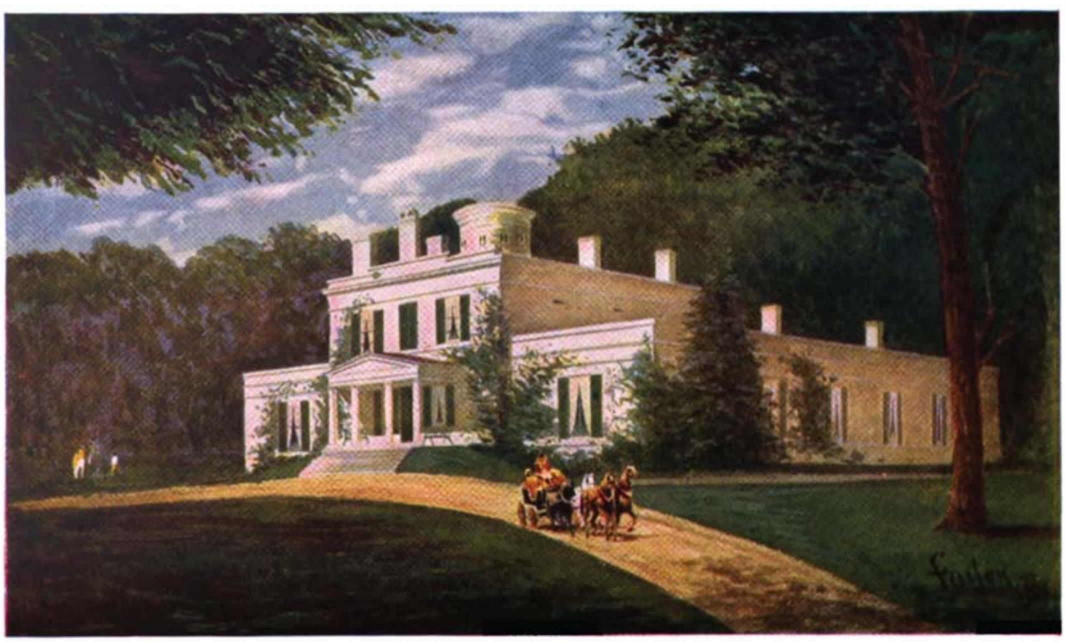
The Main Front Entrance to the Coast Survey Headquarters, circa 1872, with Captain Carlile Patterson's Office of the Hydrographic Inspector of the Survey

In 1874, an amicable transition in the leadership of the Coast Survey was made, as Benjamin Peirce returned to his primary role as an Endowed Professor of Mathematics and Natural Sciences and Philosophy at Harvard College, and Carlile Pollock Patterson ascended from his post as the Chief Hydrographic Inspector of the Survey to become Superintendent. Patterson led the Survey until the day he died suddenly in 1881. In many ways, his tenure was a golden age, if not the golden age, of the Survey. The fourth Superintendent, he was the first Survey leader chosen from the Survey's ranks, which reflected both his own abilities and the expanded capabilities of the Survey itself. Under

Patterson, every element of the Survey's work flourished and new responsibilities in entirely new areas of the nation and its lands and waters came to the Survey. Fittingly, these expanded arenas of research and labor were reflected in a name change that would survive almost a century. Under Patterson, the US Coast Survey became the US Coast and Geodetic Survey. Geodesy had been there all along, as Ferdinand Hassler's greatest gift to his adopted nation. But under Patterson, the science became literally visible in the agency.

Patterson Becomes a Captain

Carlile Patterson was born to captain ships and lead men. He was born in 1816 in Mississippi as the son of Commodore Daniel Todd Patterson of the Navy. Carlile Patterson's brother Thomas Patterson became an admiral, and his sister George Ann married David Dixon Porter, who also became an admiral and was a major naval leader during the Civil War. On September 2, 1830, Carlile Patterson was appointed as midshipman in the US Navy. He served in the Atlantic Ocean and the Mediterranean Sea. He returned home and was educated at Georgetown College in Kentucky, where he graduated as a civil engineer in 1838. In the 1830s, he married Eliza Pearson who was the daughter of Joseph Pearson, a Congressman from North Carolina. His marriage gave him access to the Pearson estate called Brentwood where he and his wife Eliza eventually lived, and where Patterson himself died.



Brentwood, an estate in the County of Washington, in the District of Columbia
From a painting by Brig. General Joseph Pearson Farley.
The home of Carlile Patterson 1868-1881

Following his graduation as a civil engineer, Patterson returned to active naval service and was assigned to work with the US Coast Survey. It was there that he was introduced to the very beginnings of the realized fieldwork of the Survey under Ferdinand Hassler, on the seas and lands overlooking new York Bay and Harbor and the Environs, as Hassler's first great charts titled the area. In 1839, he was an officer aboard the Coast Survey brig *Washington* when that ship discovered the slave ship *Amistad* in Long Island Sound, the beginning of a remarkable story in American history. In 1845, he was assigned to lead hydrographic surveys in the Gulf of Mexico. In 1846, he prepared an analysis of the tidal patterns of Mobile Bay on the coast of Alabama[1]. Around 1848, around the time of the Mexican War, Patterson left active duty in the Navy and the Survey to work as a merchant marine steam ship captain. He resigned from the Navy on September 2, 1853, exactly 23 years after he began.[2]

Captain Patterson steamed into a part of the world that was transforming rapidly, and people like Patterson were major agents of the change. Gold was discovered in California, California itself was acquired by the United States through the Mexican War, and all at once a great many people wanted to travel to and from California. A major commerce sprang up, based on steamship travel from the Atlantic and Gulf coasts to Panama, overland travel to the Panamanian Pacific coast, and steamship travel from Panama to California. Captain Patterson specialized in the Panama to California journeys, which were quite lucrative, as the same steamships that carried miners to California also returned with gold bound for the coffers of Eastern banks. The steamship captains received a proportion of the wealth. Patterson worked for the Pacific Mail Steamship Company as Captain of such ships as the *Oregon* and the *Golden Gate*, between about 1849 and 1853.

Through this era, Patterson remained steadfast in his political beliefs as an abolitionist and supporter of the Union. His beliefs were displayed to dramatic effect in the matter of the admission of California as a free state in the Union. There was no legal slavery in California—slavery was abolished in California and throughout what had been the Spanish empire in the 1830s—nor was there much sentiment to establish slavery in the new American territory. However, there was strong sentiment in the southern states to resist the admission of any new free states into the Union because of the votes they would add to the abolitionist cause. But in 1850, California was admitted to the Union as a free state. There was no continental telegraph at the time, so the news had to travel by ship. As it happened, Captain Patterson in command of the *Oregon*, sailed through the Golden Gate on October 18, 1850 to deliver the news. His arrival was dramatic:

> "We were all excitement to hear the result of California's knock at the door of the Union; and as the day approached when the steamer would bring the decision, many eyes were strained toward Telegraph Hill. At length the signal went up – the *Oregon* was outside the heads and would soon be in the harbor. As she neared, another signal indicated that she carried flying colors, implying good news, and presently she appeared in sight of those, who like ourselves, overlooked North Beach, gay with streamers and flags of all nations, -- the Stars and Stripes most prominent,

[1] Patterson, Annual Report for 1846, App. 8, pp. 68-70.
[2] Callahan, 1901, p. 424.

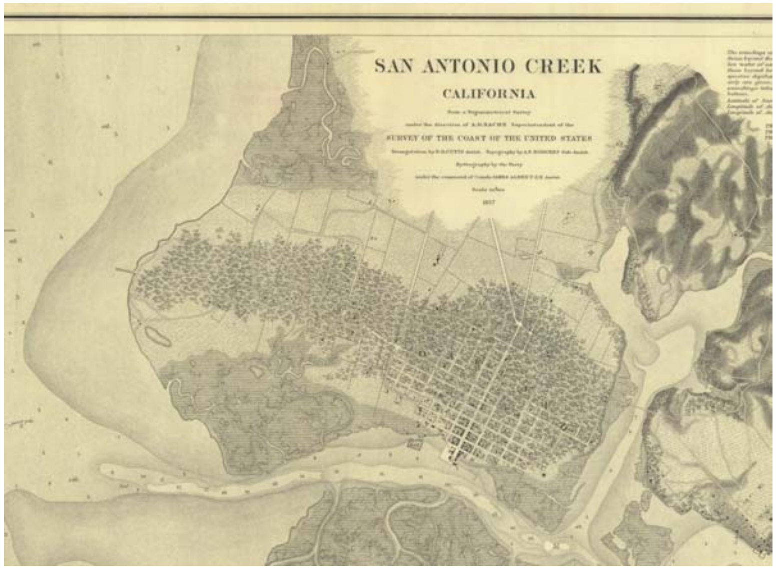
> and above them, straightened out by the generous wind which seemed to blow a long breath on purpose, floated the longest streamer of all, displaying the words "California Admitted!" The roar of cannon rolled over the waters, and met answering roars from forts and ships."[3]

The subsequent celebrations in the city convey much about Patterson himself, considering that he was now a prominent member of the society of San Francisco as it had been so rapidly transformed in the new American era of California.

> "Such an occasion beyond all others demanded a proper celebration at San Francisco; and the citizens, accordingly, one and all, united to make the day memorable. A procession of the various public bodies and inhabitants of the city, with appropriate banners, devices, music and the like, marched through the principal streets to the plaza. The Chinese turned out in large numbers on this occasion, and formed a striking feature in the ceremonies of the day. The Honorable Nathaniel Bennett, of the Supreme Court, delivered a suitable oration to the people on the plaza, and an ode, composed for the occasion by Mrs. Wills, was sung by a full choir. During the day repeated discharges of fire-arms and a proper salute from great guns carried off some of the popular excitement, while the shipping displayed innumerable flags. In the evening, public bonfires and fireworks were exhibited from Telegraph Hill, Rincon Point, and the islands in the bay. The houses were likewise brilliantly illuminated, and the rejoicings were everywhere loudly continued during the night. Some five hundred gentlemen and three hundred ladies met at the grandest public ball that had yet been witnessed in the city, and danced and made merry, till daylight, in the pride and joy of their hearts that California was truly now the thirty-first State of the Union."[4]

Soon after this, Patterson brought his wife Eliza and their children out from Washington to Oakland, where Patterson was based for the next decade. He worked as a steamship captain, and also bought and sold real estate. It is likely that the Patterson home is included in the Coast Survey's first chart of Oakland.

[3] Sarah Royce, *A Frontier Lady*.
[4] Alta California, October 20, 1850



Oakland, from Figure No. 62, the Annual Report of the Superintendent for 1857

But the nation was in turmoil, and war was looming. It was clear to all that the coming war would not be fought in California. Superintendent Bache had, by about 1858, started dismantling the Survey on the west coast, returning personnel to work in anticipation of the coming war. Bache also solicited his former officer to return to the Survey. It seems that the Survey's chief of the hydrographic division, Sidney Smith Lee, the older brother of Robert E. Lee, resigned to join the Confederacy. Patterson heeded the call, and returned to the agency he would be with until the day he died. As Bache's annual report for 1861 declared:

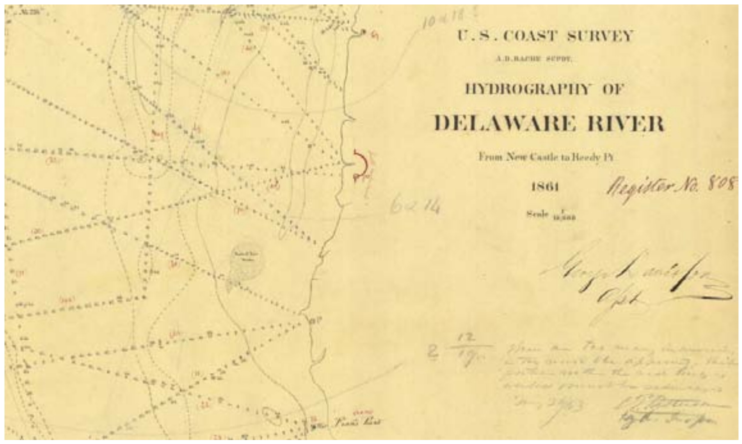
> "Captain C.P. Patterson, some years ago an officer of the United States Navy, and well known by his intelligence and sagacity as chief of one of the hydrographic parties of the Coast Survey, was assigned to duty as the head of the [hydrographic] division on the 6th of May. The principal occupation under the direction of its chief has been the examination and verification of original hydrographic work, including the charts resulting from it; furnishing sailing directions; compilation of hydrographic sketches, and making projections for hydrographic parties"[5].

Patterson became at once one of the most important officers of the Survey. Bache's initial plan for the coming war was to update, extend, and improve the many nautical charts and aids to navigation of the Survey covering the coastal waters and estuaries where the war would likely be fought. Patterson's division was at the heart of this enterprise. Patterson is listed as a co-compiler and author of the text for most of the volumes of Bache's "Notes on the Coast" the important series of lithographed memoirs

[5] Annual Report, 1861, p. 72.

that bundled coast pilot text, strategic sailing directions, and folded maps and wind and tidal diagrams in small discrete volumes for Union forces.[6]

Patterson was also critical to all “examination and verification of original hydrographic work”, which included major re-surveys of the Delaware River between the coast and Philadelphia, in anticipation of a possible Confederate invasion of the city.



A portion of H-808 (1861) a hydrographic re-survey of the Delaware River at Philadelphia with signatures of George Davidson and Carlile Patterson. Patterson’s note rejected the work as inadequate.

As a critical division chief, Patterson was in constant motion during the war, but always returning frequently to headquarters in Washington. But he was directly connected by family lineage or through their marriages with a major part of the leadership of the Union military, especially the Navy. His talents and also his connections must have become particularly critical around 1864, when the Survey’s great leader Alexander Dallas Bache was incapacitated outside Philadelphia while overseeing fortification work. Bache was both mentally and physically stricken, and, although he survived almost three years more, from that point on the entire leadership of the Survey was left in the hands of people like Patterson. Eventually Bache died in 1867. It was really only then that the post-war history of the Coast Survey began.

[6] Notes on the Coast of the United States. See : http://www.nauticalcharts.noaa.gov/nsd/hcp_notesoncoast.html

Carlile Pollock Patterson (1816-1881)
(undated photograph)

As was examined in the chapter on Benjamin Peirce, the question of Bache's successor was both difficult and important, and Joseph Henry, first Secretary of the Smithsonian Institution and a major friend and ally of Bache, played the major role. Captain Patterson and Julius Hilgard were both potential candidates from within the Survey for Bache's post. However, Henry wanted a "scientist", and specifically Benjamin Peirce of Harvard. As noted, Peirce agreed to the post of Superintendent so long as he could maintain his professorship at Harvard and his primary residency in Cambridge, Massachusetts. There was a residential suite for Peirce built into the new Coast Survey headquarters for his use when occasionally in town. However, as the floor plan of the headquarters building makes clear (p.1) when one entered the Coast Survey's main building by the formal entrance from New Jersey Avenue, just a block from the Capitol, the very first office on the right was the suite of offices of Carlile Patterson. The very architecture says something about both his accessibility, and his ability to tolerate being accessible. Further, once Patterson and his family returned east from California, they never returned to the west. In 1868, Patterson's wife Eliza's mother died, and Eliza inherited Brentwood, the great estate in NE Washington just in time for the administration of President Grant (1869-1877). Patterson and Grant had known each other since 1852, when Captain Patterson had ferried Grant and his Army troops from Panama to assignments along the Pacific coast. With their experiences through the war on top of that, Patterson was as connected to the political life of the Capital as was possible. And Brentwood was a major center for socializing in the city, famous for its balls and relaxed parties on a beautiful hilltop site that was close to the city but also removed from and literally above the life of the crowded and pestilential city. It was in that world of the Capitol and the White House and Brentwood that the decision was made that Carlile Patterson would succeed Benjamin Peirce as Superintendent. Peirce was the first Superintendent whose tenure was not ended by death; Patterson was the first Superintendent chosen from within the Survey. It was as peaceful and cordial a transition as could be imagined. And thus began a short but golden age of the Coast Survey.

The Survey's Many Aids to Navigation

Maps and charts, tide tables, and other aids to mariners were fundamental to the mission of the Survey; but, since the beginning under Hassler, they came after the geodetic and astronomical foundations had been developed. Under the first three Superintendents there came a cascade of basic progress in the requisite sciences: vast and accurate data sets of such phenomena as tides registered at harbors, the complex hydrology of estuaries and rivers, etc. beginning under Hassler; novel uses of the telegraph as a scientific instrument as pioneered under Bache; and sophisticated tools for harmonic analysis under Peirce. These gave the Survey under Patterson the basis for a new generation of aids to mariners and navigation in general. In addition to new and updated versions of the harbor charts, sailing direction charts, and other charts that the Survey had published since Hassler, under Patterson the Survey created the "modern" series of Coast Pilots, which have remained continuously in print into the 21st century.

The Pacific and Atlantic models of the Coast Pilot were as distinctly different as the portions of both oceans that are American territorial waters. The Pacific Coast Pilot, under a variety of different names, was originated by George Davidson as essentially a side project for his voluminous energies. The original version was published as an annual report appendix in 1858.[7] These Pilots covered the coast of California, Oregon and Washington Territories, and the basic routes of the Inside Passages between the lower United States and Alaska. In 1867, after his initial voyage to Russian America (Alaska) he published a major report on the territory, its coasts, and many elements and resources of the land and sea.[8] Under Patterson, elements of both of Davidson's previous efforts were merged into the Pacific Coast Pilot (1880).[9]

Apart from San Francisco Bay and the interior seas of Washington Territory, the major part of the Pacific coast along the three western states is profoundly linear, with only a handful of offshore islands. The counterpart coast along the Atlantic is quite different, with rocky and indented harbors, many thousands of islands, profound bays and estuaries, vast barrier islands and seaside wetlands, etc. Under Patterson's predecessor

[7] Davidson, Directory for the Pacific Coast, 1858, pp. 297-458.
[8] Davidson, 1867, Alaska Territory; coast features and resources, pp. 187-329.
[9] Pacific Coast Pilot, Coasts and Islands of Alaska: Dixon Entrance to Cape Spenser with the Inland Passage, 1880

Benjamin Peirce, the Coast Survey had purchased the rights to the Atlantic Coast Pilot publications from the Blunt family in 1867. It took considerably longer, and considerably more personnel that George Davidson, to create the Survey's first version of its own Atlantic Coast Pilot. The first edition was published in the year of transition from Peirce to Patterson, in 1875.[10] In 1879, the Survey published a new, revised, and expanded version of the Coast Pilot.[11] The volume was massive (over 700 pages) and covered the coast only from Maine to Boston. So, the same year, the Survey began a series of Atlantic Local Coast Pilots, which were small folios covering sub-divisions of the coast. These started in Maine in 1879, and reached the southern coast of Florida by 1885 with Sub-Division 22.

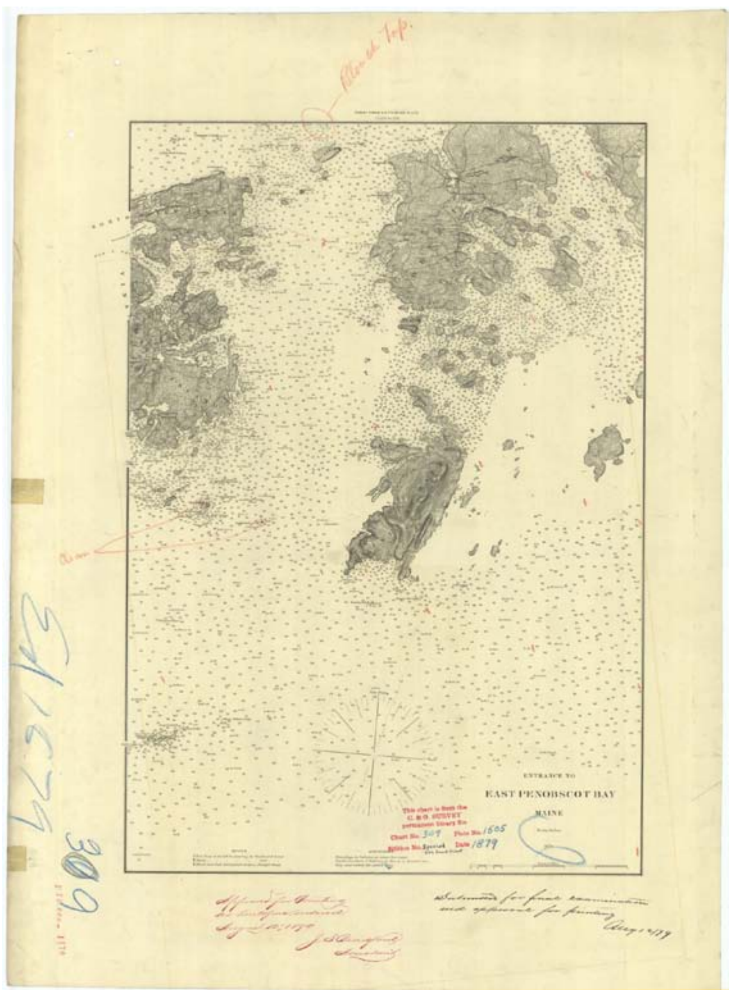
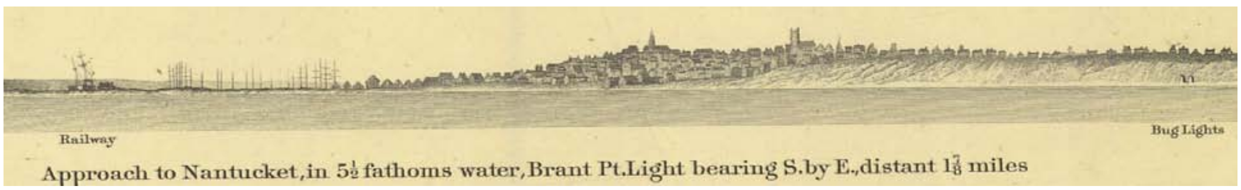


Chart 309 Entrance to East Penobscot Bay, Maine (1879)
Printers Proof for a chart published in the Atlantic Local Coast Pilot, Sub-Division 1 Passamaquoddy Bay to Schoodic. It bears corrections and the signature of Ass't. John Service Bradford, Coast Survey Assistant, who directed the Coast Pilots

[10] Coast Pilot for the Atlantic Sea-Board, Gulf of Maine and its coast from Eastport to Boston.
[11] Atlantic Coast Pilot, Eastport to Boston.

The new Atlantic Local Coast Pilots, like the large volume covering Maine to Boston, had a number of important cartographic innovations. In addition to harbor charts and smaller scaled sailing direction charts, these Coast Pilots featured a new map series of charts that "tiled" along the coast so that the entire coastline was covered at the same scale. The maps were printed on a fine semi-translucent vellum with engraved electrotype plates and folded into the volumes. The same plates were also used to make stand-alone separate copies of many of the charts printed on chart-quality paper.

The new Coast Pilots also featured a series of coastal views drawn by John Barker, who was hired around 1873 to create the views, starting in Maine and working steadily south. He was both a worthy successor to John Farley, the first major artist in the Coast Survey, and also a major innovator in his own right. As Barker progressed southward, his views became increasingly sociological or anthropological, as he rendered coastal American industry and society visible from the sea in extraordinary detail.



Approach to Nantucket, by John Barker. Published on the chart
Monmonoy Island to Block Island, 1874

Barker's primary task was to draw accurately key landmarks and profiles to aide mariners to determine their positions relative to harbor mouths, etc. But he rendered far more detail than that, leaving an amazing record of American culture and technology at a time of great transition in technologies and resources.

The Survey and American Industrial Rivers

The Coast Survey's principal objective in charting was always the American coasts, but from the beginning under Hassler the Survey had mapped the Hudson River up to the head of tides, which is 150 miles inland from Manhattan. During the Civil War, the Survey began mapping American freshwater rivers as they fought their way upstream with the Union forces. The Survey also accelerated hydrologic and current studies of rivers as a part of preparing for the defense of Philadelphia and other Union strongholds during the war. After the conflict, the Survey and its scientists continued research on freshwater rivers. This was clearly a major personal interest of Captain Patterson. In the relatively thin stock of Patterson's correspondence that survives in the Patterson-Winslow family papers, there is a letter to Patterson in Washington from George Davidson, written in 1866 from his home, then in Germantown, Pennsylvania. Davidson wrote several pages of detailed descriptions of proposed research, asking for Patterson's advice on how to proceed at certain points.

> "When we get above tidal waters, I shall try to get a line of soundings across the stream each day, and the width, so as to get a section of the

> stream. These with the velocity of the current will give us the amount of water then passing, and also <u>the slope of the water surface</u>. I have examined Hum[phrey's][12] physics formulae for that purpose and taken some of them for use. A full series of such observations at ordinary seasons, with a plan of the river to calculate the retarding force of the curves would give an approximate height above the tidal waters"[13].

These hydrological research questions were augmented by Patterson's cultivation of Congressional funding sources, and under Patterson the Survey began to map major American river systems, along the lower parts of the rivers and related bodies of water that were heavily used for navigation and trade. We may refer to these as 'industrial rivers": the Kennebec and Passamaquoddy in Maine, the Hudson River and Lake Champlain in New York and Vermont, the Passaic and Raritan Rivers in New Jersey, the Sacramento River and San Francisco Bay in California, and the Columbia River in Oregon and Washington Territory.

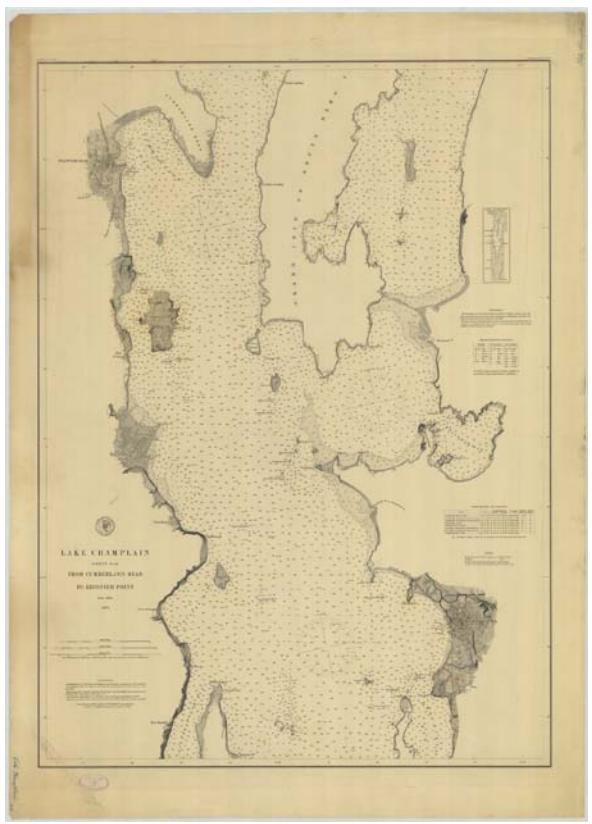


Chart 554, Lake Champlain, Sheet 2 (1879)
From Cumberland Head to Ligonier Point with the city and port of Burlington, Vermont

[12] The reference is to: Humphreys, Andrew and Henry Abbot, Report upon the Physics and Hydraulics of the Mississippi River, (Professional Papers of the Corps of Topographic Engineers, United States Army, no. 4 (1861).

[13] George Davidson to Carlile Patterson, July 1, 1866.

The Survey had performed detailed studies of harbors and their many changes since the beginning with Hassler's work in New York Bay and Harbor and the Environs. Under Patterson, these studies continued, and acquired much greater historic depth, as the Survey integrated historic charts and other data into their analysis, as in the case of the Survey's re-survey of Plymouth Harbor, Massachusetts.

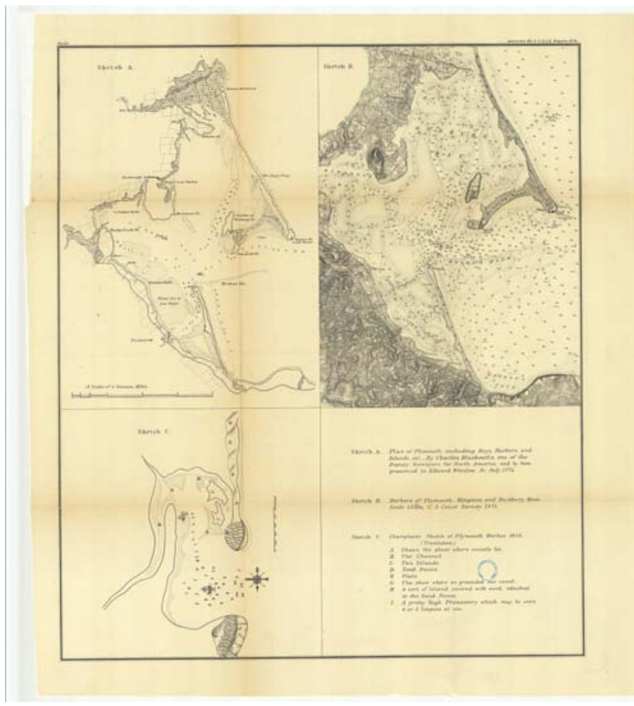


Figure No. 22 Studies of Plymouth Harbor in 1605, 1774, and 1875 (1876)

Charting the Routes between American Coasts

Captain Patterson had a celebrated career steaming between Panama and the American west coast during his years outside the Survey in the 1850s. Under Peirce, in 1873, Congress authorized hydrographic surveys for an anticipated set of sailing charts covering the major routes between Panama and San Diego, along with harbor chart scaled maps of various islands that could serve as harbors of refuge off the Mexican coast. Fittingly, under Patterson the first of the set was published, a chart of the northern part of the coastline of Baja California, including the first American published chart showing Scammon's Lagoon, the major grey whale breeding grounds first mapped in detail by Captain Scammon, an old friend of Pattterson. This was the first published Coast Survey chart to map outside American waters, apart from a chart of a harbor in Labrador, produced after a Survey ship went there for a solar eclipse.

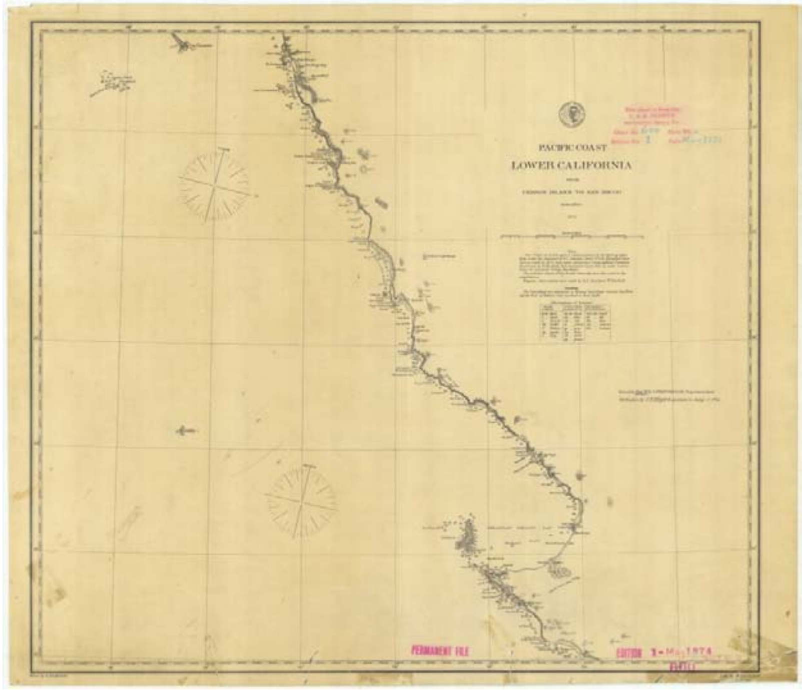
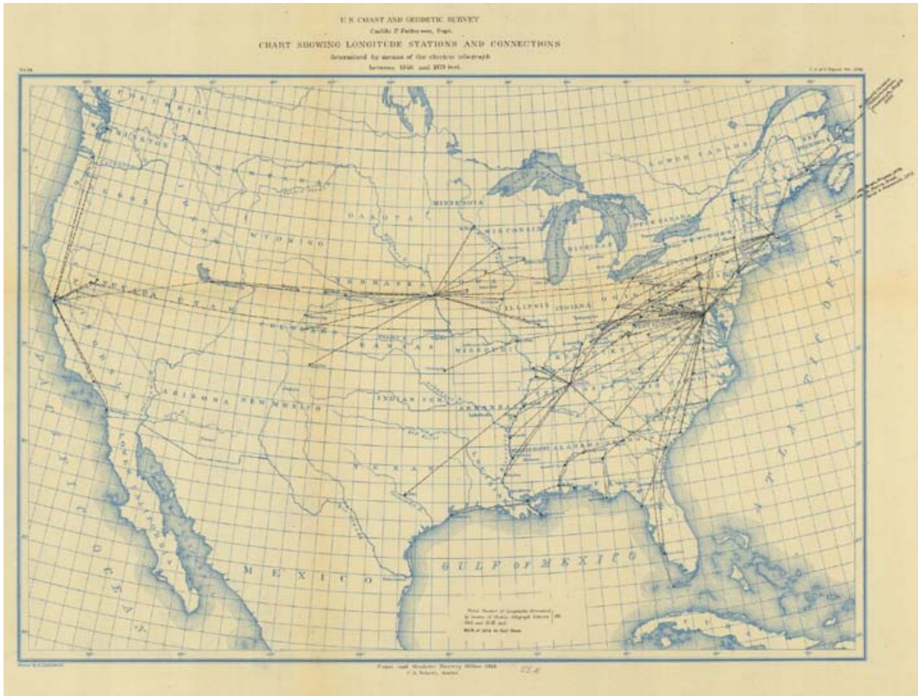


Chart 600 Lower California (1874)
From Cerros Island to San Diego

Scientific Research at Continental Scales, and larger still

Under Bache, the Survey acquired responsibilities on the coast of two oceans and the Gulf of Mexico. Under Peirce, the great project to stitch the Atlantic, Gulf, and Pacific coasts into one geodetic system began. Under Patterson, this project was much advanced. In addition, under Patterson the scope of Survey research and activities expanded substantially beyond continental scale to embrace truly global scientific research.

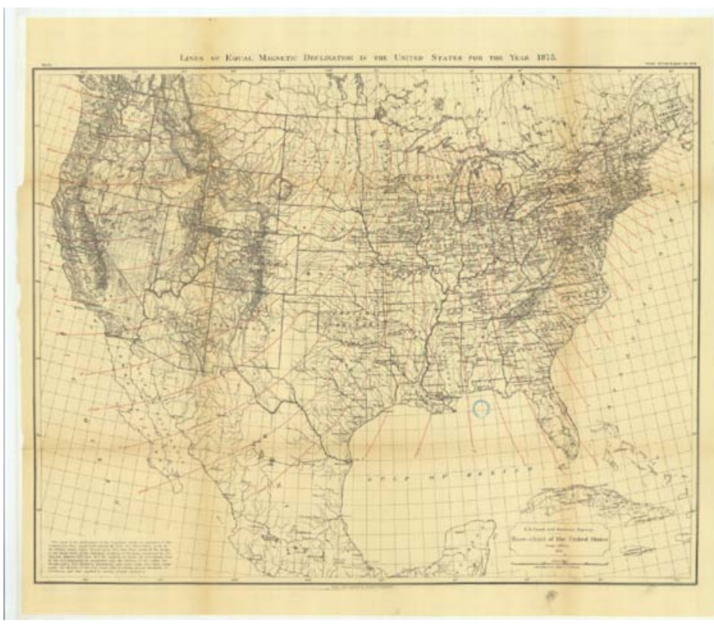
With the completion of the telegraph system that accompanied the Transcontinental Railroad, utilized by the Survey for telegraphic longitude (Bache's American Method), the Survey could provide precise positioning across the country for the burgeoning state and local mapping and surveying systems established in the great expansion of American settlements after the Civil War. Survey research and applications became increasingly continental.



Sketch No. 32 Longitude Stations and Connections determined by means of the electric telegraph, between 1849 and 1879from the annual report for 1879

Mariners at sea, and land surveyors on the prairie all required intensive use of the compass, and hence needed to know the local magnetic declination. As early as the immediate post-Civil War periods, the best minds of the Survey were envisioning a continental-scaled system of magnetic observatories to determine magnetic declination and its constant changes on a scale and with an accuracy consistent with extremely detailed applications. In 1870 and 1871, Charles A. Schott, the great computer of the Survey, was continuing work on the side for Joseph Henry of the Smithsonian Institution which he began during the war. In his workbook for 1870-71, he folded in a chart of anticipated magnetic declination for the year 1870, which the Survey had published in 1866. The chart featured fairly detailed isogonic lines in the Northeast, reflecting the number of terrestrial magnetic observatories and magnetic data that had been acquired there. There were much smoother (and hence more conjectural) isogonic lines on the Pacific coast, and no lines in the middle of the continent. Schott drew a hypothetical triangulated network of observatories that would provide the necessary data to fill in the declination system for the country. This triangulated network as such was never created, but magnetic observatories were set up temporarily at enough locations, that less than a decade after Schott's network was hypothesized, the Survey published a map of general magnetic declination that 'filled in" the United States.

Coast Survey 1866 Sketch of Magnetic Declination for the year 1870, overdrawn by Charles A. Schott with a hypothetical network of magnetic observatories (1870-71)[14]

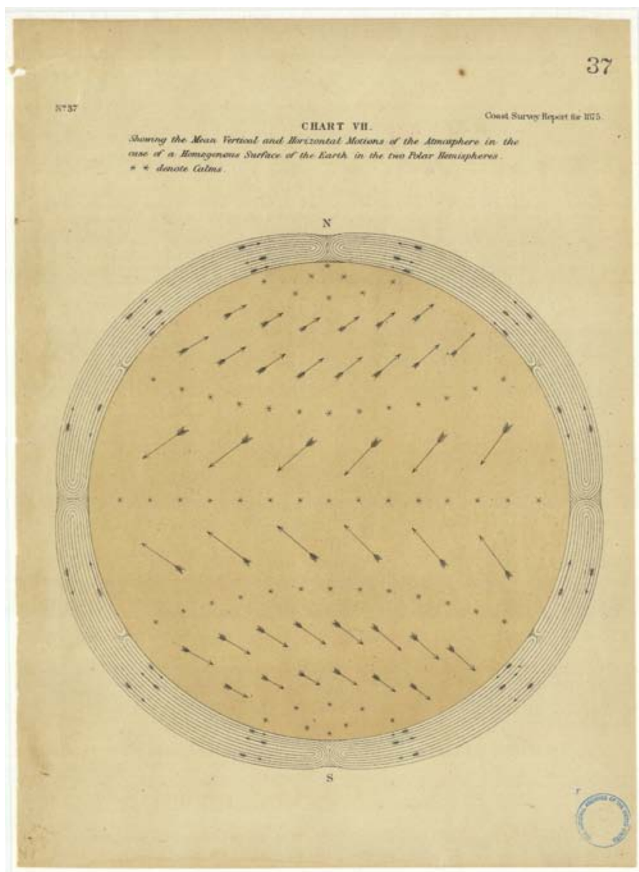


Sketch No. 24 Lines of Equal Magnetic Declination in the United States for the Year 1875 from the annual report for 1876

[14] Sketch folded into Schott's Memoranda Notebook 1870-71, work conducted for Joseph Henry and the Smithsonian Institution, now in the Library of Congress, Manuscripts Division, Schott Collection, Box 2.

The Survey and Ocean and Air Circulation

Under Peirce, a great new era of the applications of harmonic analysis to geophysical problems in many areas began. William Ferrel was a critical member of this core of Survey scientists. Under Patterson, he was working on his great analytical engine the Tide Prediction Machine, but it would take many years, until after Patterson's death, before it was completed. Ferrel made many studies of tides for specific harbors and coasts during this time. Ferrel also returned to the study of atmospheric circulation by tools of harmonic analysis which he had begun before working for the Survey. The project of the new Coast Pilots allowed him time and funding to revisit the subject in order to provide aids to mariners. Under Patterson, he published two major contributions to the subject. The first concentrated on general mechanics and motions of the global atmosphere, while the second was a pioneering analysis of cyclonic storm systems and tornados. The former treatise presented the first graphic rendering of the atmospheric circulation elements now known as Ferrel cells[15].



[15] Ferrel, 1875, Meteorological researches for the use of the Coast Pilot. Part I: On the mechanics and general motion of the atmosphere; Ferrel, 1878, Meteorological researches for the use of the Coast Pilot. Part II: On cyclones, waterspouts, and tornadoes.

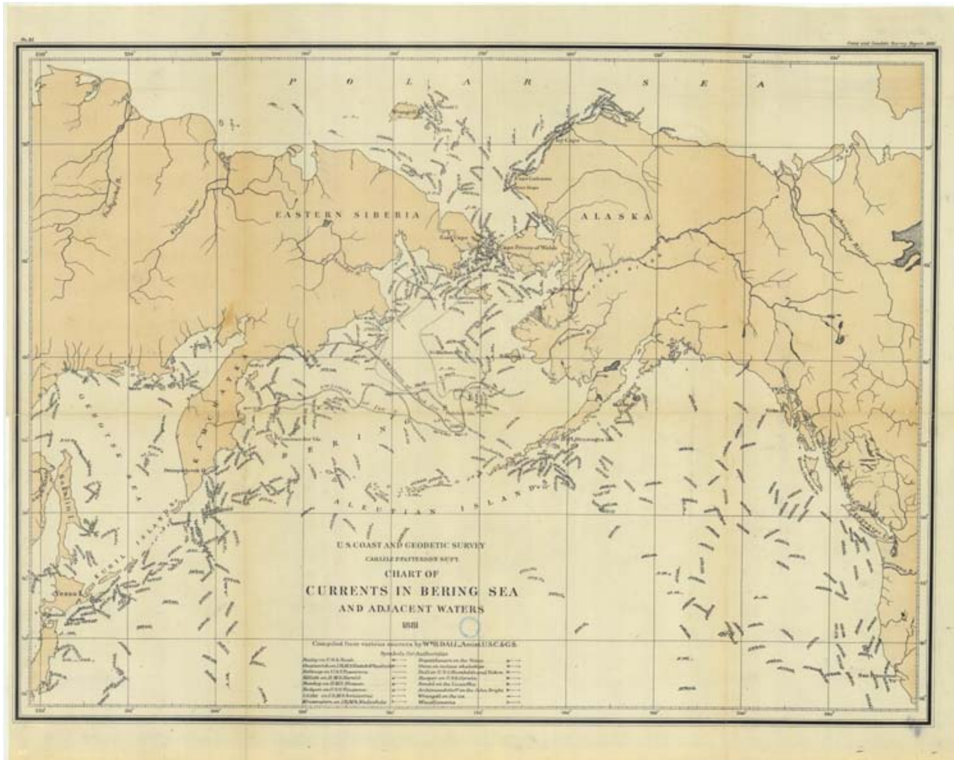
Chart No. VII Showing the Mean Vertical and Horizontal Motions of the Atmosphere, by William Ferrel, from Appendix 20, Annual Report for 1875

The atmosphere and weather were major concerns of almost all Survey personnel, in part because so much of the field work involved ships, most geodetic and hydrological and topographical work was dependent on clear visual observations over distances, and field work in general was so shaped by the local weather. Charles A. Schott, the Survey's greatest computer, also examined meteorological data analytically, performing much work on the side for Joseph Henry at the Smithsonian. Henry was, in part, struggling to design what could turn into a national weather observation and analysis system, and Schott was integral to the development of his data sets and even the design of the forms. He worked closely with the famed lithographer Julius Bien, who had worked in various ways with the Survey since the 1850s. At one point, Bien returned a corrected form for a template for a weather data chart to Schott. In the letter, Bien made a comment to his old friend that speaks volumes about the lives and values of the scientists and other workers of the Survey: "It gives me great pleasure to learn that you are satisfied with the work, after all appreciation from the right sources in the only true reward for conscientious labor".[16]

As the American coasts expanded, and with them the Survey's responsibilities, Survey scientists spent more time travelling farther and more frequently. In addition, the travel to far-flung destinations for observations of transient cosmic phenomena, such as solar eclipses and transits of planets, which began in earnest under Peirce, accelerated under Patterson. So it was that George Davidson and his small party went to Kyoto, Japan for the rare Transit of Venus in 1874, and returned with the rare map of Japan from the high Japanese official the Tykoon for Captain Patterson.

With the purchase of Alaska, the Survey acquired, as it were, the services of William H. Dall. Dall noted and mapped air and ocean currents between San Francisco and the Aleutians from his very first voyage for the Survey in 1871 and 1872. Under Patterson, Dall made many reconnaissance trips by sea and inland to Alaska and many adjoining regions. His decade of research on the system of the Bering Sea and its relation to the Pacific and Arctic Oceans was synthesized in his report published in Patterson's final year.[17]

[16] Bien to Schott, February 22, 1875.
[17] Dall, 1881, Bering Sea.



Sketch No. 81 Chart of Currents in the Bering Sea and Adjacent Waters by William Dall from Appendix No. 16, annual report for 1880

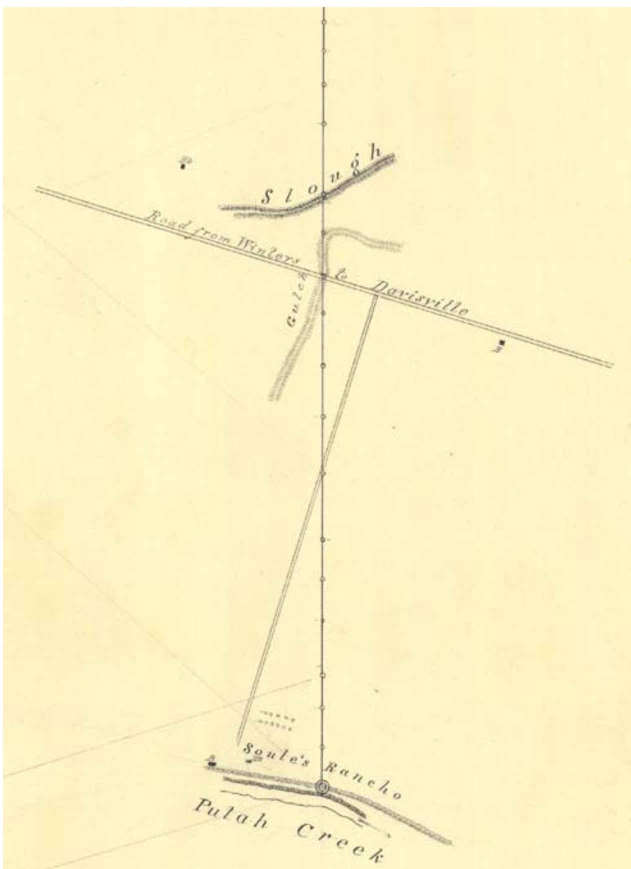
The Coast Survey becomes the Coast and Geodetic Survey

The Coast Survey had always been geodetic; that was Hassler's foundation. But as the foundational scientific agency in the US government, the Survey had always to be responsive to the needs and desires of Congress, or at least specific Congressmen, to obtain the funding required in order to function appropriately. In the post-war era, there were many "scientific" expeditions sent to the American west and southwest, led by present or former Army officers. US Navy officers still were assigned to the Survey, and filled many important roles, but US Army officers had been withdrawn from service with the Survey early in the Civil War, and the Army never returned. This soon led to a powerful tension between the Survey, and its many allies, and the myriad of potentially or actually competitor government science and mapping agencies then being formed, or at least promoted. The subject is a complex one, and will become far more complex after Patterson's death, as the Survey was plunged into its darkest era. But as a part of the process of solidifying its position and clarifying it primary responsibilities for American government science, in 1878 Patterson orchestrated the name change from Coast Survey to Coast and Geodetic Survey, to differentiate the Survey from the new geographical and geological surveys and agencies being formed or proposed.

And so, during an era popularly regarded as dominated by valiant expeditions led by Army veterans plunging farther and deeper and westerly, always westerly, into the great American west, at the very same time, the Coast and Geodetic Survey was busy occupying the very same country, or perhaps a little farther north than most of the other expeditions, but traveling in the opposite direction[18]. Instead of plunging into a savage wilderness, the Survey was leaving coastal California and the world city of San Francisco, enriched by the mines of the Comstock Lode and the cornucopia of agriculture in the Central Valley, and was headed easterly, ever easterly, at times guided by John Muir, into an eastern arid fastness inhabited by Mormons and Paiutes.

Peirce initiated the Triangulation Network of the Great Arc of the 39th Parallel in 1871; it would be decades before the arc was completed. Advancing the triangulation network westward from the Atlantic coast involved surveying approaches very similar to those Hassler had introduced when he began the Survey. Working eastward from the Pacific coast was different, for two reasons. First, there were great differences in mountainous terrain, and very different atmospheric conditions from those in the east. Second, out west there was George Davidson.

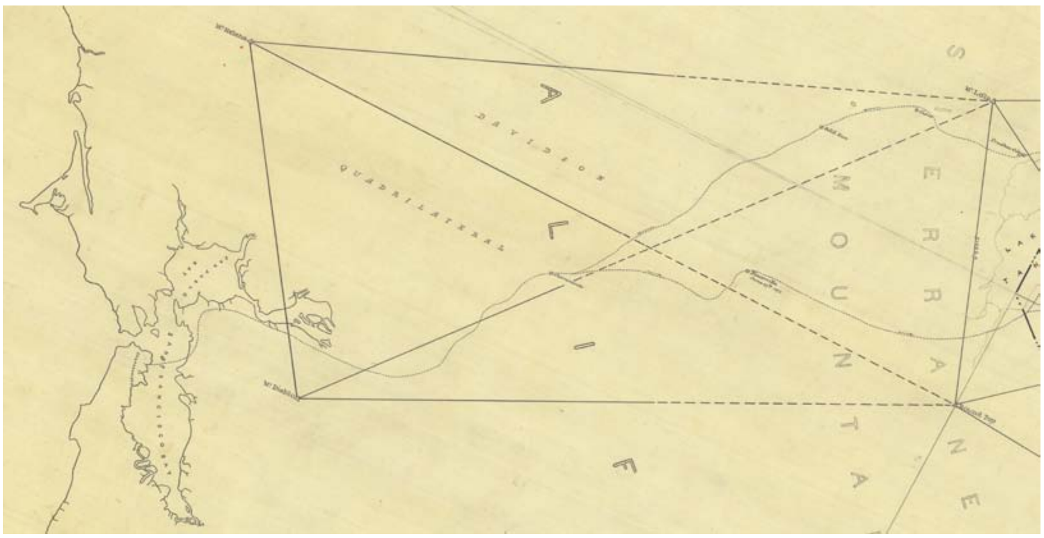
The western end of the great Arc was anchored by a particularly meticulously measured baseline, the Yolo Base Line, laid out on reasonably flat ground in the Central Valley of California, near the present city of Davis in 1876.



[18] For the westward-bound surveys, see Evans and Frye, 2009.

The southern end of the proposed base line, from T-1602 Preliminary Examination of the Yolo Base Line

George Davidson proposed to “ground” the western end of the triangulation arc by setting up a quadrilateral, a four-sided figure, composed of four very tall peaks, each visible from the others. From one of the peaks, Mount Diablo, the two ends of the Yolo Base Line were visible. Meticulous horizontal angles would be shot from each peak to all other peaks in the quadrilateral. Davidson immodestly proposed to name the quadrilateral after himself.

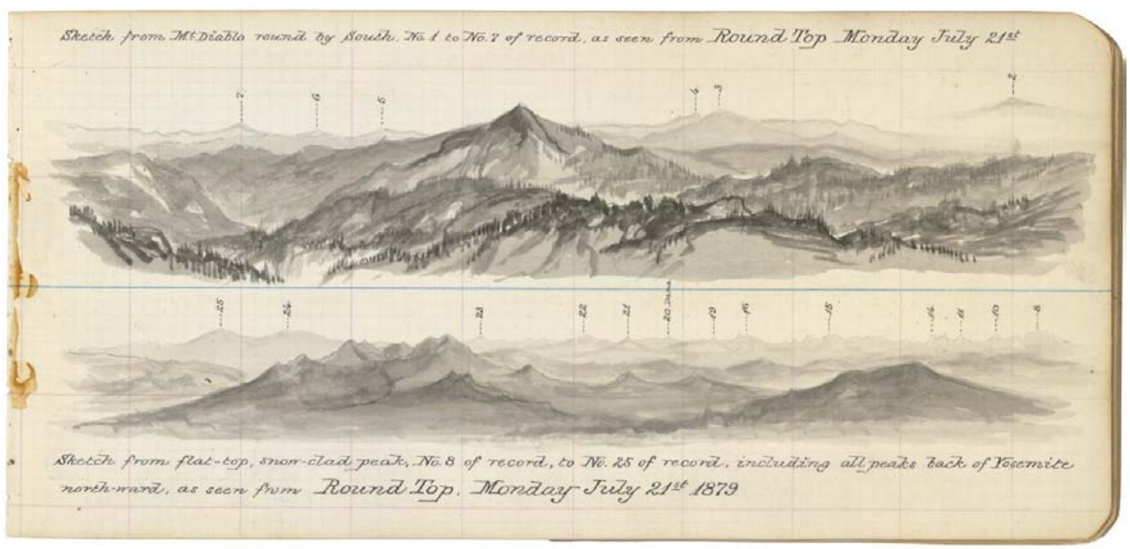


George Davidson’s original 1878 schema for the Davidson Quadrilateral as projected and drawn by George Farquar, using angles computed by Davidson from preliminary reconnaissance from the peaks

As the project evolved, the plan grew larger and more complex. There would be two quadrilaterals, on either side east and west of the Yolo Base Line. Mount Diablo would be used to sight to the baseline ends, and also to serve as an observatory to shoot long time series of vertical angles to the seven tall peaks of the multiple Quadrilaterals, in order estimate their heights. The height estimates could then be used to check for possible atmospheric diffraction due to the great heights of the peaks. With the plan ready, the Survey set out for the Sierra Nevada in the long, fruitful field season of 1879.

The View from Round Top

A condensed example of the work along the entire network can be seen in the work accomplished in 1879 at the primary first-order triangulation station on the top of Round Top, a dramatically isolated tall peak, 10,381ft. or 3,164 meters tall in the Sierra Nevada range near Lake Tahoe in California. The triangulation between first order stations was the most exacting work of the Survey, and had been that way since Hassler. Using the latest model theodolites and heliotropes (pivoting mirrored reflectors which could flash tiny bright beams of light that could be seen as much as 100 miles or more away) Survey crews could extend the triangulation network rapidly and accurately over terrain entirely unlike that of the rounded and forested east coast. But the Quadrilateral mountains were necessarily the tallest ones available, and occupying the summits meant enduring intensely hostile conditions, waiting for appropriate weather for observations, and also waiting for other Survey crews to traverse the hundreds of miles necessary to get to the other stations within view. Under these conditions, Louis Sengteller, the head of the Drawing Division, camped on top of Round Top for nearly a month in the summer of 1879. His task was geodetic reconnaissance; he would find the farthest and highest mountains, which he and the rest of his Survey crew would then identify and evaluate as potential stations. After a terrible summer storm passed over Round Top with punishing fury and dangerous lightning, on July 21, 1879 Sengteller got the vista he had waited a month for.

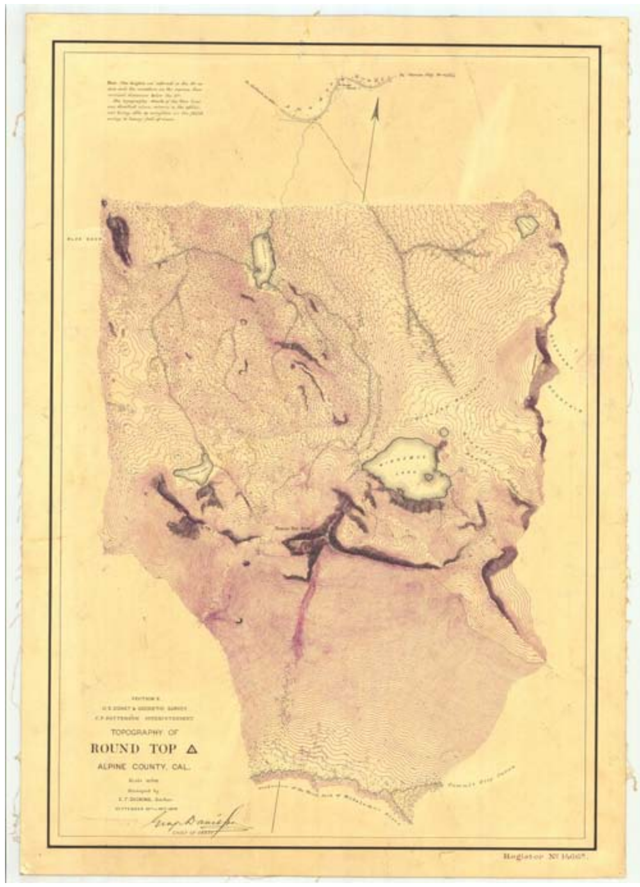


Sketch of Mountains as seen all around from Round Top, CA,
on Monday, July 21, 1879 by Louis A. Sengteller[19]

After geodetic reconnaissance came the triangulation work. It required an additional two months to have crews situated on the other stations at the right times with the right instructions and equipment. In September, a party under E.F. Dickens occupied Round Top for over two weeks. Heliotrope observations were best done near dawn and near dusk, and when atmospheric conditions allowed. This left the great majority of the time for other things. Several Survey crews that summer worked very hard on topographic surveying of their peaks, in collaboration with Edwin Hergesheimer, the great Survey draughtsman and topographer, who was preparing his manual of plane table surveying and possibly testing manual materials using the triangulation station crews. Dickson and his crew produced an extraordinarily detailed contoured map of the summit and its environs. It is part of a set of topographic maps of high country in the Sierra

[19] In Sengteller Reconnaissance Sketchbook No. 74, GAR series, Section X (California) 1879

Nevada, also including Mount Lola and the Moraines of Fallen Leaf Lake, by Hergesheimer himself, that were the cartographic fruits of the field season of 1879.

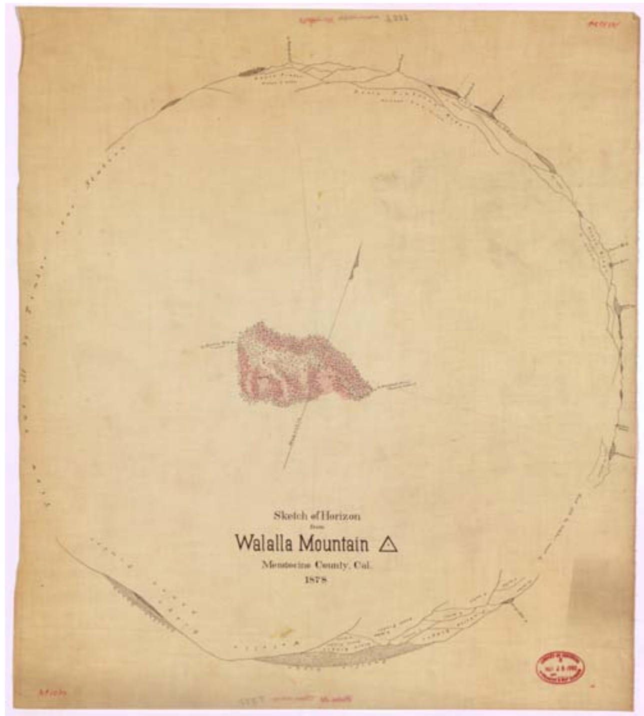


T-1466A Topography of Round Top, Alpine County, California
Surveyed by E.F. Dickens and party, September 13 to 30, 1879

The final objective of the many months of work getting to Round Top and back was the completion of the sightings of the horizontal angles between both sets of four peaks composing the Davidson Quadrilaterals. By calibrating the quadrilaterals to the precisely measured length of the Yolo Base Line, Davidson and his crews By integrating in the geometry of the baseline, as shot from Mount Diablo, and by resolving as many tiny errors due to atmospheric diffraction based on heights of the peaks, and other sources of error, the resultant geometric figure of the Davidson Quadrilaterals was the largest geodetic structure ever shot by observation to that time.

Davidson's original plan was to develop quadrilaterals in all directions radiating out from the original ones in central California, but the remarkably varied geography of California made this difficult, particularly to the north from central California. Assistant Cleveland Rockwell was dispatched into northern California beyond Point Arenas for reconnaissance. It was rugged and mountainous terrain, with many distinctive peaks.

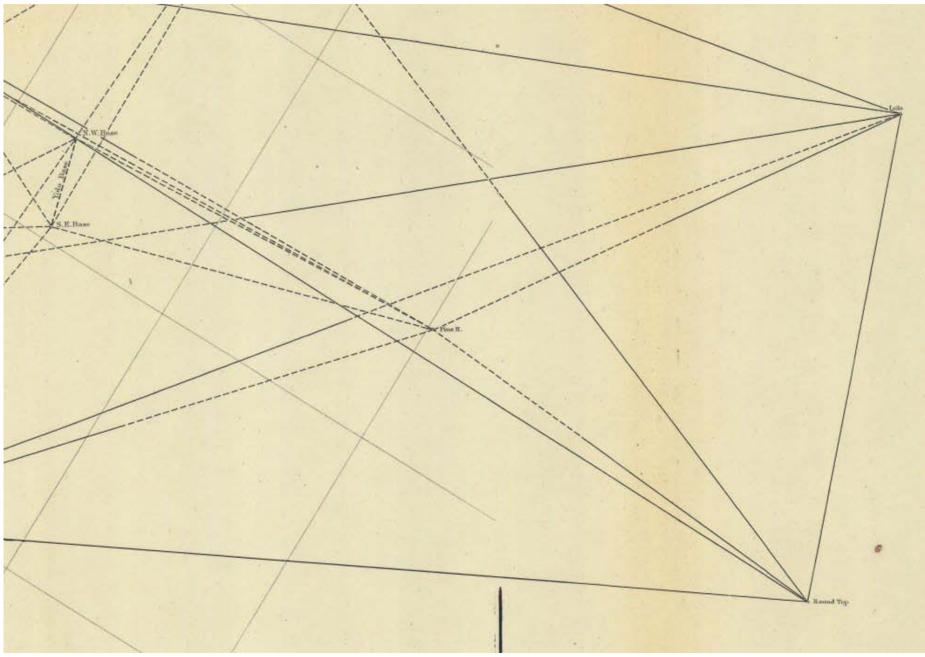
But, as Rockwell noted: “In this region it was found extremely difficult to observe on distant points because of the density of the redwood forest”.[20]



Sketch of Horizon from Walalla Mountain, Mendocino County 1878
By Cleveland Rockwell

As Rockwell and his party journeyed north into Humboldt County, the geography grew ever more problematic. They were able to find peaks and establish stations, “but with a disadvantage with respect of distance from the coast”. Finally they made it as far north as inland from Cape Blanco on the Oregon coast. “Some of the points from which observations were made are upwards of four thousand feet above the level of the sea. During the summer the heat of the rocks in the ascent was found very oppressive by the party. Much of the region traversed is extremely rough and destitute of trails”.[21] It is interesting that Rockwell, who was an accomplished artist, after retiring from the Survey, was a member of an exploring party that traversed the very same country, from the Oregon coast south and inland to Orleans, California on the Klamath River. This time, Rockwell and party made sure they traveled in spring, instead of summer. Rockwell filled sketch books with watercolors of beautiful native spring wildflowers in the mountains. These sketchbooks are now in the archives of the Oregon Historical Society.

[20] Rockwell, p. 48, Annual Report for 1878.
[21] Rockwell, ibid., p. 49.



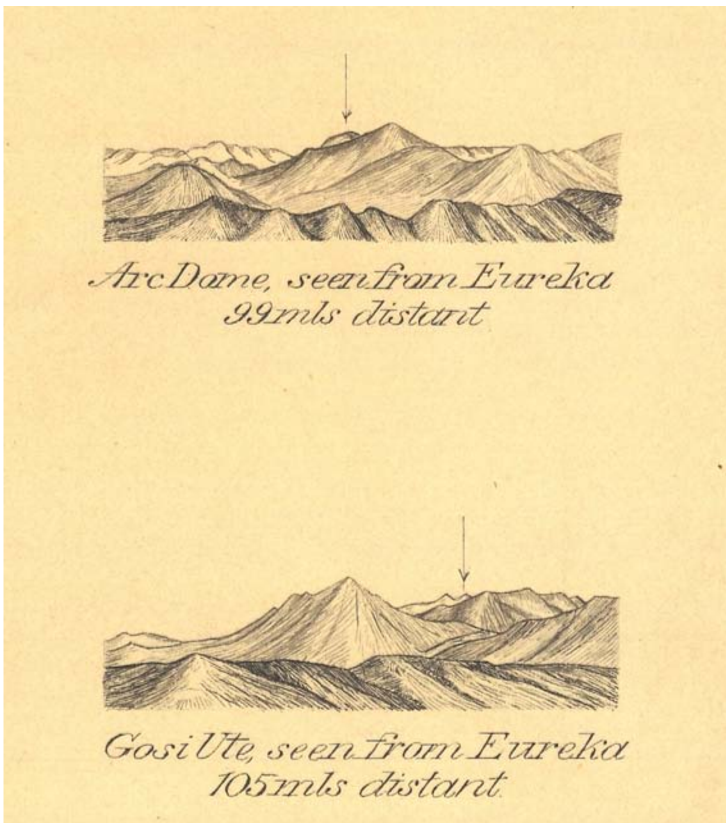
From Sketch No. 23, Progress of the Survey from Point Sal to Tomales Bay, CA Showing Round Top (lower right hand corner), Mount Lola (upper right), and the Yolo Base Line (upper left) (1879)

In other directions the convergence of terrain, vegetation, and atmosphere proved more favorable. With the geodetic foundation of the Quadrilaterals, horizontal angles could be shot eastward and northeastward to other tall peaks in the great Sierras. Benjamin Colonna, Davidson's chief assistant in the San Francisco office, was head of the party that climbed Mount Shasta, in far northern California for preliminary reconnaissance observations. His report of their observations gives a good sense of confidence and success of the Survey in extending the triangulation network, the very skeleton of the Survey since the first work of Hassler.

> "Friday, August 1, proved to be the day I had been waiting for. The wind had hauled to the northward during the night, and the smoke had vanished as if by magic. At sunrise, I turned my telescope in the direction of Mount Lola, and there was the heliotrope, 169 miles off, shining like a star of the first magnitude. I gave a few flashes from my own, and they were at once answered by flashes from Lola. Then turning my telescope in the direction of Mount Helena, there, too, was a heliotrope, shining as prettily as the one at Lola. My joy was very great; for the successful accomplishment of my mission was now assured. As soon as I had taken a few measures, I called Doctor McLean and Hubbard to let them see the heliotrope at Mount Helena, 192 miles off, and the longest line ever observed over in the world. In the afternoon the smoke had arisen, and Helena was shut out; but on the following morning I got it again, and my mission on Mount Shasta was finished. The French have been trying for some years to measure, trigonometrically, some lines from Spain across the

Mediterranean to Algiers; they have only recently succeeded, and it has been a source of great satisfaction to French geodesists. Their longest line is 169 miles. The line from Mount Shasta to Mount Helena is 192 miles long, or 23 miles longer than their longest. And the glory is ours; for America, and not Europe, can boast of the largest trigonometrical figures that have ever been measured on the globe"[22].

Once past the redoubt of the Sierra Nevada in California and western Nevada, the Survey made rapid progress in the vast basin and range country of eastern Nevada and all of Utah. Under clear conditions in the arid expanse, observation lines of a hundred miles or more were easily performed.

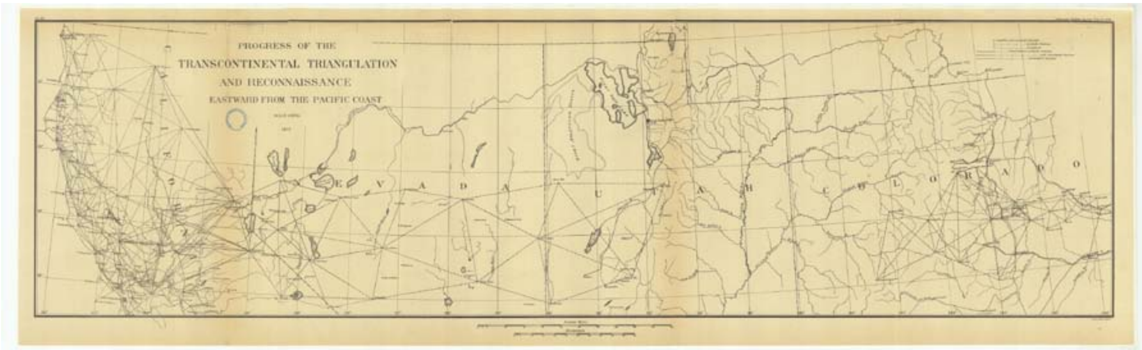


From T-2139 Transcontinental Triangulation and Reconnaissance
Showing Arc Dome and Gosi Ute (now Goshute) as seen from Eureka, Nevada (1879)

As a result, after a difficult but productive field season in 1879, the new Coast and Geodetic Survey had triangulated all the way from California to Utah. This work was a combination of reconnaissance surveying, and the more meticulous and corrected observations necessary for primary and secondary order geodetic stations. As Colonna

[22] B. Colonna "Nice Days on the Summit of Mt. Shasta" The Californian, March, 1880.

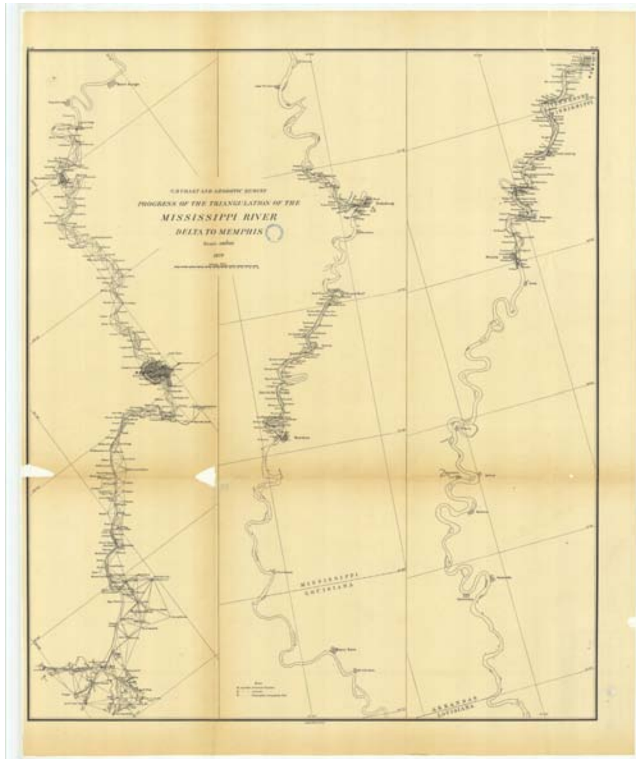
noted, at that time, there was nothing like this level of geodetic progress anywhere else on earth, not even Europe!



Sketch No. 30, Progress of the Transcontinental Triangulation and Reconnaissance Eastward from the Pacific Coast (1879)

The Survey and the Mississippi River Commission

The Mississippi River is another great American industrial river, but the work and research on the Mississippi performed by the Survey stands distinctly apart from the other major rivers of Patterson's era because of the political and hydrological context. Survey geodesists and cartographers had worked their way up the river during the Civil War as part of Admiral Porter's Mississippi Squadron. After the war, General Humphries (the man whose physics formulae George Davidson was adapting to his own hydrological studies, who had also been the assistant in charge of the Coast Survey office under Bache, 1847-1853) became the Chief of Engineers of the US Army. He and his allies were committed to major construction of levees as the way to control the river. There had been major floods in the Mississippi River Valley in 1862, 1865, 1869, and 1874. Even before the 1874 flood, the US Congress authorized the Coast Survey to conduct research and map the lower Mississippi River, in anticipation of major projects to come. The first stage of the Survey's work was a triangulation network, which was established from the Mississippi River delta upriver, and also established from St. Louis, Missouri going downriver. Eventually the entire river triangulation network was completed.



Sketch No. 19 Progress of the Triangulation of the Mississippi River
from the Delta to Memphis (1879)

The next stage in Survey work was to begin topographic and hydrographic surveying of the river to produce a map series, very similar to those produced for the other American industrial rivers. The surveys began in 1872 an 1873. By 1878, in Patterson's era, the Survey published a series of 13 charts, from Fort Jackson on the main channel of the river, and ending at Point Houmas, on a river bend between New Orleans and Baton Rouge. The series ended, because in 1879 the Mississippi River Commission was established,

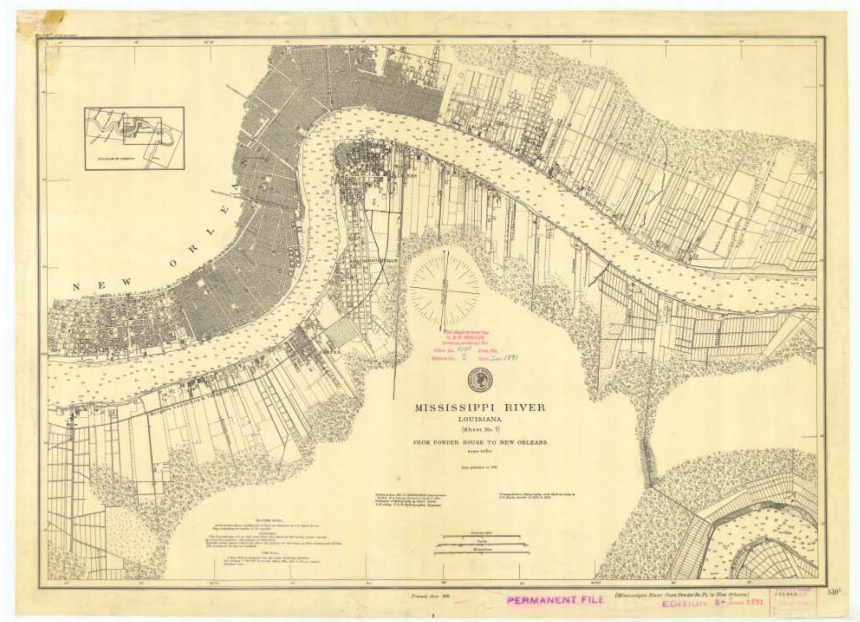


Chart 510, Sheet No. 7 Mississippi River from Powder House to New Orleans (1878)

The basic objective of the Mississippi River Commission was to create a body dedicated to a project for establishing control on the lower river for navigation and commerce. From the beginning, the membership of the commission was: three senior officers of the Corps of Engineers, one member from the Coast and Geodetic Survey, and three "gentlemen of quality" as they were originally specified, who would represent river landowners, shipping companies, boat builders, and the like[23]. The first Survey representative to the Commission was Henry Mitchell who was the Survey's best hydrologic scientist. However, the composition of the Commission dictated, from the beginning, that the Survey representative to the Commission would act primarily as a consultant or advisor to a decision-making process determined by the Army and the "gentlemen of quality". Thus, the Survey map series on the river was replaced by an entirely new set of charts developed by the Corps of Engineers, although they made use of the Survey's triangulation network. That would characterize the Survey's role on the Mississippi River Commission form then on, and essentially remains so today.

Charting Alaska and Native Peoples

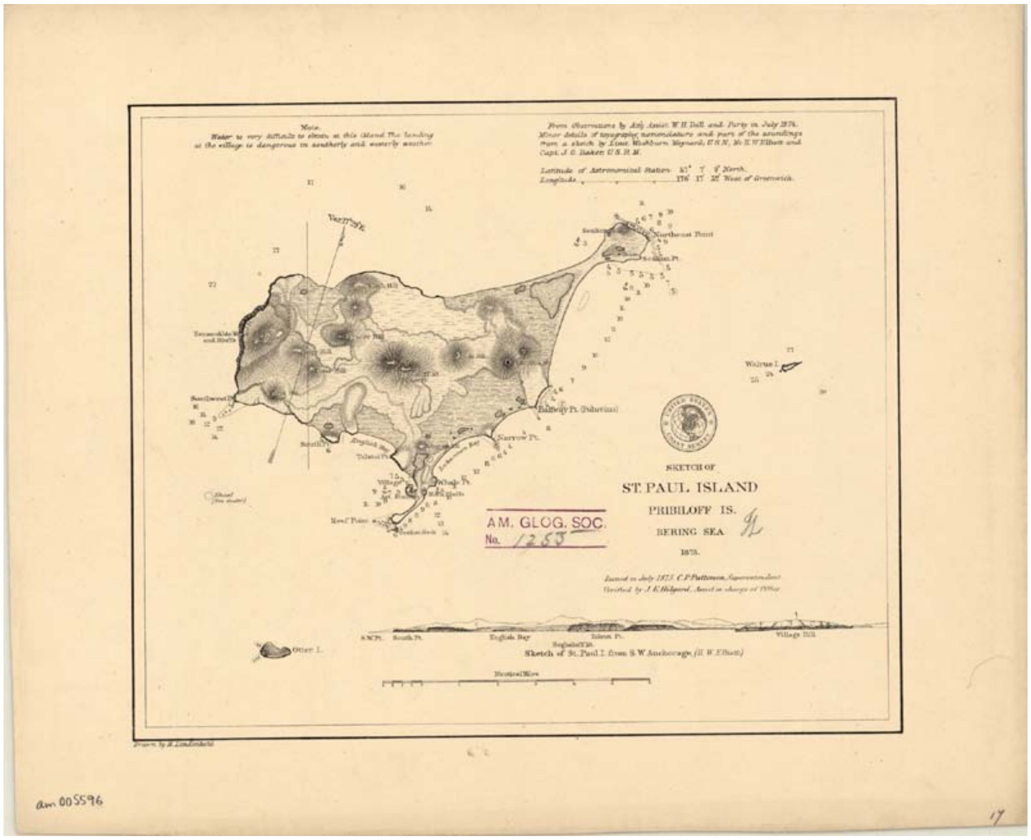
The two major chiefs of party from the Survey associated with work in Alaska in this era were George Davidson, who went north in 1867 and 1869, and William H. Dall, who had extensive reconnaissance experience in the region working for the Western Union Telegraph Company before working for the Survey. His first Survey voyage was 1871-72 to the Aleutians. He explored the coasts, the interior up the Yukon River, and throughout the Bering Sea and related places. He performed the first surveys of the major "Pribiloff" Islands, as he spelled them, in conjunction with (and apparently,

[23] Association of State Floodplain Managers, 2000.

sometimes friction with) Henry Elliott, the Special Agent of the Department of the Treasury. Elliott was a gifted artist, who became a major force in the preservation of the fur seal rookeries on the islands. In 1874, the Survey published a novel map of the land and sea areas in Alaska which Dall had explored.

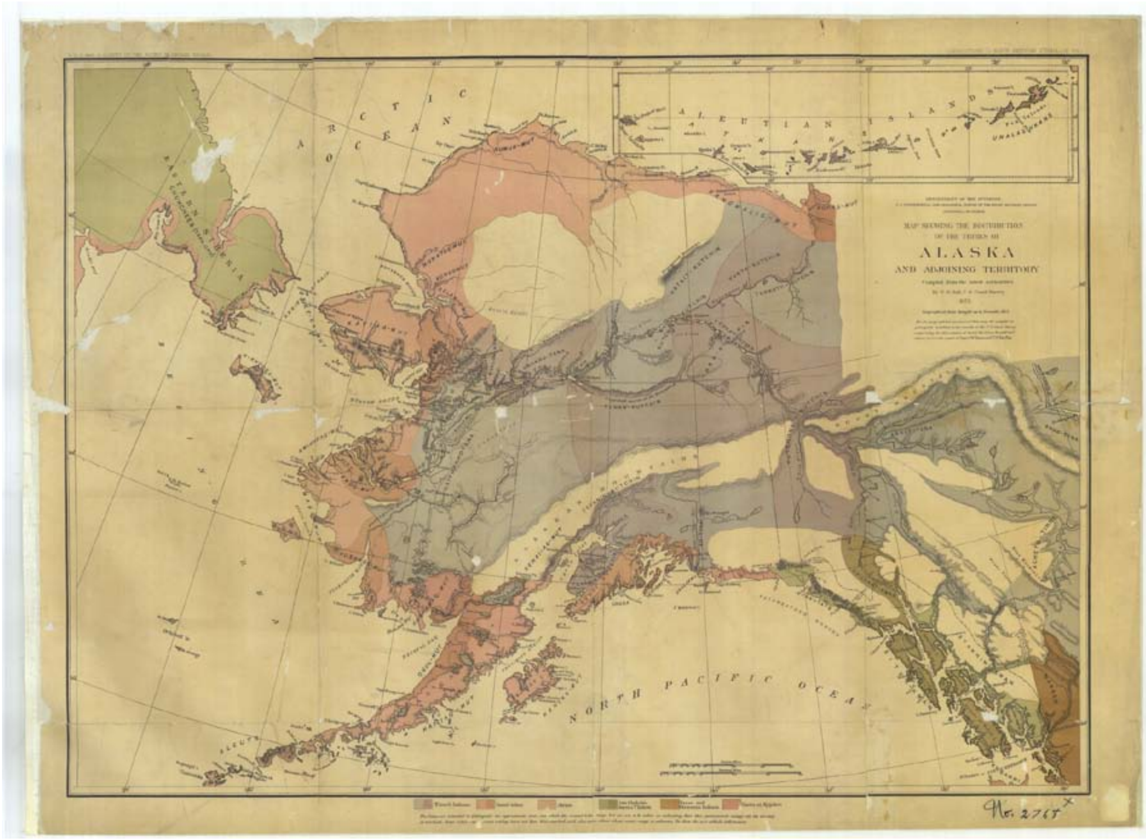
No. 22 Dall's Explorations in Alaska from the annual report for 1874

Under Patterson, the Survey published a series of charts of Alaskan ports, harbors, and islands, based on the Davidson and Dall explorations, and also on the historic charts of the same places made by Russian cartographers, which were transferred to the Coast Survey as a part of the purchase of Russian America. The Survey charts of St. George and St. Paul islands in the Pribilofs became the geodetic foundation for several series of critical fur seal rookery maps in later decades.



Sketch of St. Paul Island, Pribilof Islands, Bering Sea from observations by William Dall and party, with view by Henry W. Elliott (1875)

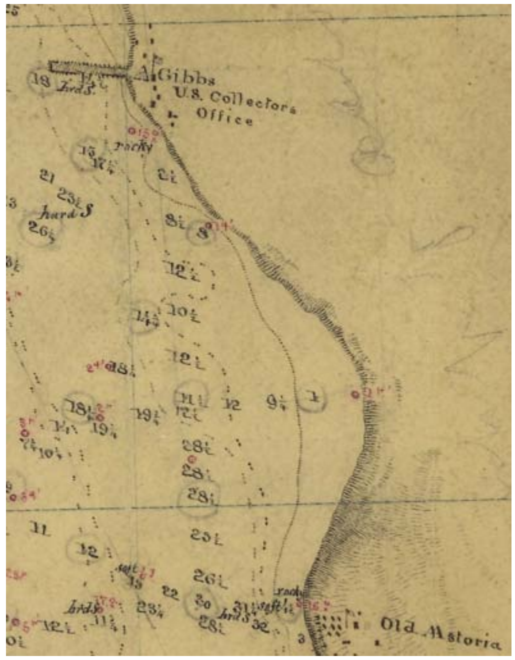
The west coast Survey under Davidson was particularly sensitive to and sympathetic about the native tribes and populations they encountered. Davidson since the 1850s had made a major point of acquiring native language vocabularies and information on native place names, most spectacularly in the case of the series of "Kohklux maps" created starting in 1869 with the Tlingit chief Kohklux and his two wives. William Dall continued and expanded this research during his many excursions on land and sea in Alaska and adjoining regions. All this research culminated in a set of reports, accompanied by two remarkable chromo-lithographed maps, which were published by John Wesley Powell as a part of the formation of what would eventually be Powell's Bureau of American Ethnology in the Smithsonian Institution. At the time though, Powell's enterprise was called the US Geographical and Geological Survey of the Rocky Mountain Region, which was one of the several enterprises of Army and ex-Army officers vying to develop what would eventually become the US Geological Survey. The first map and subsequent publication was the map by Dall with assistance from Davidson, of the native tribes of Alaska and adjoining territory. The base map is the Coast Survey's 1869 map of Alaska, with chromo-lithographed colors overprinted on the map coding for linguistic family. The section of the Chilkhat Pass between the Lynn canal and the Yukon is notable in that the basic linguistic information on the languages there came from Kohklux and his two wives.



Map showing the Distributions of the Tribes of Alaska and Adjoining Territory compiled from the latest sources by William H. Dall, with assistance from George Davidson (1875)[24]

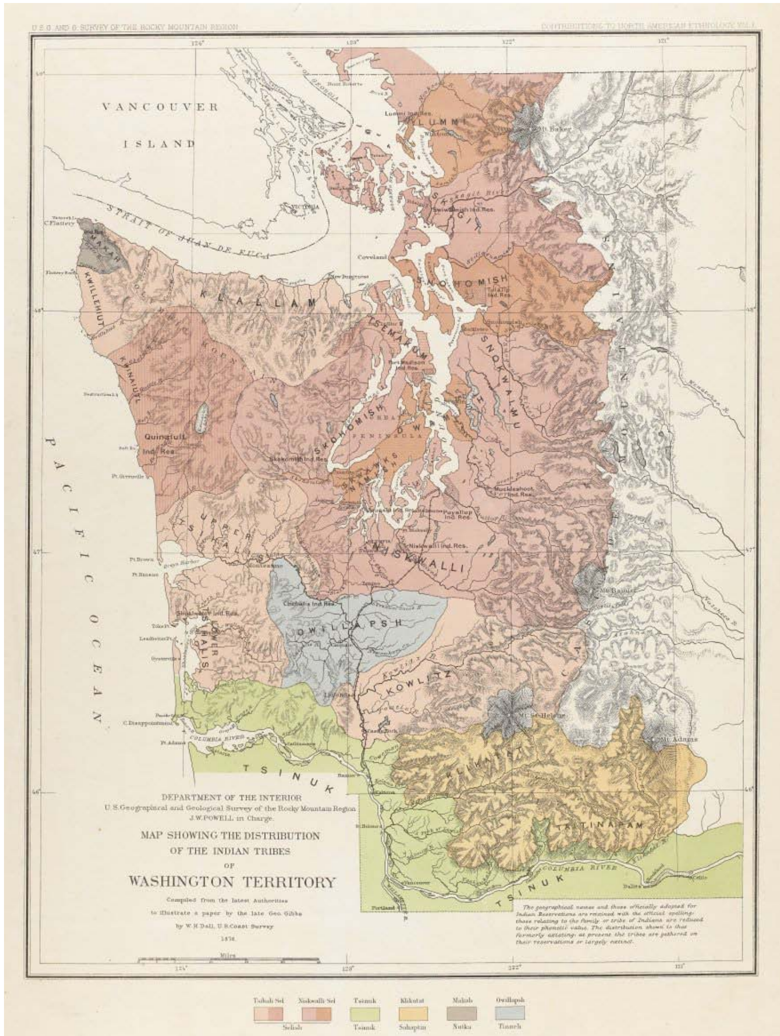
The following year, Powell published a long report written by the late George Gibbs on the Indian tribes and languages of Washington Territory and Northwest Oregon. Gibbs was a long time government agent who worked in various positions over decades, and who had become a major authority on the Indians of the region. George Davidson had known him since 1851, on his first reconnaissance up the Pacific coast. On that trip, the Survey had even mapped Gibbs' office at the government agency in Astoria on the Columbia River in Oregon Territory.

[24] See Dall, Tribes of the Extreme Northwest 91877).



From H-250 Part 2 Columbia River Entrance (1851)

To accompany the Gibbs' report, Powell commissioned William Dall to prepare another chromo-lithographed map of the linguistic distribution of Indian tribes in Washington Territory and Northwestern Oregon Territory. The map also functions as a map of the sum of territories that the Coast Survey had explored and mapped in its several decades of work on the west coast. And it maps as well the great sensitivities and sympathies of the personnel of the Survey to American Indians, then a rare phenomenon in the US government. The year the map was published, 1876, for example, was also the year of the Battle of the Little Bighorn.



Map showing the Distribution of the Indian Tribes of Washington Territory compiled from the latest authorities to illustrate a paper by George Gibbs by William H. Dall, published by J.W. Powell, US Geologic and Geographical Survey of the Rocky Mountain Region (1876)[25]

The Survey, the Blake and the Deep Ocean Basins

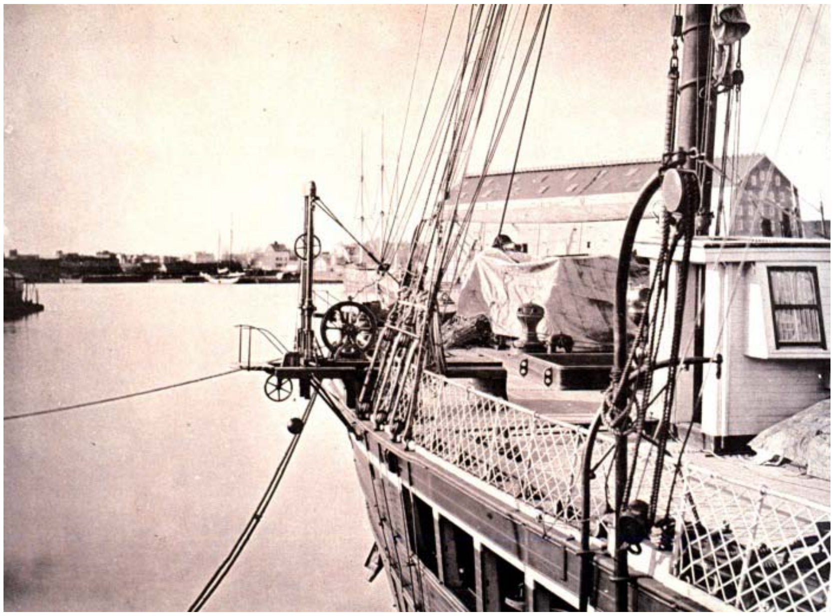
The Survey's mandate to pursue oceanographic research is as old as the idea of the Survey itself. As the initial bill passed by Congress in 1807 noted: "That it shall be lawful for the President of the United States to cause such examinations and observations to be made, with respect to St. George's bank, and any other bank or shoal and the soundings and currents beyond the distance aforesaid to the Gulf Stream".[26] Under Peirce, the Survey commissioned the *Blake*, the first modern American vessel specifically

[25] See Gibbs, Tribes of Western Washington and Northwest Oregon (1877).
[26] Section 2 of Act of Feb. 10, 1807, Sess. II, ch. 8, 2 Stat. 413-14 (1807).

designed for oceanographic research. As has been noted before, the work of the Blake was particularly paired to Alexander Agassiz, and the innovations he brought to oceanography from hard rock mining. Steel cable for sounding, and also dredging, became standard to all subsequent oceanographic research.

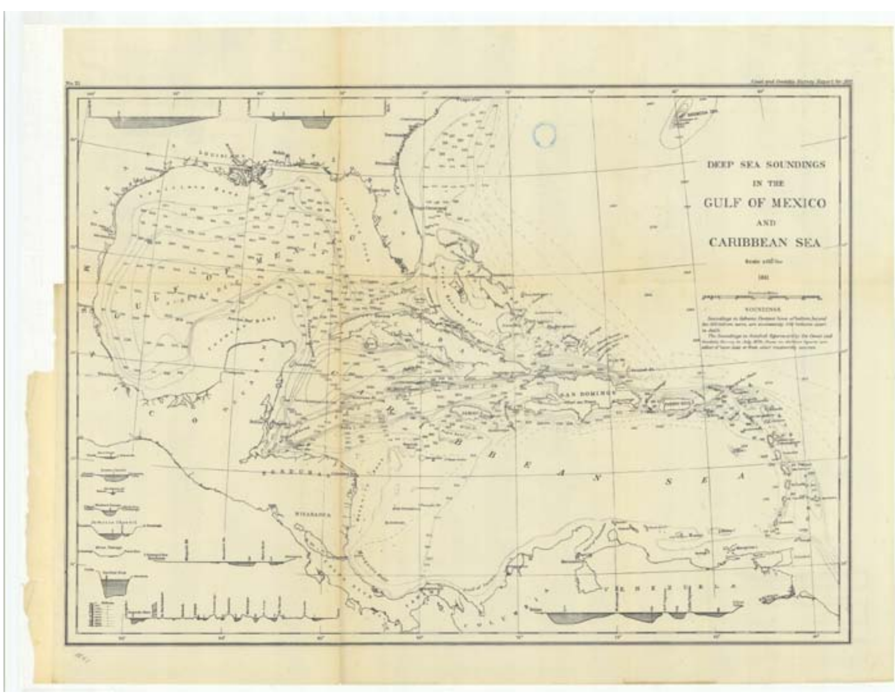
Plate 30: Steam Winch and Steel Wire on board the Survey ship "*Blake*"
from "Deep Sea Sounding and Dredging" by Charles D. Sigsbee (1880).

Agassiz was joined in Survey oceanographic work by US Navy Captain Charles Sigsbee, who developed the Sigsbee Sounding Machine, which along with steel cable, became the great technologies that opened up deeper ocean basins and trenches and other deep features to the numbers and distributions of soundings necessary to characterize the features with relative confidence.



The Sigsbee Sounding Machine in position, run out for work on board the Coast and Geodetic Survey ship "Blake" (1880)

During Patterson's era, the first publications bearing the results of the pioneering *Blake* surveys emerged. Soundings of the Gulf of Mexico, in particular, go back to the era of Bache in the late 1840s. But in the era of the *Blake*, the three-dimensional structure of the Gulf began to emerge.



Sketch No. 21 Deep Sea Soundings in the Gulf of Mexico and Caribbean Sea from the annual report for 1881

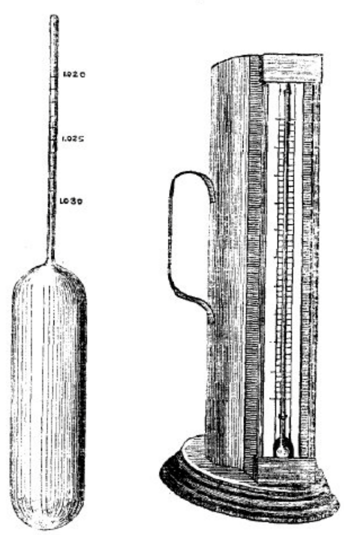
Many of the key instruments of oceanographic research were large and dramatic, but many others were small and intricate. A good number of the latter instruments developed and invented or improved in the Survey were associated with Julius Hilgard. By Patterson's era, Hilgard had been with the Survey for over two decades, having been hired by Bache in 1852. Almost two thirds of a century after Hilgard's arrival, Cleveland Abbe, long associated with the Weather Bureau but originally a scientist with the Survey, had noted that the Survey really coalesced around a primary triangle of A.D. Bache, Charles A. Schott the Survey's great computer, and Julius Hilgard.[27] Hilgard ran the headquarters, as the longtime Assistant in Charge of the Office. He also developed instruments for the research work of the Office of Weights and Measures, and also for many different arenas of scientific research the Survey engaged in.

APPENDIX No. 16.

DESCRIPTION OF AN OCEAN SALINOMETER, BY J. E. HILGARD, ASSISTANT UNITED STATES COAST SURVEY.

The density of sea-water in different latitudes and at different depths is an element of so great importance in the study of ocean physics as to have caused a great deal of attention to be paid lately to its determination. The instruments employed for the purpose have been, almost without exception, areometers of various forms. The differences of density as arising from saltiness are so small, that it is necessary to have a very sensitive instrument. As the density of ocean-water at the temperature of 60° Fahr. only varies between the limits of 1.024 and 1.029, it is necessary, in order to determine differences to the hundredth part, that we should be able to observe accurately the half of a unit in the fourth decimal place. This gives a great extension to the scale and involves the use of a series of floats if the scale starts from fresh water, or else the instrument assumes dimensions which make it unfit for use on board ship.

With a view to the convenient adaptation to practical use, the apparatus figured below has been devised for the Coast Survey by Assistant Hilgard.



The instrument consists of a single float about 9 inches in length. The scale extends from 1.020 to 1.031, in order to give sufficient range for the effect of temperature. Each unit in the third place, or thousandths of the density of fresh water, is represented by a length of 0.3 of an inch, which is subdivided into five parts, admitting of an accurate reading of a unit in the fourth place of decimals by estimation. The float is accompanied by a copper can, with a thermometer inserted within the cavity, which is glazed in front. In use, the can is nearly filled with water, so as to

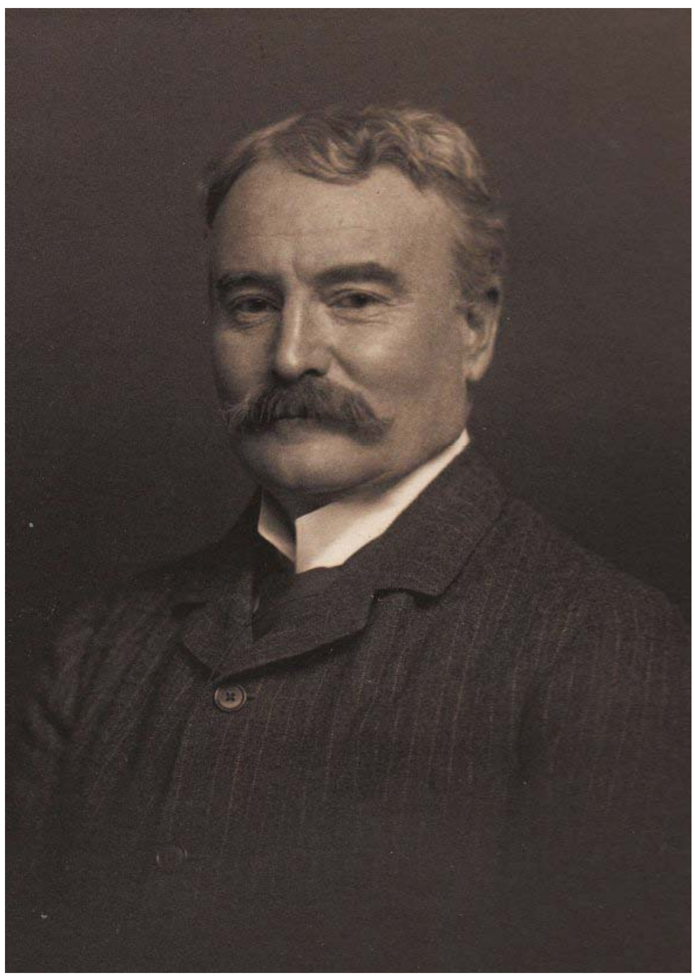
Description of an Ocean Salinometer by Julius Hilgard, Assistant in Charge of the Office Coast Survey Appendix No. 16, Annual Report (1874)

[27] Abbe, 1915.

In the difficult period following Bache's incapacity, Hilgard and Patterson were potential candidates to succeed Bache. As was discussed in the chapter on Peirce, Joseph Henry apparently actively discouraged Hilgard as a candidate for Superintendent, because he was a foreigner. Hilgard was passed over for Peirce, and Peirce was replaced by Patterson. It would soon be realized that, for Hilgard, his foreign birth was the least of his problems.

The Beginnings of the Special Oyster Work

Patterson came from a family of Navy officers, with many women relatives who married other Navy officers. Patterson's daughter Harriet would eventually be one such woman. The man she was to marry was Francis Winslow II, whom Patterson brought into the Survey to begin one of the most important research initiatives the Survey ever undertook in the 19th century, which in many respects was an early indication of what NOAA would become a century later.



Francis Winslow II
(undated photograph courtesy his descendant Edward Sisson)

Francis Winslow II was a son of Francis Winslow I, a Navy commander who died of yellow fever in the Union blocking squadron campaign in the South in 1862. Winslow II was sent to the Naval Academy to follow in his father's footsteps. Winslow apparently had some discipline problems. Perhaps because of this he was assigned to duty with the Coast Survey in 1876. Patterson welcomed Winslow to service beginning on a regular hydrographic party, but before doing so, Patterson requested Winslow report in person to the headquarters in Washington to talk to him[28]. It is fascinating to speculate about their conversation. Was Patterson cautioning Winslow about discipline? Or was Patterson evaluating Winslow as a candidate for a new type of marine research, one that Winslow eventually dedicated the rest of his life to?

The modern United States was founded in large part on maritime commerce and fisheries. Fisheries of many kinds were already in decline or exhausted by the middle 19th century. Over time, the federal government and the states turned their attention to research on fisheries and fish cultivation. Indeed, the 1807 law authorizing a Survey of the Coast mentioned studies of St. George's Bank specifically, the great fish nursery and site of rich fisheries offshore from New England. In 1871, Congress authorized the creation of the US Commission on Fish and Fisheries, originally under the Smithsonian Institution. The Commission (which originally was essentially one man, Spencer Baird) worked on fisheries research in New England. In 1873, Commission staff members used the Coast Survey steamer *Bache* for deep sea dredging, as they lacked their own equipment. Later that decade, when Winslow entered the Survey, research emphasis broadened and turned south to the Chesapeake Bay, and the rapid decline of the native Chesapeake oysters.

There were two great interrelated problems to the matter of the oyster fisheries of the Chesapeake Bay and elsewhere. The first was that no one really knew the mechanisms of oyster reproduction in the native American Atlantic coast oyster (then *Ostrea virginica*, now *Crassostrea virginica*). This ignorance limited artificial culturing of oysters, of course, but it also impacted management of the wild oyster stock as well. An interrelated question about the latter was the nature of the differences between the oyster populations on undisturbed beds (called natural beds) and those which were dredged or tonged or otherwise harvested (called managed beds). Winslow was assigned by Patterson to what was called "the special work" of oyster biology and management, an unprecedented new task for the scientists of the Survey. It turned out, Winslow had found his life's work. He essentially became the marine biologist he needed to be to learn how oysters reproduce and could be cultured. And, he applied the hydrographic surveying skills he learned in the Survey to oyster management by figuring out techniques to map and monitor oyster beds geodetically. The full fruits of his work would emerge over decades, but the first of these to emerge was his treatise on the oysters of the Chesapeake Bay and its estuaries.[29]

[28] Patterson to Winslow, Dec. 7th, 1876, In Patterson-Winslow Family papers, LOC Manuscripts Division.
[29] Winslow, Appendix No. 11, annual report for 1881. See also Keiner, 2009.

Winslow worked only two years' assignment under Patterson before the Navy called him to other duties. Winslow eventually left the Navy to pursue his oyster research. In 1880, Patterson wrote to Winslow upon his leaving the Survey:

> "I beg to express my regret that the terms of duty of Naval officers on this work do not permit your continuance in the service for a sufficient length of time to enable you to carry to completion the special work on which you have been engaged during the last two years… The admirable manner in which you have opened up this new branch of work of the Survey, with the energy, good judgment and intelligence you have shown in its initiation, with only the simplest instructions, deserve my warm acknowledgements. The methods suggested and the system adopted by you, and so successfully carried out with the limited means at your disposal will form the basis for all future work".[30]

And thus Patterson and Winslow parted officially in 1880. But Winslow was courting Patterson's daughter Harriet Livingston Patterson, so presumably they continued to meet under the great oak trees at Brentwood.

The Frontiers of Experimental and Scientific Cartography and Topography

Under Hassler, the geodetic network was absolutely foundational to the progress of the Survey. That remained the case for his successors. But, under Bache, it became critical to publish results promptly, and in particular to publish maps and charts of the most recent work. Under Pattterson, as we have seen, entire new series of maps and charts were developed. But there was also a profusion on novel maps and charts, many of them unique, several of them entirely original types of maps the likes of which had never before been seen or even imagined. The Survey even develop a numbered chart series, the "3000 charts", whose chart numbers began with "30xx" to accommodate the new charts.

One example was the chart of the topography of Mount Desert Island, off the coast of central Maine. The chart's engraver was John Enthoffer, the Chief Engraver of the Survey, after much service in Europe as institutes of military topography. In 1870 he had published a major treatise on topographical drawing, illustrated with topography taken from his work on specific Survey charts, such as the peninsula of Point Loma, at San Diego Harbor[31]. The Mt. Desert chart is distinctive, for a Coast Survey chart, in that, although it represents an island with a major port (Bar Harbor) offshore in the Atlantic Ocean, it has no hydrographic data of any kind.

[30] Patterson to Winslow, January 6, 1880, in the Patterson-Winslow Family Papers
[31] See Enthoffer, Manual of Topography, 1870

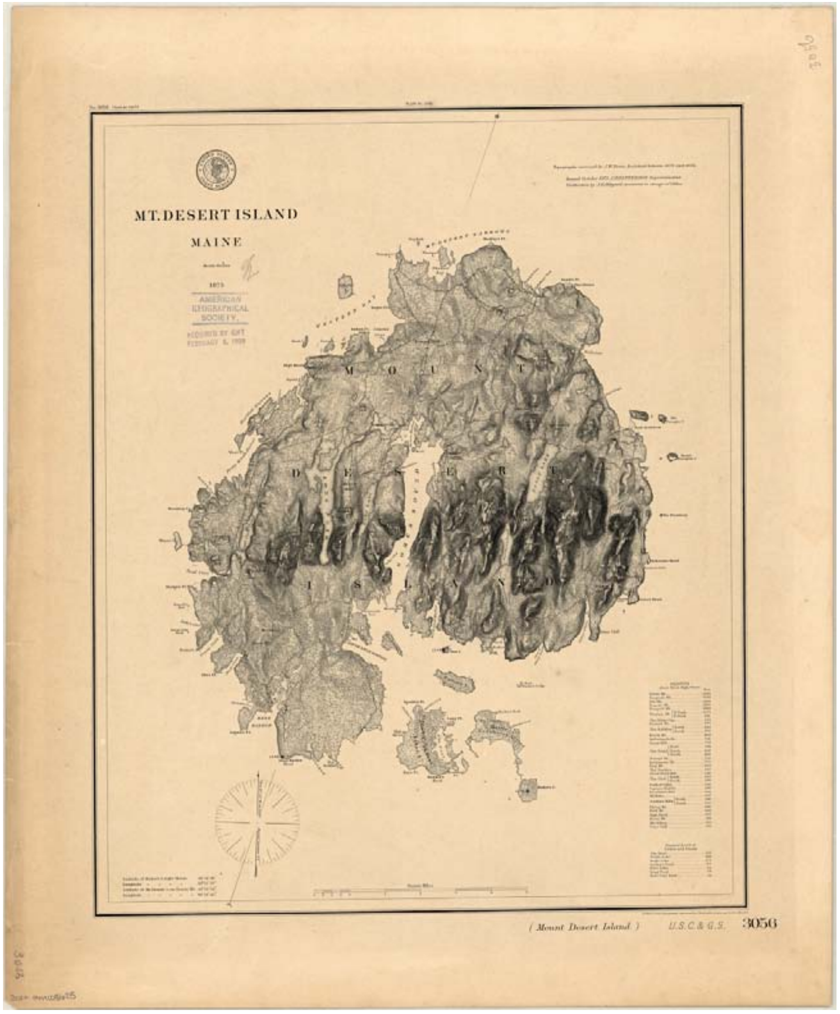
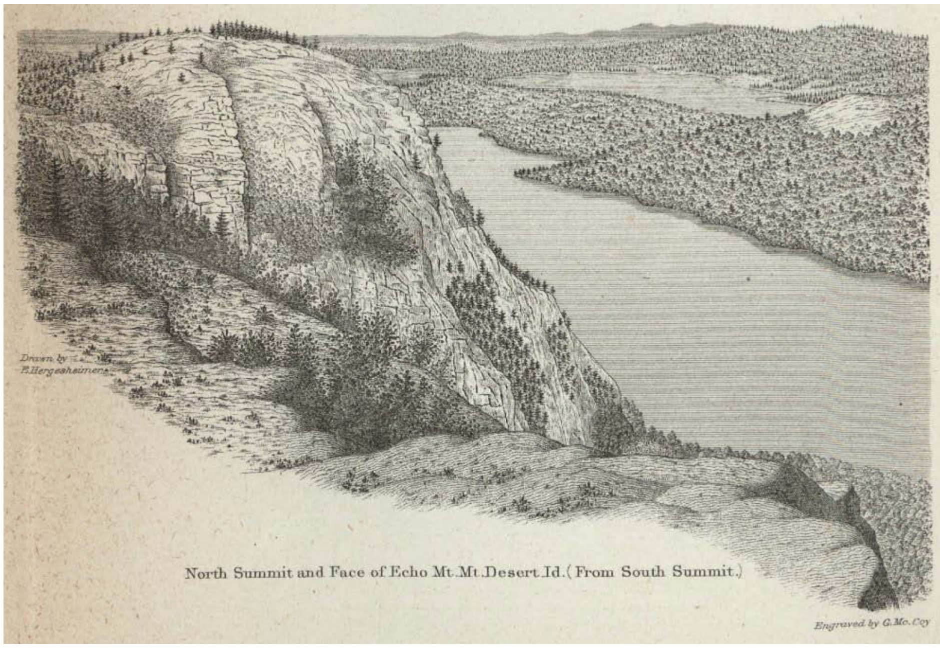


Chart 3056 Mount Desert Island, Maine (1875)
Topography surveyed by J.W. Donn, engraved by J. Enthoffer

A natural complement to the chart is one of the many illustrations that Edwin Hergesheimer prepared for one of the many versions of his great treatise on the use of the plane table for topographical mapping, and the preparation of standardized types of topographical drawings[32].

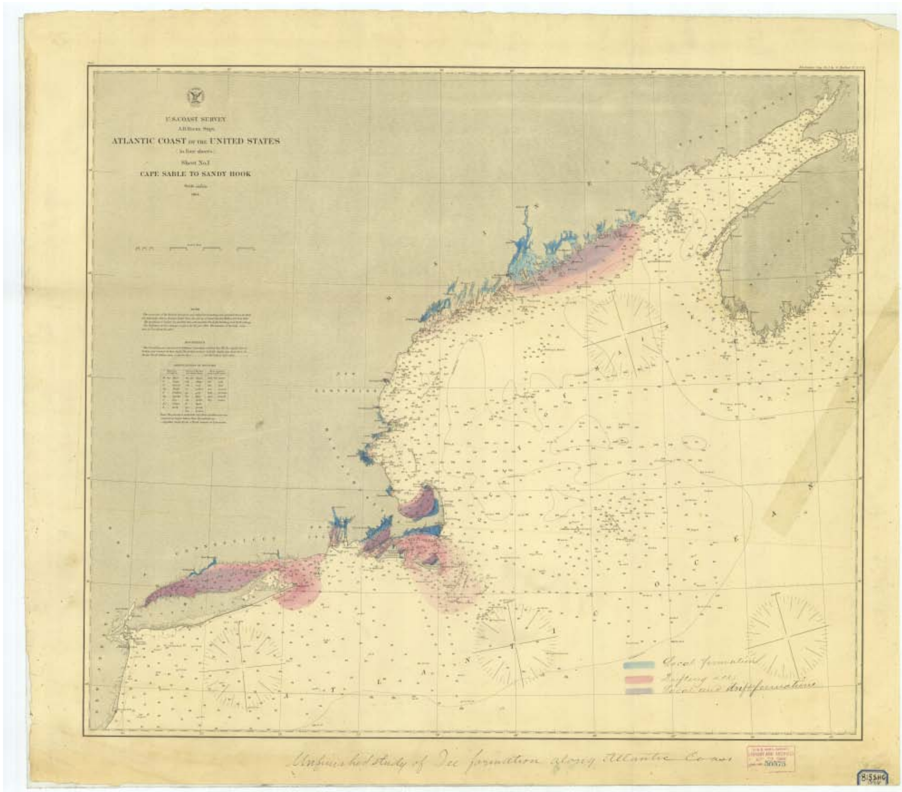
[32] E. Hergesheimer, Appendix No. 14, Annual Report for 1883.



North Summit and Face of Echo Mountain, Mount Desert Island, Maine
(from South Summit) Drawn by Edwin Hergesheimer From Appendix No. 14 Report on the preparation of standard topographical drawings. (1883)

The Cold Winter of 1874-75, Lt. Francis Bradbury, and the Ice Charts

The very active period in Survey work on the Atlantic coast that began with Patterson's tenure and the beginning of what would become the Atlantic Local Coast Pilots also happened to fall when an exceptionally cold winter settled on New England and the Atlantic Ocean offshore in 1874-75. US Navy Lt. Francis Bradbury was assigned to the Survey as a hydrographic surveyor, and also assistant in various aspects of the work of compilation of a myriad of data for the sailing directions and guides to hazards to navigation. Bradbury took a special interest in the extreme state of local and sea ice in the harbors and shipping lanes than winter. He began a study, ultimately left unfinished, by the end of his tour of duty with the Survey, to present and analyze the ice conditions, compared to normal winter conditions. He hand water colored 14 different Survey charts, at harbor chart and sailing direction chart scales, with the maximum extents of the ice that winter, along with the formation status of the ice.



The Atlantic Coast from Cape Sable to Sandy Hook over painted with winter ice at maximum extent, by Lt. Francis Bradbury. Ice of local formation is blue, drifting ice is pink, mixed formations are lavender (1875)

The Experimental Worlds of Charles S. Peirce

Charles Sanders Peirce came to the Survey courtesy of Bache, and then stayed with the Survey through his father Benjamin, when the elder Peirce was Superintendent. As was presented in the Peirce chapter, C.S. Peirce was the pioneer in Survey experimental work with many subjects, including gravitation. He established a pendulum station on the summit of Hoosac Mountain in western Massachusetts, which has a celebrated railroad tunnel and many access tunnels thorough it. The tunnels allowed the geological structure of the mountain to be known in great detail. Peirce used that structure and the local topography to create a model of local mass around the pendulum station, which allowed him to correct his gravitation measurements and also correct for the local contribution to astronomical deflection of the vertical. It also allowed him to create another chart in the Survey's 3000 series. It has got to be the most singular contoured topographic map ever published by the US government.

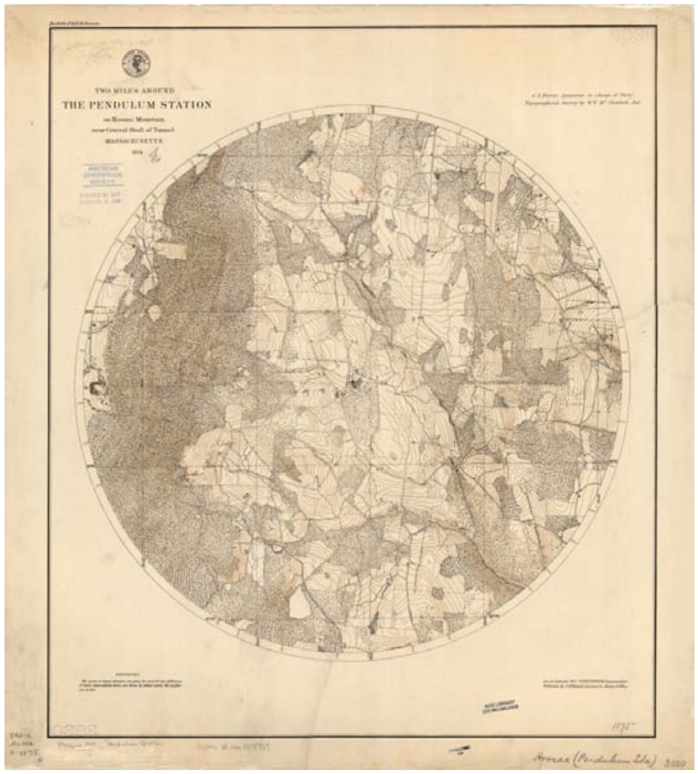
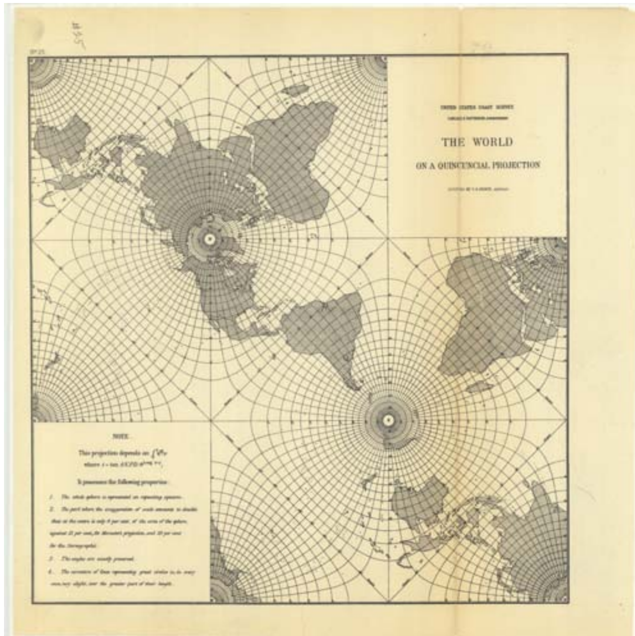


Chart 3030 Two Miles around the Pendulum Station on Hoosac Mountain, MA
near Central Shaft of the Tunnel by C.S. Peirce (1874)

During the Patterson era, Charles A. Schott and others published a series of appendices presenting and analyzing many disparate world map projections which could be used for various purposes. C.S. Peirce developed several new projections of his own especially his quincuncial projection. Peirce also was increasingly responsible for research on measurements and standards in the Office of Weights and Measures.



Sketch No. 25 The World on a Quincuncial Projection, by Charles S. Peirce (1877)

Patterson's Finale

Carlile Patterson was above all else the First Captain of the Survey, a master mariner, the chief hydrographic inspector for the nation. Under Patterson, the Survey did new and superb work in identifying and presenting hazards to navigation to keep mariners safe at sea. In 1878, Amherst College made Patterson an "honorary graduate" of the college, with the degree of Doctor of Letters (LL.D).

But under Patterson, for the first time, the Survey also produced charts like this final masterpiece: an aid to navigation to amusements, and to a class of mild hazards that were perhaps only self-inflicted: The US Coast and Geodetic Survey's chart of the excursion railroads, amusement parks, hotels, casinos, and bathing facilities of Coney Island.

Coney Island, New York as surveyed in 1878 and 1879 (1879) 25 cents.

On August 15, 1881, Carlile Patterson died suddenly at the family's great estate Brentwood, in the country outside Washington. Patterson began his tenure as Superintendent in the first smooth transition of leadership the Survey had ever seen; the sudden death of Hassler, and the prolonged incapacitation and decline of Bache had presented crises to the Survey and its allies. Patterson's sudden death plunged the Survey once again into crisis. Unfortunately, this crisis was not one to be resolved by an apt appointment of the correct successor. This reflects, in part, the choice of Patterson's successor and his fate, but it also reflects a larger and darker and more turmoiled context of the Survey and other enterprises in the federal government. As the first of many memorials and obituaries began to appear in the wake of Patterson's death, one noted presciently:

"When Patterson succeeded Benjamin Peirce It was a time of general commercial depression, when all appropriations were cut down close to, and often below, the point of efficiency. This was the case with appropriations for the Coast and Geodetic Survey, and the full powers of the Superintendent were put forth to keep unbroken the organization of the work, knowing well that once seriously impaired it could with difficulty be restored. This struggle the late Superintendent successfully maintained, despite every obstacle, to the close of his administration, and his death took place at a time when a bright prospect appeared in view".[33]

The Coast and Geodetic Survey and its people would spend at least the next two decades looking for another bright prospect to come in view.

[33] Carlile P. Patterson: Secretary Windom's Tribute to a Valuable Officer. The National Republican, Washington DC, Aug. 22, 1881.

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The New "Epoch of Metrology" and the Tenure of Thomas C. Mendenhall in the Coast and Geodetic Survey 1889-1894

Mendenhall Glacier near Juneau, Alaska. named in 1892 for Superintendent Thomas Corwin Mendenhall

Science, Congress, and Grover Cleveland

As the premier scientific agency in the US government, the Coast and Geodetic Survey had never been immune to changing administrations and Congresses and their dictates and budgets. But the tenure of Thomas C. Mendenhall (1889-1894), although productive and largely brilliantly successful, occurred in the middle of the darkest period in the history of the Survey. For the first time in the Survey's history, the leadership of the Survey and their tenure was almost entirely determined by Presidential administration. Grover Cleveland was the Democrat President from 1885 to 1889, Republican Benjamin Harrison was President from 1889 to 1893, and Cleveland returned as President in 1894 to 1897. The dates of those administrations correlate precisely with the disgrace and resignation of Superintendent Julius Hilgard in 1885, Superintendent Frank M. Thorn's tenure from 1885 to 1889, Superintendent Thomas C. Mendenhall's tenure from 1889 to 1894, and the coming nadir of the Survey, Superintendent William Duffield's tenure of 1894 to 1897. To the standard difficulties of the Survey, which included constant struggles with Congressional budgeting and periodic attempts by the Navy to take over the Survey, was added the additional burdens of major changes in senior management in response to the Presidential tide changes.

This Gilded Age, as Mark Twain called it, saw a largely progressive change in federal employees increasingly shielded from politics by the development of Civil Service positions in lieu of patronage appointments by election winners. But these changes occurred mainly at the lower levels of employment in government bureaus. Superintendents and key top staff members now served for specific Presidential tenures. To further complicate matters, much of their productive time and energy was now devoted to managing and/or fending off political appointments to leadership positions, or threats of such appointments. The result was an era of periodic instability at the top, coupled to depressed funding and even declining wages for Survey personnel, as the field expenses monies that had been a de facto supplemental income were reduced or eliminated during the Thorn tenure. Further, as a result of the Hilgard scandal and the Allison Commission, all funding for the agency was under much closer scrutiny by Congressional committees and the auditors of the Department of the Treasury.

On the other hand, the Survey had survived several perilous attempts to dismember it, and the Allison Commission had largely validated its status and significance as the leading scientific agency in the federal government. Further, the Survey was at the forefront in American participation in increasingly internationalized science, which was noted and appreciated by American politicians even when they were entirely ignorant of the science involved. Superintendent Thorn had been brought in as essentially a trusted operative of President Cleveland, and one with broad positive experience in managing government operations. He was the first non-scientist to head the Survey, but he had proved quite successful in rescuing the Survey from the disgrace of Hilgard and his attacker Chenowith. But Thorn, especially, advocated that a proper scientist should succeed him for the good of the Survey.

In 1888, Cleveland ran for re-election for a second term against the Republican candidate Benjamin Harrison. The Republicans were both well organized and corrupt. In New York, Cleveland's own state, they formed an alliance with the New York City and Albany based Tammany Hall to counter Cleveland, the hated Buffalo-based reformer. Although Harrison received 100,000 fewer votes than Cleveland, Harrison controlled the votes in the Electoral College, and Cleveland was defeated.

The new President Harrison appointed William Windon as his Secretary of the Treasury. Windom, a Republican from Minnesota, had served in the House and Senate, and had been Secretary of the Treasury once before, under President Garfield. Harrison and Windom, and no doubt others, decided on a successor to Superintendent Thorn. This took some time. They came into office in March, 1889. The new head of the Survey was announced on July 9th, 1889.

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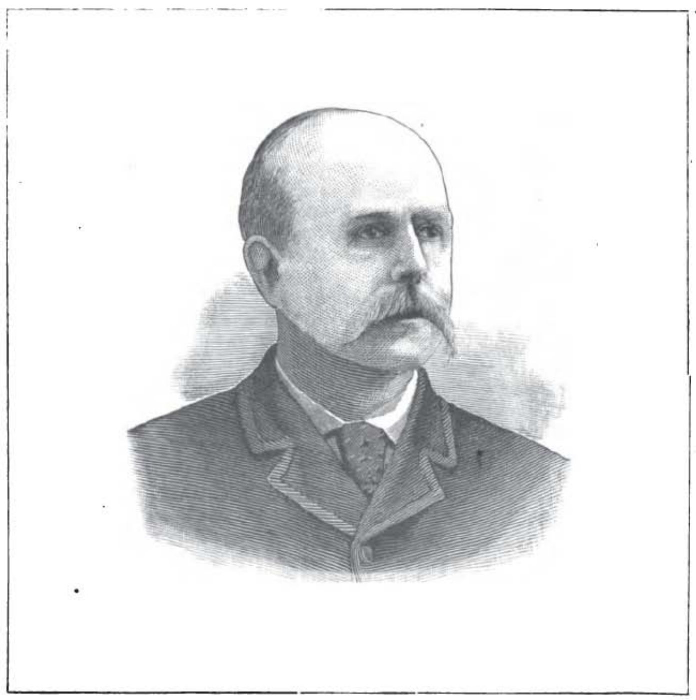


THOMAS C. MENDENHALL,
President of the American Association of Science.

Thomas Corwin Mendenhall (1841-1924)

The Soil Underneath Mendenhall's Scientific Tree

Thomas C. Mendenhall had a singular career in American and international science. Hugely productive from an early age, he did pioneering research in a variety of scientific disciplines. Formidably intelligent yet kind and balanced, he played many roles in a long life, and generally rose to leadership positions wherever he went. He was, more than anything else, a master educator, beginning as a village teacher in Ohio. He ended as a learned professor, under that definition of a professor devised by President Gilman of Johns Hopkins University, that a professor was "a student who can also teach".[1]

[1] As cited in Crew, 1925, p. 336.

Mendenhall was born into a Quaker family on a farm near Hanoverton, Ohio, in 1841. Like so many others who ended up in leadership positions in the Survey, he was a fervent Abolitionist. Every year, his family made the pilgrimage to Salem, Ohio, "the western center of the anti-slavery movement" where they would listen to William Lloyd Garrison and Sojourner Truth and other leading lights of the movement. He attended public schools, and also learned independently from books and teachers he found here and there. He ended up in Southwest Normal School, in Lebanon, Ohio. In 1861, he graduated with the degree of *Institutor Normalis*, or Normal Instructor, which was the only degree he ever earned.[2] As a young village schoolteacher in Salem, he celebrated with the rest of this celebrated Ohio community when news came that Lee had surrendered and the war was won. Near the end of his long life, he recalled vivid details of the celebrations that followed. He noted that, for the people of Salem, it was the end of not just four years of war, but also forty years of struggle against slavery.[3]

By 1866, Mendenhall was elected Superintendent of Schools in Butler County, Ohio. In 1868 he became Principal of a school in Columbus, and later that year an instructor of mathematics and science at Columbus High School. There he departed from traditional instruction techniques involving recitation, and instead created a real laboratory. "'Home made' appliances were designed and constructed of lamp chimneys, fruit jars, bonnet wire, and other accessories that one could buy at small cost in the city stores…. From the Western Union telegraph Company he borrowed a discarded 'registering telegraph receiving instrument' which, after being subjected to much labor, would run at a fairly uniform speed. This instrument served as a chronograph for the study of falling bodies and the determination of the frequency of tuning forks, the time element being measured by a seconds pendulum which was perfected to an accuracy of two-hundredths of a second".[4] Mendenhall and his students made experiments in many fields of what would now be called sensory perception and experimental physiology. He also used the rotunda of the state capitol in Columbus to create a Foucault's Pendulum one hundred twenty feet long.

In July, 1870, he married Susan Allen Marple. They were wedded until her death forty-six years later. They had one son, Charles Elwood Mendenhall, who became a physicist.

In 1873, Mendenhall was nominated to be the first instructor of physics and mechanics at the new Ohio Agricultural and Mechanical College. The institution later changed its name, and hence Mendenhall was the first faculty member of Ohio State University. In 1876, for the great centennial celebration of the Fourth of July, he displayed an electric arc light on the top of the state house dome.

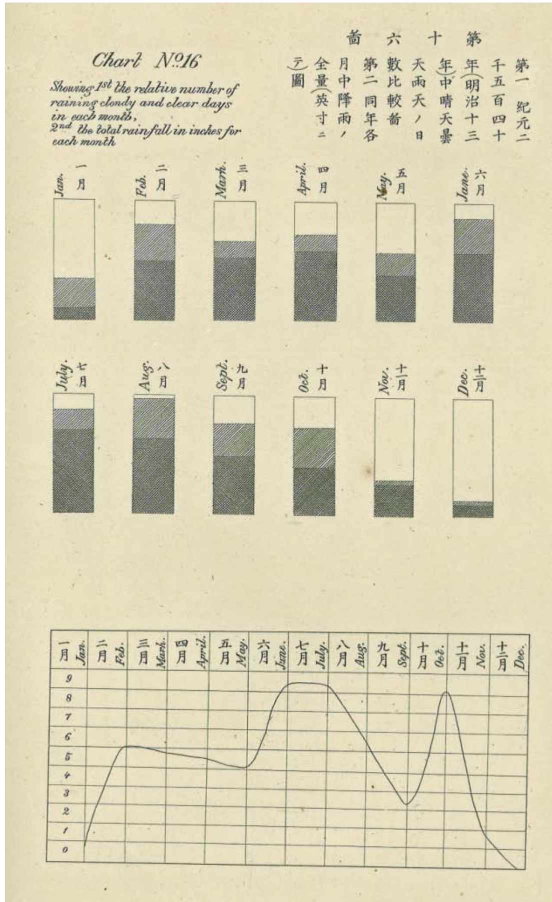
Science and Calamity in Tokio

[2] Siebert, 1925, p.2
[3] Mendenhall, 1922, p. 3.
[4] Siebert, p. 5.

In 1878, Mendenhall was nominated to go the new Tokio Daigaku, the Imperial University, in Tokyo (Tokio in Mendenhall's treatise) Japan, as a professor of physics. He and his family lived in Tokyo from 1878 to 1881. As might be expected from his career in Ohio, he engaged in a wide range of research and teaching. One of his new fields of study was meteorology, although even here his interest in sensory perception continued. "Early in the present year a telegraph line connecting the Observatory with the physical laboratory was completed which will without doubt prove to be a great convenience. One of the special considerations which led to its construction was the desirability of taking advantage of the exceptionally favorable conditions for the study of the velocity of sound. At 12 M. of each day a time gun is fired which can be distinctly heard at both the Observatory and the University… It is expected that in this way a large number of observations upon the transmission of sound under widely varying meteorological conditions will in time be secured, which may contribute to the solution of a problem of very considerable importance. Although not a question pertaining strictly to meteorology it is one of great interest and it is hoped that a considerable series of results may be ready for the next general report."[5]

Mendenhall and his students and staff recorded baseline meteorological data from their observatory, and published the results with simple but elegant and effective graphics.

[5] Mendenhall, 1879, pp.41-42.



Monthly totals for rain and raining and cloudy days
For 1879 as measured at the Tokio University Observatory

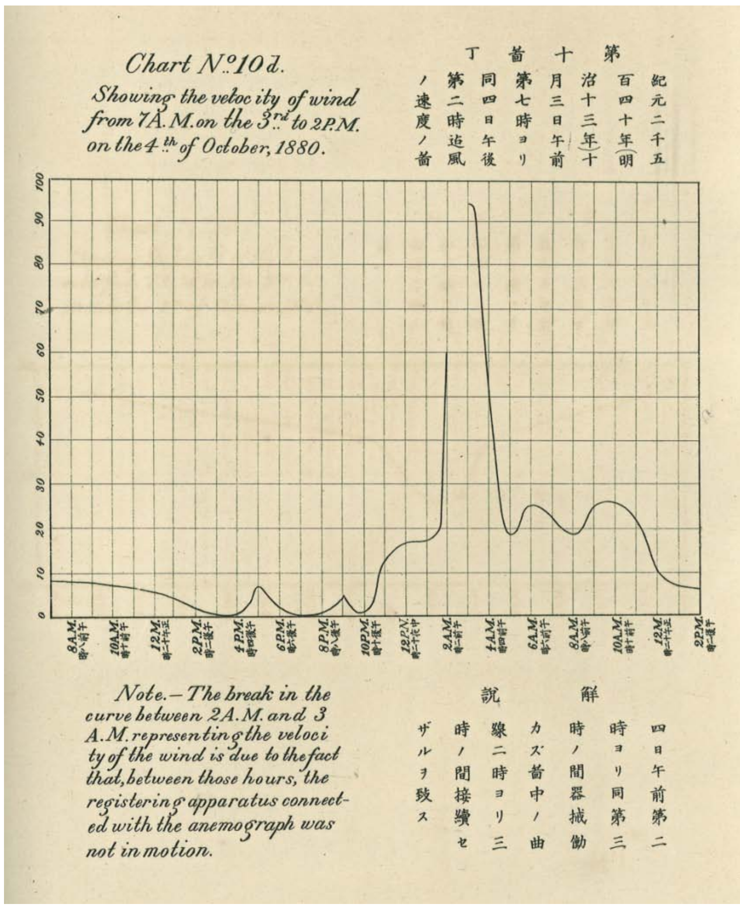
Mendenhall used a set of half second pendulums to measure the force of gravity at Tokyo and also on the summit of nearby Mount Fuji (called Fujinoyama in Mendenhall's treatise). In this, he closely paralleled the earlier work of Charles S. Peirce of the Survey.[6]

Mendenhall, possibly because of his Quaker background, took great notice of calamities and disasters around him in Tokyo, and attempted to apply his theoretical and experimental skills to address them. One arena was that of the frequent and destructive earthquakes of Japan. "There is another phenomenon which, although not strictly meteorological, is of such interest and importance to all residents of Tokyo, and indeed of Japan, as to demand attention and investigation whenever and wherever possible. Much attention has already been given in this country to the study of the phenomenon of earthquakes, and a great variety of seismographs have been constructed and used in their observation. Some of these are very complex… while others are more simple in their construction… While I would not recommend the construction or purchase of any complex registering apparatus for use in the meteorological observatory, I regard it as

[6] Mendenhall, 1881.

highly desirable to erect some simple indicator, which may not be liable to get out of order and which, in connection with some of the time cylinders in use, or to be used in the observatory, may indicate the time of the shock, certainly, or with the smallest of failure. If we shall succeed in this one determination with unfailing, certainly the result will be a contribution of no small value and well worth the trouble and expense which will be rendered necessary."[7]

Another major problem he addressed were the infrequent yet hugely destructive typhoons that swept over the city. One specific storm struck the city on October 4th, 1880. Mendenhall studied it in detail.



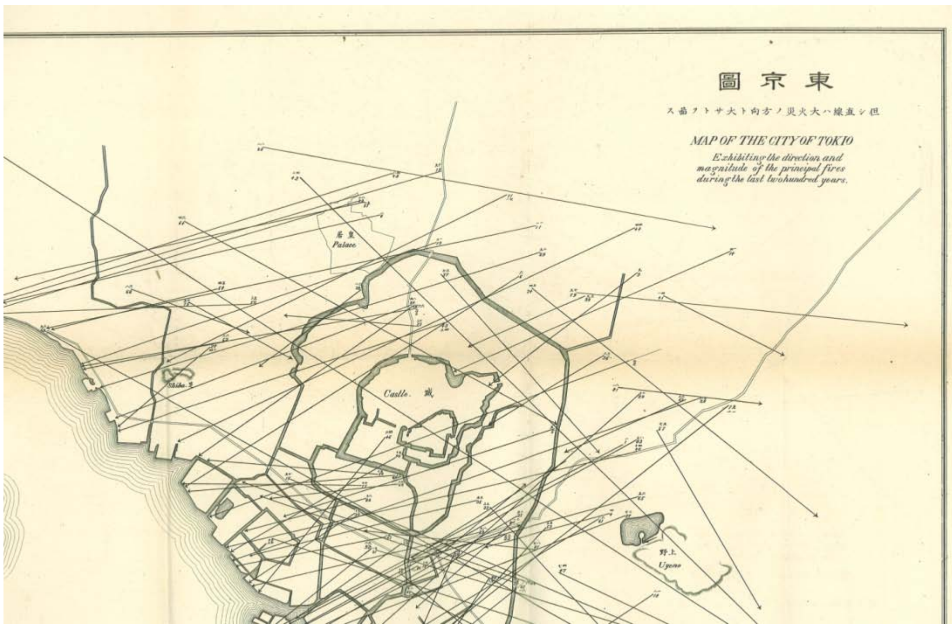
Wind velocities on Oct. 4, 1880 as measured at the Observatory

Characteristically, Mendenhall mused that it would be possible to develop a storm warning system for the public good. "In conclusion, it may safely be said, especially in view of the damage done to buildings, shipping, etc. that this was one of the most violent storms experienced here for many years. From facts already known concerning other points along the coast of Japan, it would seem that, had an efficient system of

[7] Mendenhall, 1879, p. 42.

observations, telegrams, and signals existed, timely warning might have been given of its approach and, possibly, much property and many lives saved.”[8]

Mendenhall’s final research arena was that of fires in Tokyo. The city was famously constructed of wood and paper, and densely populated, and when fires occurred, especially under high wind conditions, the resulting damage could be enormous. With Professor K. Yamagawa, Mendenhall prepared an analysis of Tokyo fire behavior for the previous 200 years.



Detail from Fire Direction and Damage Scale for the last 200 Years
In Tokio, prepared 1880

In 1881, Mendenhall and his family returned to what was now Ohio State University. Following the trajectory established in Tokyo, he was now becoming a specialist in the physics of meteorology. He also spent more time as a lecturer in science, which brought him to attention outside of Ohio. “The lecture season at the Lowell Institute in Boston is drawing to a close…This year an unusual variety has been offered, and the audiences have been large and attentive… These series were followed by a course of six lectures on Motion and Matter by Professor Thomas C. Mendenhall of the Ohio State University, beginning Dec. 4.”[9]

Mendenhall comes to Washington and the Signals Service

And thus, in 1884, he was called to Washington to his first stint as a federal scientist. He served two years as a Professor of Electrical Science in the U.S. Signal Service, the predecessor of the Weather Bureau and the National Weather Service.

[8] Mendenhall, 1880, p. 27.
[9] Science, 1883, p. 236.

Signal Service Headquarters, 1880
From Frank Leslie's Illustrated Newspaper

At the Signal Service Mendenhall was introduced to the practice of science in the federal government, and also in a sense to the Coast and Geodetic Survey. The chief scientist of the Signal Service was Cleveland Abbe, assisted by William Ferrel, both of whom had been employed in the Coast Survey at earlier stages of their careers. Near the end of his long and active life, Mendenhall returned to those years in the Signal Service, as a part of the memoir written after the death of Cleveland Abbe. Mendenhall wrote a uniquely detailed and reflective account of Abbe and the Signal Service and its science and its awkward place in the US Army which is worth examining, in part for the perspective it gives on his subsequent return to Washington to lead the Coast and Geodetic Survey.

> "Although the years of my acquaintance with Professor Abbe were nearly fifty in all, my intimate association with him began about a third of a century ago. It was in the 'early eighties' of the last century when the Weather Bureau was the Signal Corps of the Army or the Signal Corps was the Weather Bureau, both modes of stating the relation of the two being essentially correct, as for many years the operations of the Signal Corps were practically restricted to its activities as a weather forecasting service. In order to understand and appreciate the almost unique combination of qualities, moral and intellectual, which enabled Abbe to play his great part in the creation and development of what is in many respects the most important of the scientific bureaus of the Government, it is necessary to know something of the conditions under which he worked during the earlier stages of that development.

"At thirty years of age, as the enthusiastic director of the Cincinnati Observatory, he had successfully inaugurated a system of weather reports by telegraph from which daily forecasts were attempted. His success led to an act of Congress providing for the utilization of the Signal Corps of the army for the organization of a general weather service, and Professor Abbe was called to Washington as meteorologist in that service. At that time he was the only man in the country having experience in or knowledge of weather forecasting for the use of the public based upon the principles of scientific meteorology, and for some time the duty of daily interpreting the meteorological observations made in all parts of the country devolved upon him alone. The new service was immediately popular, and though barely thirty years of age, he soon became generally known as 'Old Probabilities,' or 'Old Prob.' Realizing that the then state of our knowledge of meteorology was quite inadequate for anything like accurate forecasting, he sought to induce the War Department to obtain an annual appropriation for the purpose of maintaining a systematic study of the subject, both theoretical and experimental. Methods of transacting business assumed to be necessary in a military organization in time of peace are decidedly inimical to scientific investigation and research, and from the start Abbe's plans met with obstruction at almost every turn, not always due to unfriendliness-indeed more often to mere inertia of the system. In overcoming this opposition, which at times was so unyielding as to completely discourage all others who were interested, he was successful, because of his two most characteristic traits were an inexhaustible enthusiasm for the work, which amounted almost to an obsession, and an equally inexhaustible patience in meeting unfriendly or unintelligent criticism.

"I think not much was actually accomplished until Gen. W.B. Hazen became Chief Signal Officer in 1880. For the two great advances made during the first few years of his administration credit belongs to Abbe, almost if not quite alone. Certainly the initiative and general plans were his, though, of course, there could have been no success without the friendly support of the chief Signal Officer. Perhaps the most important of the two was the improvement of the character of members of the corps by means of a provision for special enlistment of young men, mostly college graduates, with the rank of sergeant in the Signal Corps, with exemption from most of the ordinary duties of the regularly enlisted soldier.

"The other was the establishment of what was known as the 'Study Room,' in which all meteorological problems arising in the service were subjects of investigation by civilians employed for the purpose, two or three of whom had the rank or title of 'Professor' and some others that of 'Assistant Professor,' and arrangement probably suggested by the practice of the military and naval academies. This was shortly supplemented by the establishment of a laboratory for experimental investigation, the inauguration of which I undertook at the earnest solicitation of Professor Abbe in 1884.

"The study room and the laboratory formed, also, a sort of school for the enlisted men, to whom courses of lectures on meteorological, physical, and allied topics were given. The distinguished meteorologist, William Ferrel, was one of the professors, and in addition to a part in the instructional work his assignment embraced a theoretical investigation of the general principles of meteorology with a view to the improvement of the work of forecasting the weather. The vitalization of the service through these important changes resulted, happily, in the acquisition of such young men as Marvin, Fassig, McAdie, Morrill, McRae, Russell, and a number of others, some of whom are still in the service, and from several of whom have come in later years contributions to the science of meteorology of very great value.

"The difficulty of doing scientific work, either theoretical or experimental, under conditions, then existing, can be appreciated only by those who have attempted it, and it is because of Professor Abbe's extraordinary courage and success in meeting these difficulties that I am referring to them at such length. There was at that time a sort of tradition among military men-which may not yet be extinct-implying that a properly signed written order from a superior officer to do a certain thing carried with it not only the duty of doing it, but also the capacity to do it, which I imagine may be a rather stimulating idea for one engaged in battle, though of doubtful value in scientific research.
"Our duties were assigned to us in regular instructions or 'orders' from the chief Signal Officer, written on regulation order slips on which our initials were placed, as evidence that we had received and understood our instructions.

The North Side Offices of the Signal Corps, G St. Washington, DC

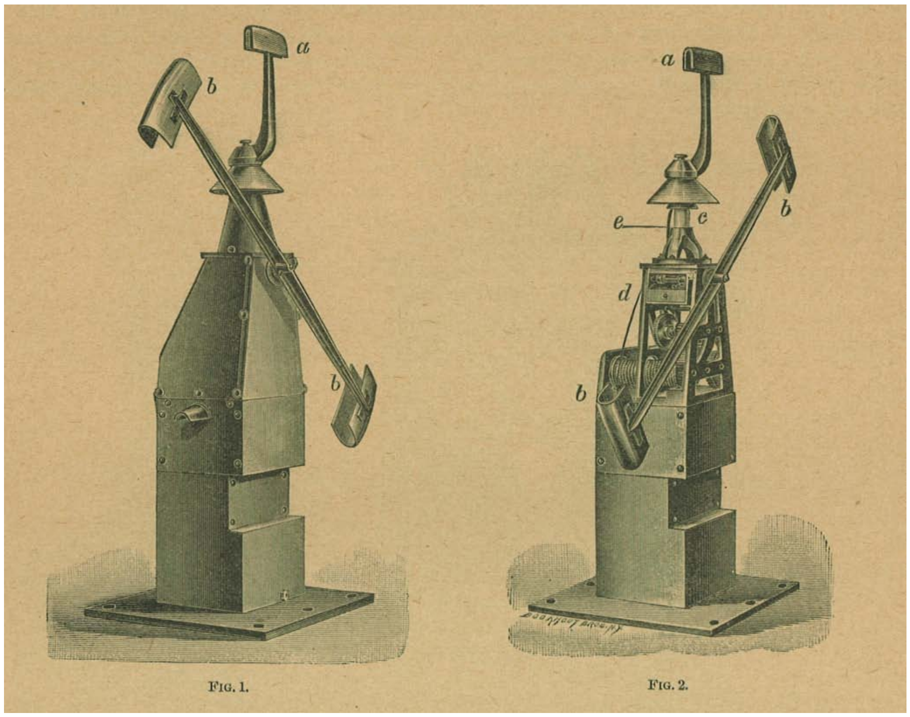
"The headquarters of the Signal Corps were at that time on 'G Street,' near the War Department, and by a curious chance the two somewhat conflicting elements were housed on opposite sides of the street, the study room, the laboratory, the instrument testing division, etc., being in one building on the south side, while the offices of the Chief Signal Officer and his military aides, the property and disbursing officer, the forecasting officers, etc., were on the north. That controversies between the two were on the whole rather infrequent and rarely acute was due, more than to anything else, to Abbe's unfailing good nature and general willingness to be the subject of the obloquy of both sides.

"The military tradition I have referred to above did not harmonize with the traditions and practice of scientific research. The most industrious and enthusiastic investigator would be somewhat dismayed by the receipt of 'instructions'-not much unlike the following: "you will begin on Monday next an investigation of the cause or causes of the attraction of gravitation, and make a preliminary report upon your work in two weeks. A final report is to be ready by the first of next month.' Unfortunately Nature does not yield her secrets in response to orders, and there were naturally many failures to 'get results' on time."[10]

Atmospheric Electricity

[10] Mendenhall in Humphreys, 1919, 479-481.

Mendenhall's major research project was the study of atmospheric electricity and its relationship to storms and storm systems. His major instrument was his modification of the water dropping collector device originally designed by William Thompson (later Lord Kelvin). Photographic exposures of the behavior of water droplets as influenced by atmospheric electrical potential allowed the changes in electric potential in the air to be detected at the site of the instrument.



Mendenhall's Modified Water Dropping Collector
Seen with housing and with housing removed

Mendenhall created a small network of collectors, their data and timing linked by the telegraph network that was at the heart of the Signal Service. As Mendenhall noted, the great distances between his collectors made it impossible to use them to examine any specific storm system collectively. Only in one instance, when he had two collectors, one mounted at the Signal Service headquarters, the other mounted in the observation room at the top of the Washington Monument, was he able to acquire one data set on the remarkable differences in electric potential at the ground and at elevation, as a summer thunderstorm moved over Washington.

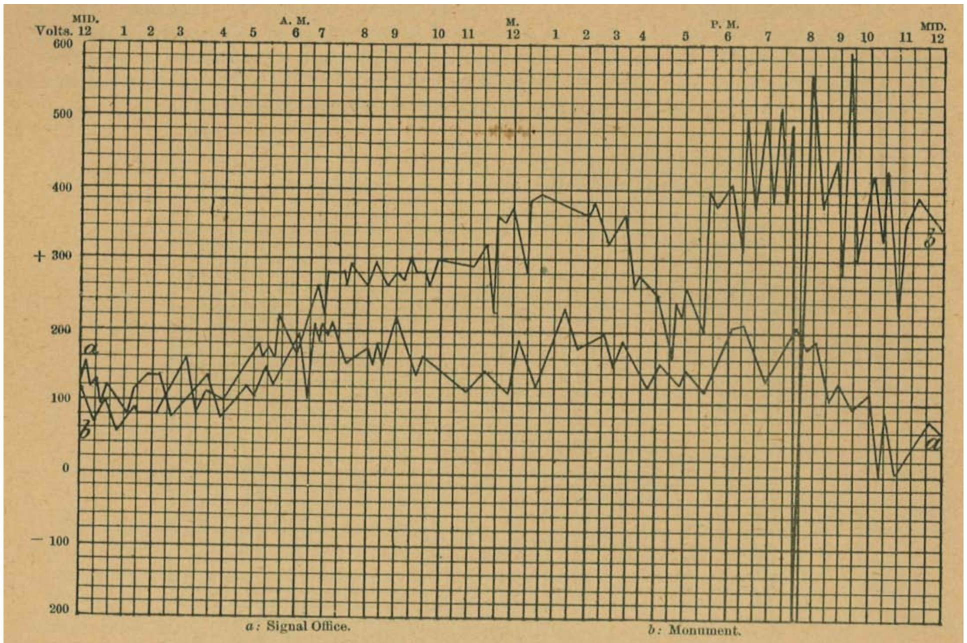


Fig. 14.—Curves showing variations of potential during a series of simultaneous observations taken on top of Washington Monument and at the Signal Office, Washington, D. C., June 27, 1886.

Variations in Electric Potential, June 27, 1886
Between the Signal Service office and the top of the Washington Monument
The great potential spike occurred as a lightning storm crossed over the Monument

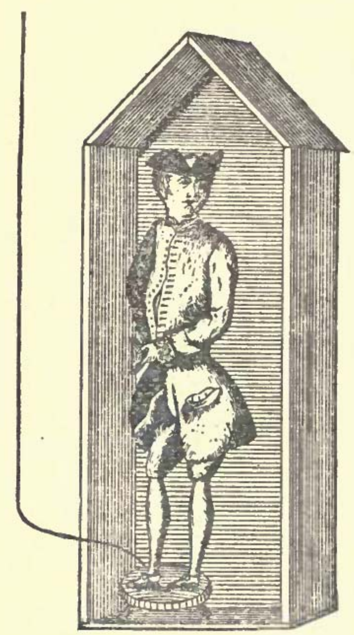
On August 31, 1886, the great Charleston earthquake struck the coastal areas and piedmont of South Carolina. Mendenhall was sent to the scene to describe and analyze the earthquake. His report on what he encountered, published in the Monthly Weather Review, includes some observations that harken back to his time in Tokyo, and his speculation about seismic networks and linkages between observers. “The table below contains a resume of information received at the office of the Chief Signal Officer from regular observers of the Service and from a number of voluntary observers. The time, place, supposed direction, duration, and estimated intensity are given. Much discrepancy will be observed in the records of time…A study of this column will show the great importance, in making such observations, of determining the error of the clock or watch at the earliest possible moment by comparison with the time of some known meridian. It must be said, however, that the extended use of standard time has rendered these results vastly more accurate than they otherwise would have been. Telegraphic time signals are now within the reach of most people, and during the last two or three years a great improvement in the accuracy of time-keeping among the people has taken place.”[11]

The Increasingly Public Mendenhall

Mendenhall’s first tenure in Washington ended when he was elected President of the Rose Polytechnic Institute in Terre Haute, Indiana. His return to teaching led to an elegantly written general history of the development of electrical science called *A*

[11] Mendenhall, 1886, p. 234.

Century of Electricity.[12] He begins the volume: "Within these hundred years there have been three notable discoveries in electricity, around which all others cluster, and from which they have all grown. These three have immortalized the names of Galvani and Volta, Oersted and Ampère, and Faraday."[13] Mendenhall would in turn "re-immortalize" these foundational scientists by giving their names to the definitions of the fundamental electrical units.



Method of drawing electricity from the clouds suggested by Franklin. Enlarged from cut accompanying his original paper.

From Mendenhall's *A Century of Electricity*

Finally, Mendenhall was elected to increasingly higher positions in the infrastructure of science in the United States. By 1882, upon his return from Japan, he was elected Vice President of Section B (Physics) of the Association for the Advancement of Science. He gave a concluding address at the end of his term which sounded a theme which resonated throughout his career, and one that is fundamental to understanding his tenure as Superintendent of the Survey. He noted:

> "We are mistaken if we suppose that science is advanced only through contributions which are the results of original research in our laboratories and libraries. Even if so narrow a view be taken, it will be admitted that the talent for research is fostered and encouraged, if not,

[12] Mendenhall, 1888.
[13] Ibid., p. 221.

> indeed, created by an atmosphere of recognition and appreciation. The existence of such an atmosphere is in itself a blessing and its production is certainly worthy of our highest efforts. To this end it is desirable and necessary to bring about a more general diffusion of accurate knowledge concerning the elementary principles and propositions of the science of physics, as well as some degree of familiarity with the methods of physical investigation. I do not refer, of course, to the demands or the necessities of those who expect to undergo a course of training for the purpose of becoming themselves physicists; but rather to the diffusion of this knowledge among the masses of the educated people in general. That this diffusion is not taking place to any great extent and will not, according to natural laws alone, is patent to any observing physicist, who cannot fail to have come in contact with prevailing and pernicious errors, which often carry the weight of repetition, and now and then of recognized authority. I am aware that this is not an association of educators, and that pedagogics is not, as yet, one of the sciences specifically indicated as worthy of advancement at our hands; but if the growth of a tree is to be made healthy and permanent it is not safe to neglect the soil into which its roots penetrate. Train it and prune it as you will, to grow into vigor and strength, it must spring from a generous earth which, though beneath it and below it, must be in harmony with it in order to supply the proper and necessary materials for its sustenance."[14]

Mendenhall's summation as Vice president of the AAAS section marks an apex in his Quakerish optimism about nurturing the soil from which the scientific tree will flourish. After his first round of federal science in the Signal Service, and at the end of his tenure as President of the AAAS, he sounded a more nuanced and troubled theme, reflecting what he had learned in the years since. His reflections would prove a prescient foreboding for his future second career in federal science:

> "It is generally recognized that, aside from all questions of a particular political nature, this country is to-day confronted by several problems of the utmost importance to its welfare, to the proper solution of which the highest intellectual powers of the nation should be given. The computation of the trajectory of a planet is a far easier task than forecasting the true policy of a great republic, but those qualities of a human intellect which have made the first possible should not be allowed to remain idle while an intelligent public is striving to attain the last. That men of science have not, thus far, made their full contribution to the solution of some of these great problems is due to the fact that many have exhibited an inexcusable apathy towards everything related to the public welfare, while others have not approached the subject with that breadth of preparation in the close study of human affairs which is necessary to

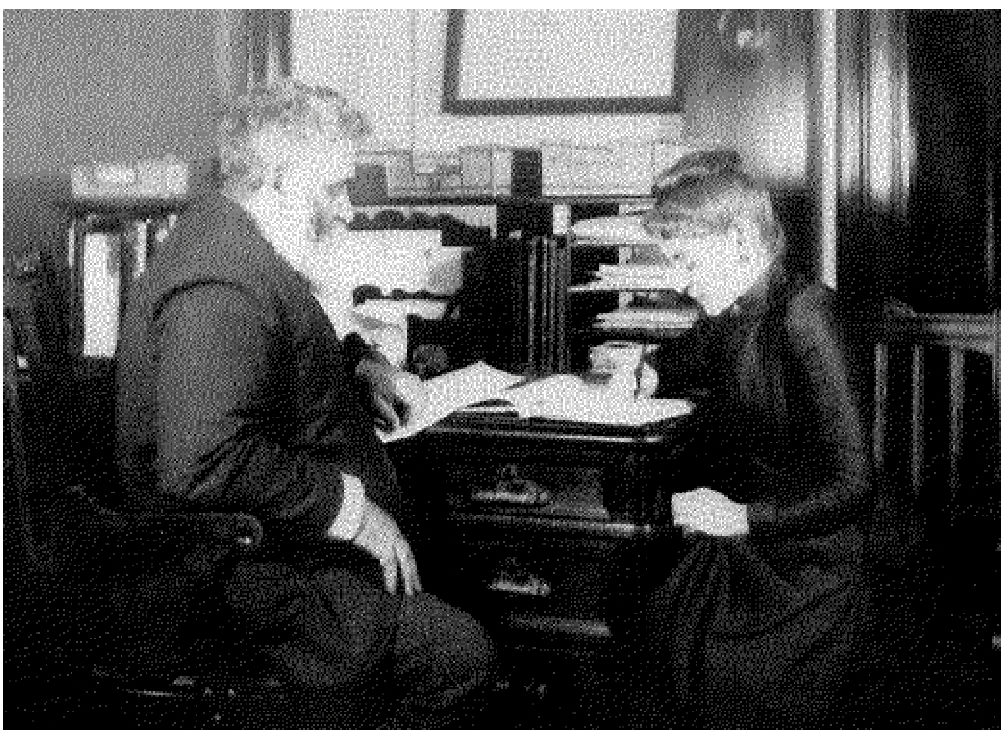
[14] Mendenhall, 1882, p. 5.

> establish the authenticity of their equations of condition. As already intimated, we do not seem to be getting on in this direction."[15]

The Coast and Geodetic Survey as Mendenhall found it

The Survey had survived many crises when Mendenhall arrived, but its stability was fragile. The shift in the White House from Cleveland to Harrison had ended—or actually just postponed—certain threats to the agency, but the see-sawing balances of power between the Democrats and Republicans in both the House and the Senate kept the agency's budget uncertain, and additional threats to turn the Survey over to the Navy were likely, as they had been for decades. Mendenhall, to be effective, would have to work fast. For the first years of his tenure, he was quite successful, but then the Survey's fortunes turned.

The effective leader of the Survey was Benjamin Colonna, who had proved critical to Thorn's tenure because Thorn knew neither the agency or its science. Mendenhall, although not a geodesist, had become a proficient scientist and learned quickly. So Mendenhall and Colonna continued in a partnership in managing the agency. Colonna also forged another partnership.



Benjamin Colonna and Fannie Bailey at Survey headquarters
Undated photograph from B. Colonna's biography by Judith Scharle

[15] Mendenhall, 1890, p. 12-13.

Fannie Bailey had worked as a secretary to Colonna since 1885. When she was absent with a family emergency for several weeks, Colonna realized how much he missed her, and that he was in love. He proposed, and in 1890 they wed in Washington. Their marriage was successful, and was also possibly the only documented relationship between any personnel in the Coast and Geodetic Survey.

Mendenhall's tenure was short enough that perhaps the best way to summarize the Survey in his tenure is to divide the coverage between Survey work that was the continuation or accomplishment of previous efforts presented first, followed by activities that began under his tenure, or that displayed his particular stamp.

Major Circles Closing and Projects Completed

In 1881, Congress had ended the division of the District of Columbia between the City of Washington and the County of Washington. From that point on, the entire District was to be administered as a unit. The Army Corps of Engineers had mapped the City several times. With the unification of the District, the former county lands and developments remained to be mapped. The Survey was given the task. It took almost a decade, reflecting the detailed scale of the mapping (1:10,000 scale), the densely rugged terrain and the thickets of vegetation that had regrown after the denudation of the Civil War, and the fact that mapping work in the District was often reserved for what would have been the office season for topographers working on isolated coasts. Under Mendenhall, the last of the maps of the District were completed.[16]

[16] See Baker, 1894 for a thorough summary of the Survey's mapping project in the context of cartography of the District in the 19th century.

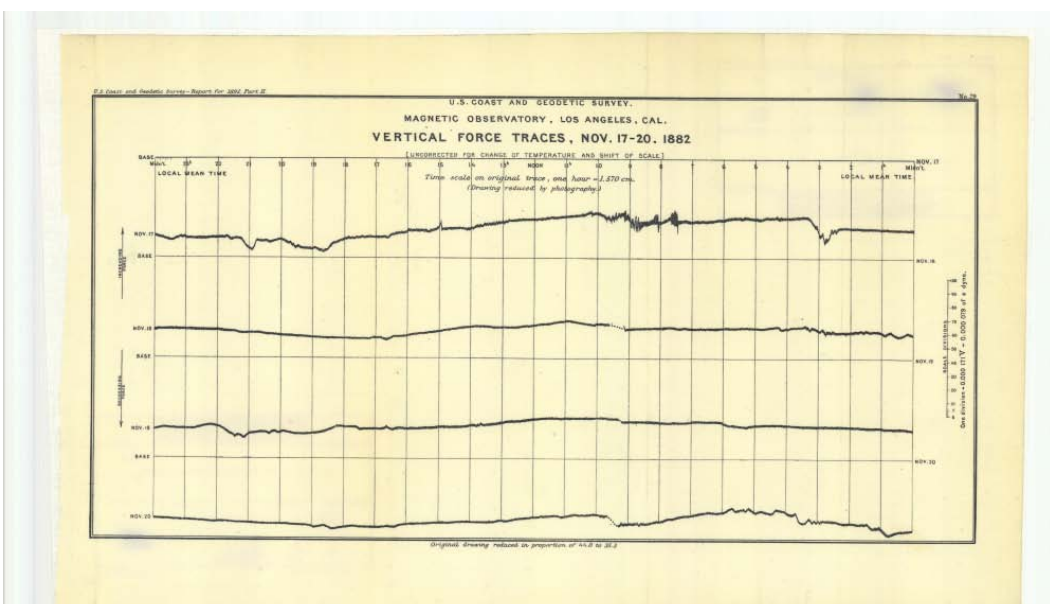
District of Columbia Sheet No. 34, 1892 The unmapped lower right-hand corner is the former City of Washington, the mapped area part of the former County

From 1882 to 1889, the Survey had maintained a magnetic observatory in Los Angeles, California, the first long-range outpost of magnetic research outside the east coast. The key instrument used was an Adie recording magnetograph that A.D. Bache has purchased during the Civil War.

FIG. 5. Adie magnetograph as operated at Los Angeles, California, later at San Antonio, Texas, and now at Cheltenham, Maryland.

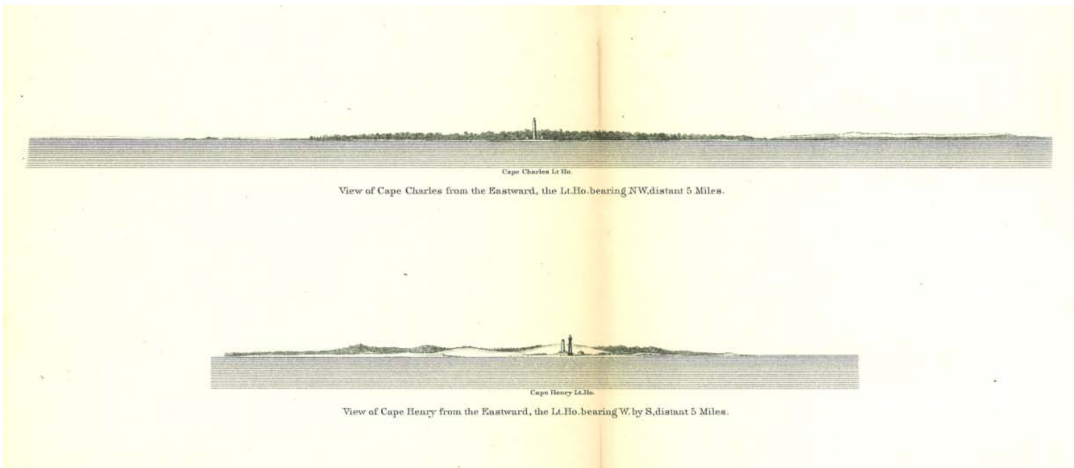
Adie magnetograph

The Los Angeles observatory was moved and re-assembled in San Antonio, Texas. For the next three years, Charles A. Schott analyzed the Los Angeles data, and published descriptions and analysis of the data in the annual reports.



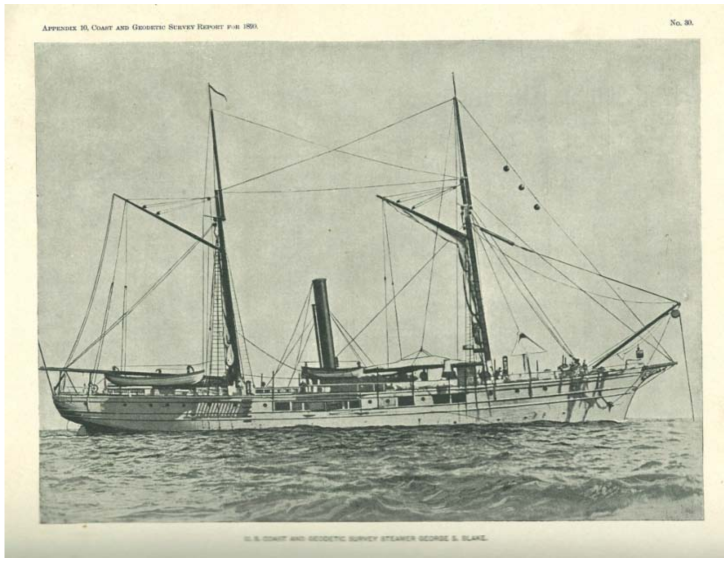
Vertical Forces Traces of the Great Magnetic Disturbance,
November 17-20, 1882. Figure No. 22, 1892

In the 1870s, the Atlantic Local Coast Pilot series had been published, a culmination of the project initiated in 1867 when the Survey acquired the Coast Pilot franchise from the Blunt family. A decade later, there had been so many changes to ports and navigation along the Atlantic coast that a major revision was necessary. The original series was called “local” because the 22 volumes each covered only small areas of the coast. The revised and republished series, now called the Atlantic Coast Pilots, consolidated the material into seven parts published in six separate volumes. For whatever reason, there had never been a Local Coast Pilot volume for Chesapeake Bay. The new series included Chesapeake Bay, and utilized the coastal views originally drawn by John Barker in the 1870s, but never before published.



Views of Cape Henry and Cape Charles, at the mouth of Chesapeake Bay,
By John Barker, 1891

The Survey’s major research in deeper water hydrography and the structure and currents of ocean basins really began in 1874 with the launching of the steamer George S. Blake, which, along with its “sister’ ship the Albatross of the US Fish Commission, were the great American oceanographic research vessels of the 19th century. Lt. Commander John Elliott Pillsbury perfected deep ocean anchoring, which, in conjunction with newly designed current meters and other instruments, allowed the three-dimensional structure of the Gulf Stream to be investigated.



The Steamer *George S. Blake* 1874-1905

These culminated in 1890 and 1891 with Pillsbury's publication *The Gulf Stream*, considered to be among the best series of oceanographic observations from its century. Pillsbury was a forceful writer, and his text is a classic in its conveying some sense of the enormous powers of the ocean:

> "Man stands with bowed head in the presence of nature's visible grandeurs, such as towering mountains, precipices, or icebergs, forests of immense trees, grand rivers, or waterfalls. He realizes the force of waves that can sweep away light-houses or toss an ocean steamer about like a cork. In a vessel floating on the Gulf Stream one sees nothing of the current and knows nothing but what experience tells him; but to be anchored in its depths far out of the sight of land, and to see the mighty torrent rushing past at a speed of miles per hour, day after day and day after day, one begins to think that all the wonders of the earth combined can not equal this one river in the ocean."[17]

New Frontiers under Mendenhall

The Coast Survey as such really stabilized and took its form under A. D. Bache. Perhaps nothing was as constant in the Survey than the massive folio volumes of the annual reports that Bache had initiated. These were, in effect, a scientific journal that published one issue a year. There were advantages to that, but also disadvantages, which became increasingly apparent as the scientific status and reach of the Survey expanded. Under Thorn the Survey had begun to publish Bulletins, which were essentially specific scientific appendices published by themselves. Mendenhall himself wrote one of the most important of them, which will be discussed in the final section of this chapter,

[17] Pillsbury, 1890, p. 462

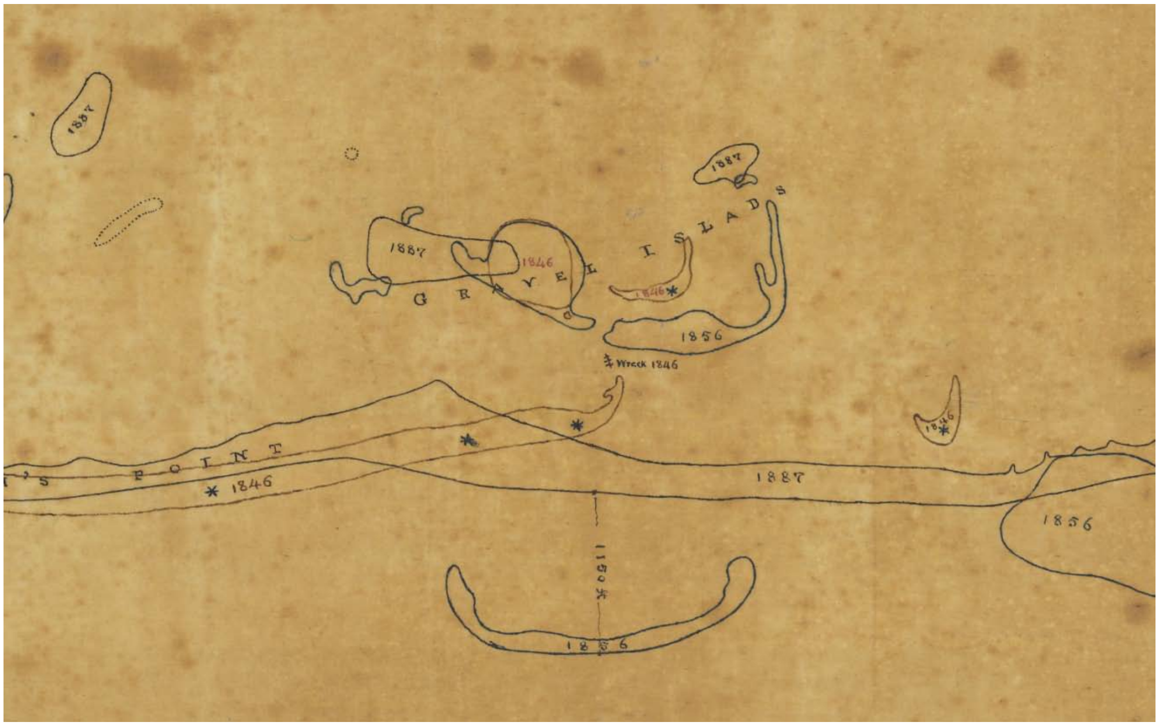
featuring the Coast and Geodetic Survey at the World's Columbian Exposition of 1893, which was in many ways Mendenhall's finale with the Survey.

Mendenhall continued the Bulletins, but reduced their size from quarto (8½ by 11 inches) to octavo (5 ½ by 8 inches) to make their distribution easier. He also divided the annual reports into two sections: Part I, the historical section, represented the reports of progress form the various divisions in the various sections, while Part II, reduced to octavo size, included "the professional papers related to the methods, discussions, and results of the Survey which have been approved for publication during the year. Such illustrations as are needed accompany them….In the future distribution of the Report, Part II only will be sent, as it is believed that this will include all that is generally desired, and in a much more compact and convenient form than that of the old quarto".[18] It should be noted that this division for the annual reports into two sections was discontinued once Mendenhall resigned.

The Survey continued its usual series of harbor charts, nautical charts, and sailing directions, updating them as they could, given the dueling tensions of lowered budgets and fewer personnel versus rapid changes in the American coasts and maritime transport systems, which required updating charts and mapping new harbors. In this, the Survey was a major participant in the very processes that were changing the coasts. This can be seen in the introduction to Henry Marindin's 1892 appendix no. 8, "On the changes in the ocean shore lines of Nantucket Island, from a comparison of surveys made in the years 1846 to 1887 and in 1891". Here Marindin is embracing the full span of the modern Survey under Bache, through the decades of research by his mentor Henry Mitchell, to his own work as Mitchell's successor as the Chief of Physical Hydrography.

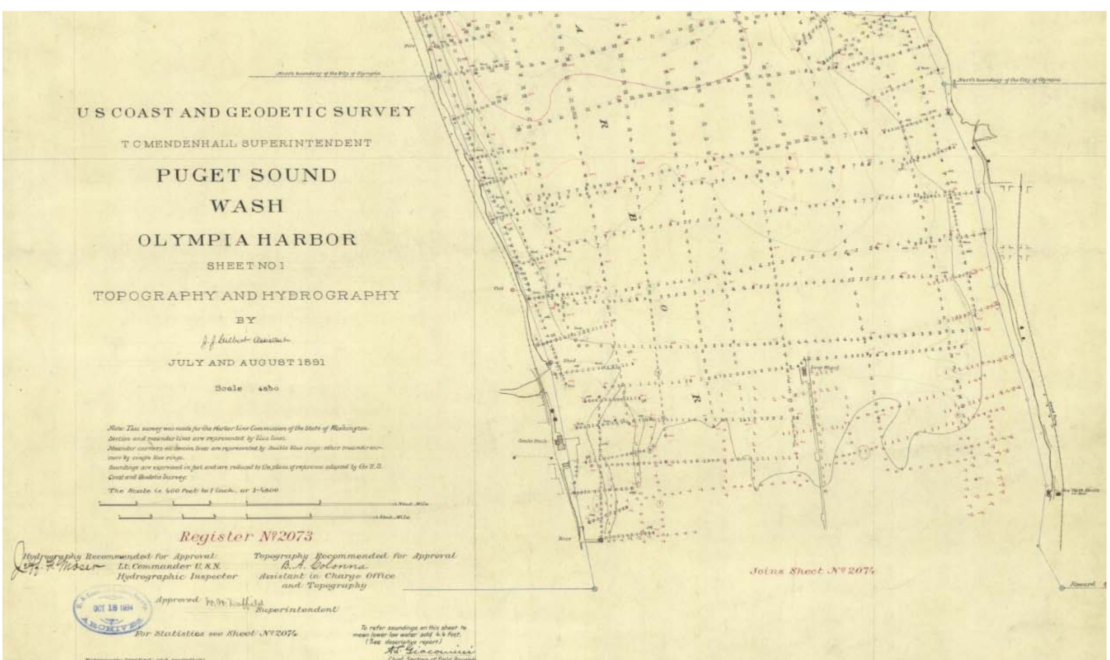
> "In comparing the surveys of the ocean shore lines of Nantucket Island, we have been obliged to limit the inquiry to an examination of the shore line as defined by the crest of the high-water line, without considering any shift in the submerged portion of the coast because of the insufficiency of the data afforded by the earlier hydrographic surveys… The island of Nantucket is fast becoming of great importance as a summer resort, a statement fully warranted by the increasing number of hotels and cottages built there each year. The examination of the stability of its shores thus becomes of prime importance to this summer population as well as to the inhabitants engaged in its shore fisheries. The absence of the knowledge which is brought out by just such a comparison as this, permitted the location, some years since, of a line of railroad and many valuable buildings upon a part of the shore where the changes are so great that in a few years more the ground on which they stand will have been washed into the sea and the capital involved lost beyond recovery".[19]

[18] Mendenhall, 1892—Part II, Prefatory Note, p. III.
[19] Marindin, 1893, p. 243



Detail from T-1785 Changes since 1846 in Muskegat Island and Nantucket Bay, 1887

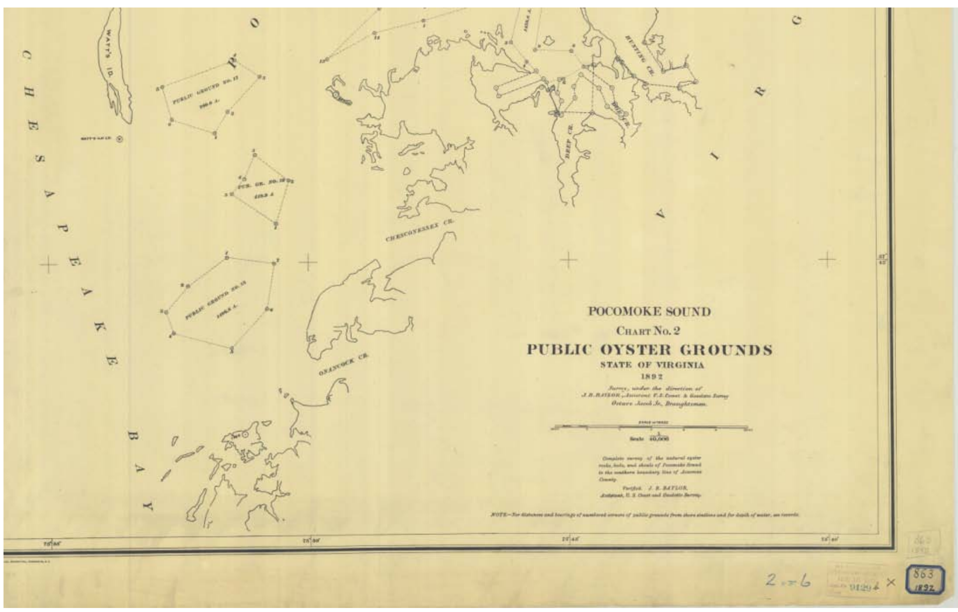
The Survey also initiated large re-surveys of important harbors that had not been examined closely since the Civil War, particularly Boston Harbor. On the west coast, the great increase in both populations and maritime commerce made charts created only a decade earlier obsolete. Many re-surveys were commissioned by harbor authorities and allied agencies.



Detail of H2073 (1891) Survey of Olympia Harbor, Washington Territory

The Survey also continued and expanded its research on the distribution and ecology of oyster beds and grounds. Francis Winslow withdrew from Survey work, as his oyster research was based on his assignment to the Survey as a Navy officer. When the Navy attempted to re-assign him to other navy duties, he quit his commission, which also severed his connection to the Survey. He then continued oyster research, and also attempts at commercial oyster management and cultivation, in Pamlico Sound and other areas of the North Carolina coast.

Other Survey personnel stepped in to continue Winslow's research path. The state of Virginia commissioned the Survey to set up a geodetic schema for mapping the public oyster beds of that state's water. And James C. Drake succeeded Winslow in oyster research in the Survey, publishing in 1890 his report on the sounds and estuaries of Georgia with reference to oyster culture.[20]



Detail from Public Oyster Beds of Virginia, No 2, Pokemoke Sound
Directed by J.B. Baylor of the Survey

Back to Alaska

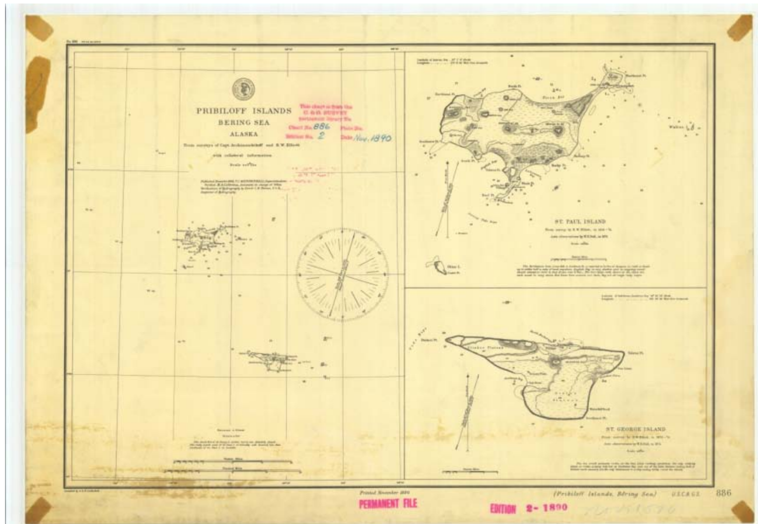
The Survey had been "present at the creation" of Alaska since 1867. But for the first several decades, work in Alaska and its extensive seas had been episodic, and limited to surveys of specific harbors, islands, passages, and other critical features of navigation. Many of the sailing direction scaled charts the Survey produced were derived primarily

[20] Drake, 1890, pp. 179-209.

from Russian and British sources. In the 1880s, this began to change. In 1884 the Survey launched the steamer *Carlile Patterson*, which had been designed primarily by the late Captain and Superintendent Patterson himself, for service in the relatively placid waters of the long inside passages between the rest of the United States and the Territory of Alaska.

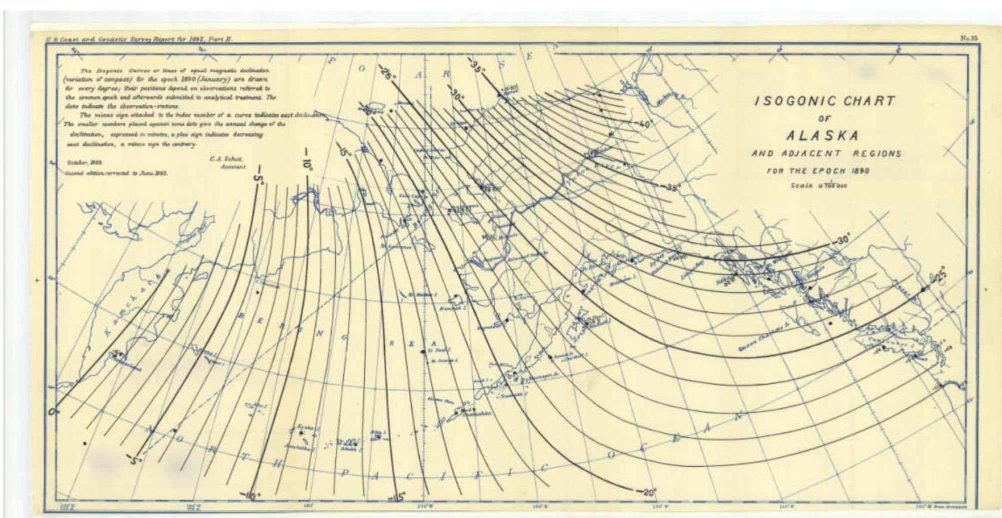
The steamer Patterson about 1910, in British Columbia
Photograph by future Survey Director Leo Colbert

The duties of the Patterson expanded by the end of the decade, driven by two major developments. The first was the continuing deterioration of the populations of fur seals on the Pribilof Islands, along with declining stocks of other marine mammals as well as fisheries in Alaskan waters. In response, American and British Navy vessels and U.S. Revenue Service cutters cruised the waters of the Bering Sea and approaches to it in management of the seal fishery. Mendenhall was appointed the American delegate to a joint U.S.-Great Britain committee to investigate the fur seals' situation, and in 1891 he sailed to the Bering Sea, taking time to make gravity observations with his half-second pendulum instrument, to be described later.



The 2nd edition (1890) of the 1875 charts of the major Pribiloff Islands
Based on Russian charts and the surveys of William Dall and Henry Elliott

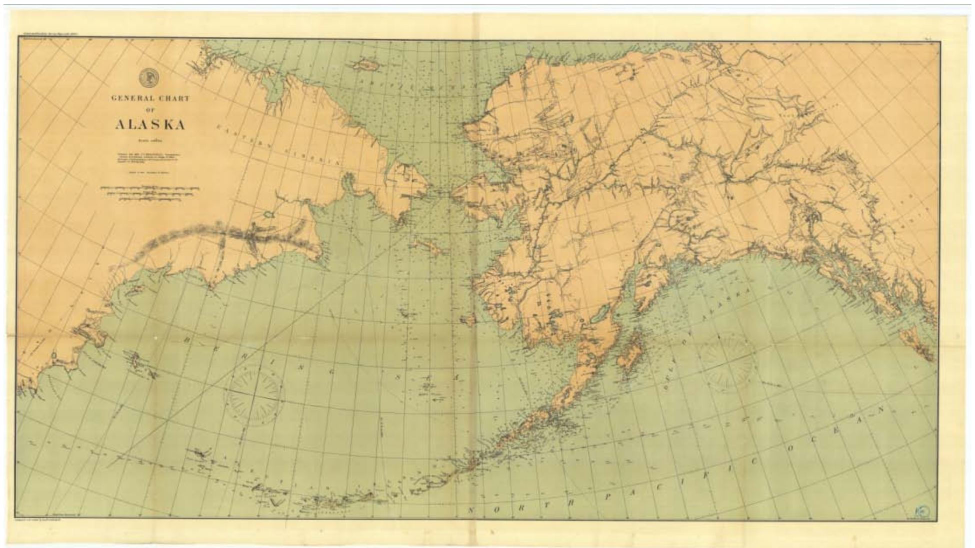
The other major development was the continuing and expanding phenomena of gold discoveries in British Columbia, and later Alaska and the Yukon Territory. This made previously small and obscure ports and harbors busy and crowded, and triggered large numbers of vessels and thousands of men to attempt travel to places never before used as ports by ocean-going steamships. The Survey was now tasked with an expanded workload of survey work over a huge area of land and water.



Magnetic Isogonic Chart for the Epoch of 1890 published in 1892.
The areas covered represent the major arena of Survey work

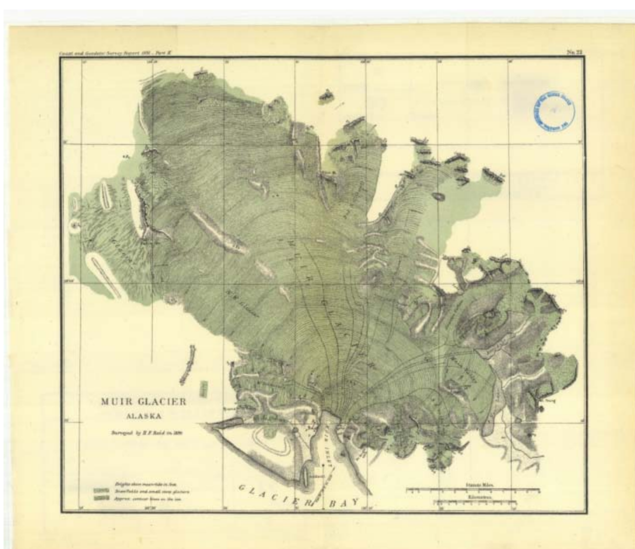
As always, new Survey work would result in new Survey charts. For some reason, never fully explained as such in the annual reports, Alaska and its adjoining area and seas, of all the American lands and waters, became the set upon which the Survey painted with color. Many Alaskan charts (although certainly not all) featured chromo-lithographic color as had not been seen in Coast Survey charts since the Civil War.

Eventually this expanded use of color would be used universally in Survey cartography, but it began in Alaska.



General Chart of Alaska, Sketch 3, 1890 Note that this chart and the previous isogonic chart use the same map projection

The use of color lithography extended to Alaskan-related maps and subjects on all scales, and even extended to color publishing in the annual reports.

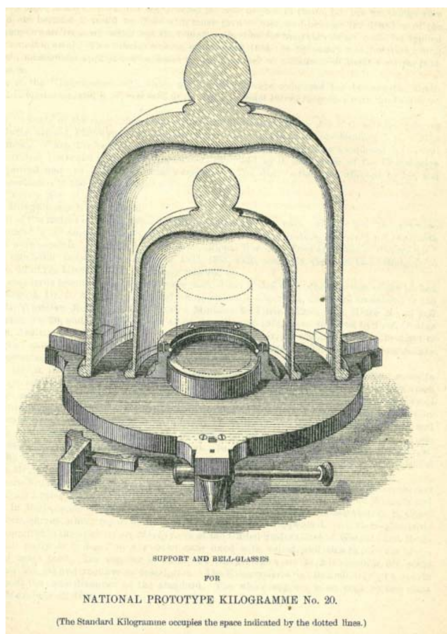


Muir Glacier Figure No. 22, Annual Report for 1891

The final major episode of Alaskan work under Mendenhall was the joint British/Canadian/American survey of the border between southeast Alaska and Canada, in which Mendenhall was directly involved. That will be further described in the section of Survey topography.

Geodetic Progress joins Metrology

Geodesy is inherently international in scope, and cooperative in nature, as all geodesists generally gain more by sharing data than by withholding it. Under Mendenhall there was the continued extension of the positioning related to the Great Arc of the 39th Parallel, lines of leveling of precision, re-determination of boundaries, etc. But the overall theme of Mendenhall's tenure was the standardization and internationalization of Survey geodetic work. Early in Mendenhall's term in 1889, George Davidson went to Paris—at his own expense, given the difficulties of Survey budgeting—as the American representative to the Ninth Conference of the International Geodetic Association. Various international research initiatives developed from Davidson's participation, including a variety of research projects in Hawai'i, described later. As a part of the collaboration, Davidson and future Superintendent Otto Tittmann played roles in transporting back to the United States various official metrological standards, including the metre bar and the standard kilogramme.[21]



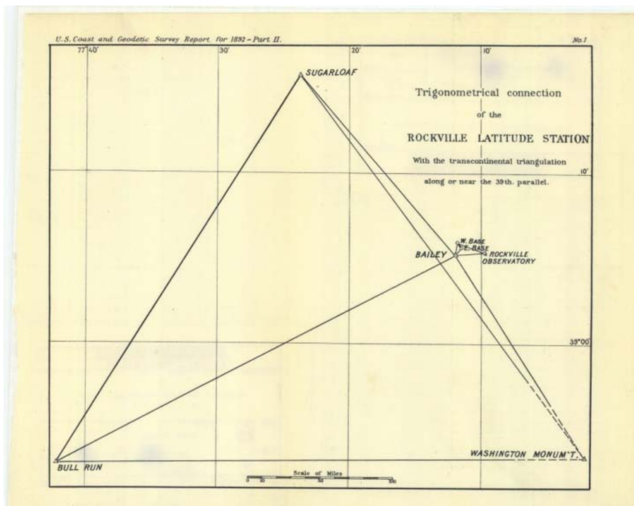
Support and Bell Glasses for the National Prototype Kilogramme
(dotted lines represent the kilogramme) No. 68, 1890

The American standards for the metre and the kilogramme brought back from Europe were taken in their sealed packing cases for a ceremonial revealing at the White House before the president and several dozen Senators and Congressmen then serving on Congressional committees related to Weights and measures, and also Judges and other leaders of society. Significantly, the observers included Julius Hilgard, the disgraced Superintendent who resigned from the Survey in 1885. Hilgard had been the first

[21] Davidson, 1890, App. 17 and Tittmann, 1890, App.18.

American delegate to the European enterprise that had resulted in the Conférence Générale des Poids et Measures (General Conference on Weights and Measures) which had defined the fundamental standards of the metric system. Hilgard had fallen under Cleveland, but President Harrison now occupied the White House, so Hilgard was welcomed back to formal Washington society, if only for the moment.

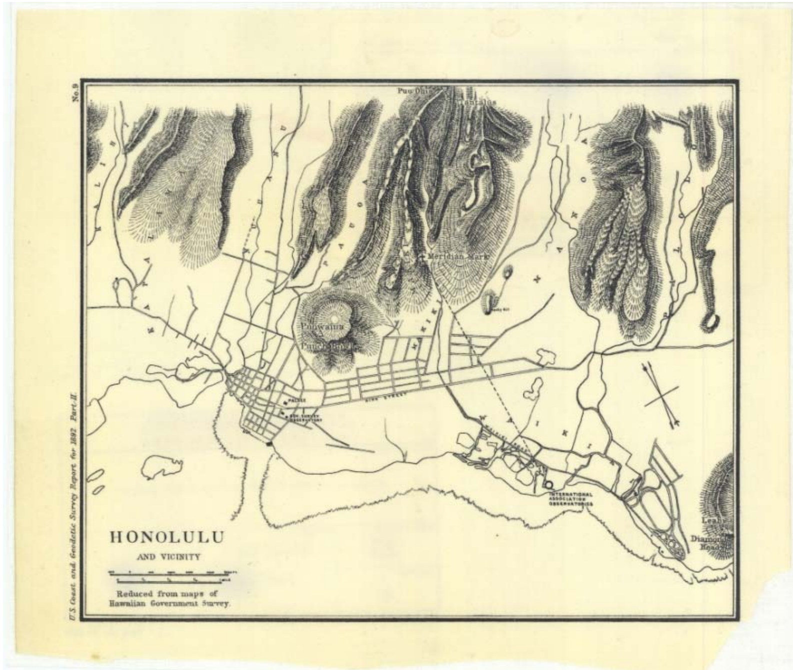
As part of American cooperation in international geodesy, the Survey accelerated astronomical latitude observations at its observatory site outside Rockville, Maryland. This was part of a set of observatories spaced around the world to determine and characterize the Chandler movements, the small wobblings of the Earth's axis. The Rockville observatory site was then trigonometrically connected to the great Arc of the 39th Parallel Triangulation Network by means of a small baseline and a near-equilateral triangle utilizing the Washington Monument.



Trigonometric Connection to the Rockville Latitude Station No. 1, 1892

Collaboration with the International Geodetic Association also greatly expanded the scope of Survey research in Hawai'i. The context was recalled by the formidably named Assistant Erasmus Darwin Preston: "Some latitude observations made in Germany at Berlin and Potsdam, and at Prague in Bohemia, showed a progressive yearly change [in latitude] in the results. As the motion was in the same direction for all three places, it became desirable to make a further study of the movement by observing at stations differing greatly in longitude… therefore to bring out the law of change most advantageously the International Geodetic Association took the matter up and proposed to send an observer to the Hawaiian Islands…This led to my assignment by the Superintendent of the Coast and Geodetic Survey, with instructions for some additional gravity, latitude, and magnetic observations during my stay in the islands."[22]

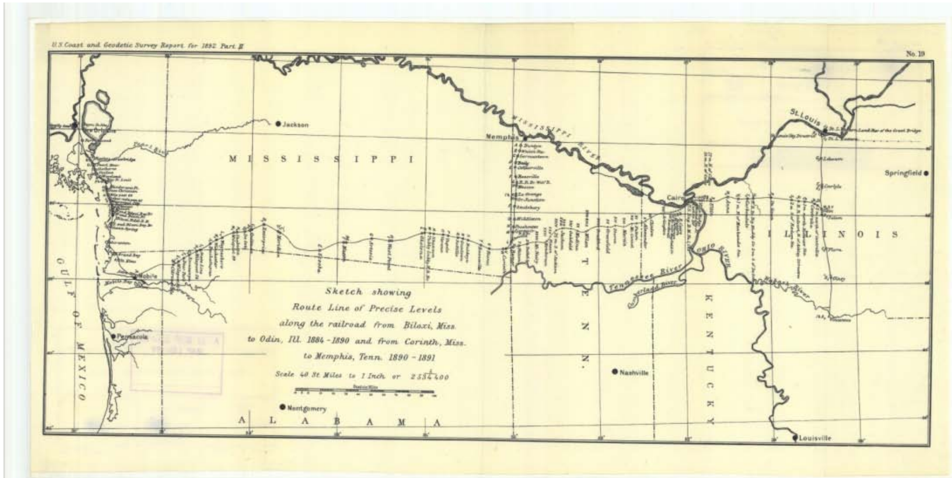
[22] Preston, 1891, App. 13, p. 479



Honolulu and Vicinity, showing several of the observatories
associated with Preston's research. No. 9, 1892

The Coast and Geodetic Survey Astronomical Observatory at Waikiki, outside Honolulu
No 6, 1892

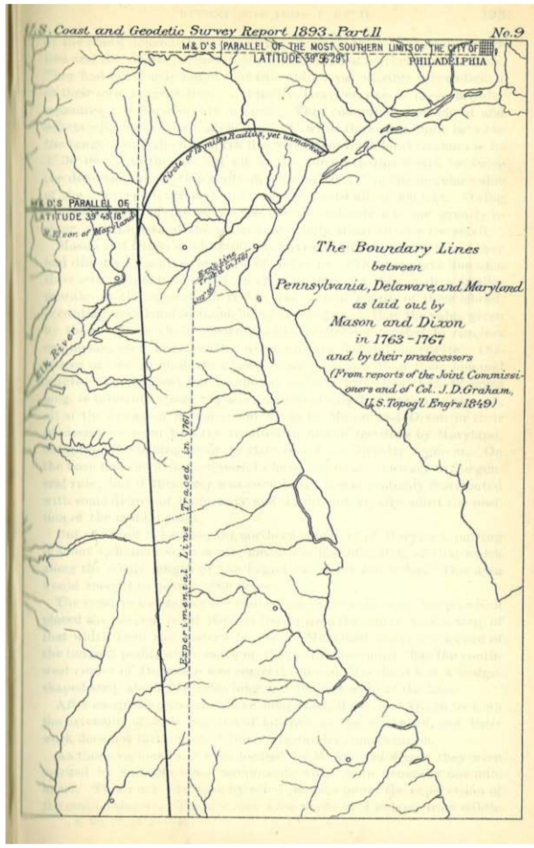
Back on North America, Survey geodetic work progressed in interesting ways. Survey parties using spirit levels of precision worked through much of the upland south, along new railroad lines established for upland logging and other transport operations.



Routes of Precise Leveling along Railroad Routes
No 19, 1892

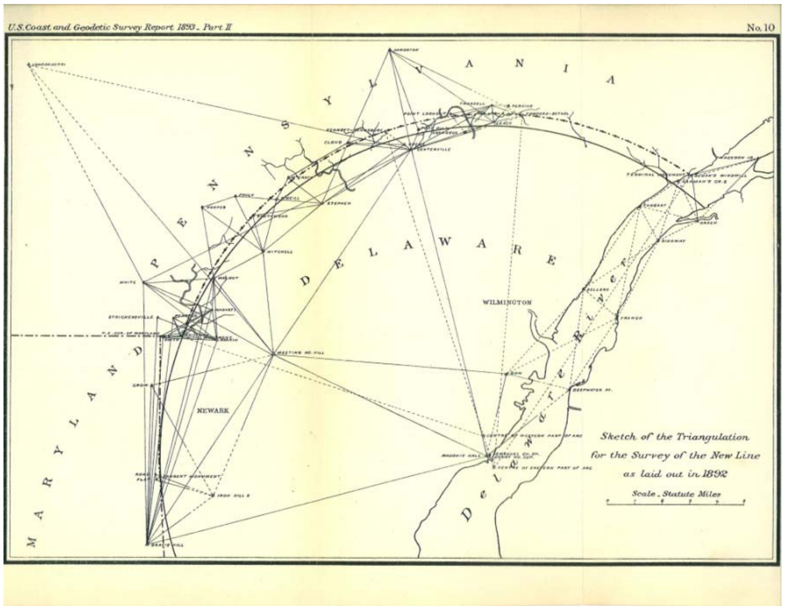
George Davidson and Charles A. Schott, among many other Survey scientists, had already done much research on historic nautical charts and other sources of maritime data both for historical research and for the aid of contemporary charting. In 1890, the Survey received an unusual task that extended their historical research to a legendary terrestrial data set. The states of Delaware, Maryland, and Pennsylvania required a re-survey of their contiguous boundaries, which are a set of lines, which are erroneously summarized as "the Mason-Dixon Line". In order to complete the assignment, Assistant W. C. Hodgkins compiled a historical account of all European settlements and colonial boundaries in the area going back to1631.[23]

[23] Hodgkins, 1893, App. 8, pp. 177-222.



The Boundary Lines between Pennsylvania, Delaware, and Maryland
As laid out by Mason and Dixon in 1763-1767 and by their predecessors
No. 9, 1893

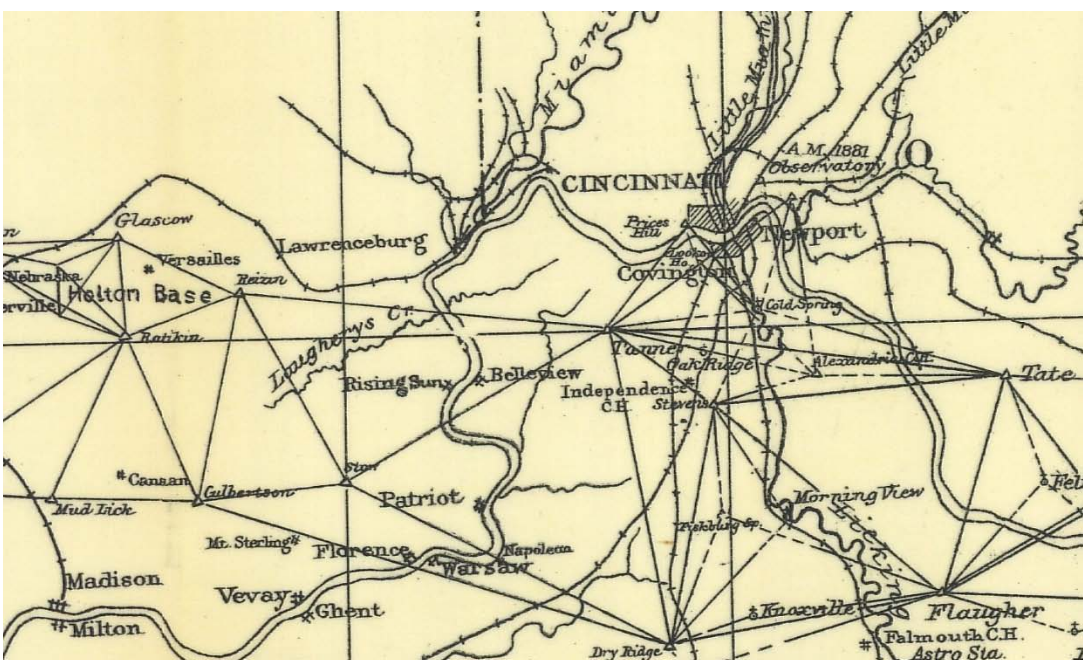
Based on the research, and the legal written descriptions of the boundary lines finally agreed to by the three states, the Survey precisely surveyed the boundary lines, and also the arc of a circle 12 (old English) miles in radius, a boundary feature unique in the United States, and possibly elsewhere.



Sketch of the Triangulation for the Survey of the New Line
No 10, 1893

The Holton Baseline

The final major geodetic project of the Survey under Mendenhall was the establishment of a unique baseline outside Holton, Indiana. It was near this place that, in 1891, the two long arcs of the Great Arc of the 39th Parallel Triangulation Network met, having marched between the Atlantic and Pacific Oceans since the beginning in 1871.



The location of the Holton Baseline west of Cincinnati, Ohio
Sketch 9, 1892

Mendenhall was both an educator and a maker of standards, and these functions converged with the project of the Holton Baseline. The major Survey personnel brought in for the project included Otto Tittmann, a major figure in the Office of Weights and measures, and later Superintendent of the Survey; John Hayford, later a major geodesist and developer of the Hayford Reference Ellipsoid, and R.S. Woodward, later to become the director of the Carnegie Institution of Washington. These were not the only principals on the project. Survey reports are often silent or cursory on the subject of the non-scientific but indispensable members of the party. One of these, who worked on the Holton Baseline, was a laboer named Jasper S. Bilby. As the geodesist William Burger noted, in his memoir of Hayford:

> "At Holton Base, Mr. Hayford formed an acquaintance with one of the men of the base party, and between them began a friendship which was destined not only to affect later his reputation as head of the Division of Geodesy in the U.S. Coast and Geodetic Survey, but in great measure to affect the geodesy of the United States and of the entire world. This acquaintance with Jasper S. Bilby lasted until the death of Mr. Hayford in 1925. When Mr. Hayford went to work on the United States-Mexican Boundary, Mr. Bilby was employed as general helper in his party and he has served continuously to date with the Coast and Geodetic Survey, with rare exceptions omitted, engaged for the most part in the Geodetic Division. Since about 1900 all of the major reconnaissance and signal-building has been in his charge and it was under Mr. Hayford's régime that special recognition was given him by conferring upon him the official title of Signalman, the first to be thus honored. In speed and economy of operation his work has had a distinct bearing upon the phenomenal success attained by the Coast and Geodetic Survey in triangulation and base work. He is the designer of the Bilby Steel Tower now being used with great success. Recently he again received official recognition by being given the title of Chief Signalman, this position having been especially created for him. The writer has had the pleasure of working with Mr. Bilby on many occasions, and believes that as an expert on reconnaissance and signal-building Mr. Bilby stands unrivaled in the world."[24]

The greatest source of error difficult to control or compensate for, in any baseline, is the expansion and contraction of the baseline instruments with temperature. Since the Holton Baseline was to be the geodetic joint between the Pacific and Atlantic baselines, it would be best if it was highly accurate. Mendenhall directed this baseline to be a test of different systems of baselines measurement compared to each other. "Soon after joining the U.S. Coast and Geodetic Survey in July, 1890, I was requested by Dr. Mendenhall, Superintendent, to devise means of testing in the most thorough way practicable the

[24] Burger, 1935, pp. 169-170.

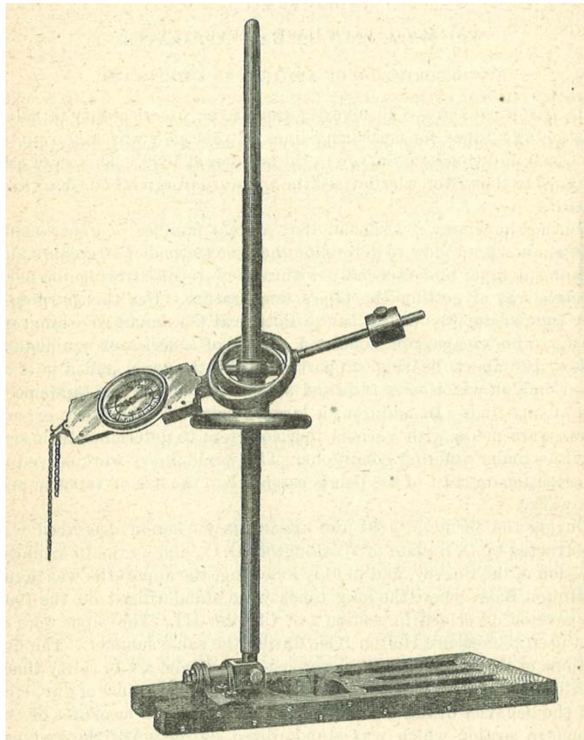
efficiency of the various forms of base apparatus used by the Survey, and especially the efficiency of long steel tapes or wires. Accordingly, considerable study was given to this subject during the autumn of 1890 and the winter of 1890—'91, and the plans and the specifications for the iced-bar apparatus considered in this paper were matured and approved early in the spring of 1891."[25]

The point of the iced-bar apparatus was to keep the baseline measuring bars as close as possible to the constant temperature of the freezing/melting point of water, to minimize differential contraction or expansion of the bars. However, the measurements of the iced-bar apparatus themselves had to be compared to non-iced-bar methods. The next set of comparative measurements involved different kinds of steel tape and steel wire, which had to be compensated for temperature and also for the force pulling the wire or tape taut.

The Iced-Bar Apparatus on the Standard Kilometer part of the Holton Baseline
No 32 1892

The iced-bar method was found to be highly accurate, and also time-consuming and expensive. But it gave a standard to which to compare various methods of measuring distances with steel wire and tape.

[25] Woodward, 1892, p. 338



Steel Tape Stretching Apparatus
Annual Report for 1892

In the end, the steel tape was found capable of working for geodetic standards of accuracy. “”The metallic tape is not only capable of giving a result of great accuracy when in the hands of experts, but it is evidently the best device for rapid base measurement where no great precision is aimed at.”[26] From that point on, steel tapes became standard in Survey geodesy work where accuracy standards allowed their use.

The Gravity of Mendenhall

The arrival of Mendenhall in the Survey led to the departure of Charles Sanders Peirce, after over 30 years of employment (most of the time) in the Survey. As always, Peirce himself and his unusual behavior was one issue, although by no means the only one. But Peirce wanted to obtain the absolute gravitational force at a site, which was not only extremely difficult, but was quite time consuming and hence expensive.

Ever since the depredations of Chief Auditor Chenowith and the investigations of the Allison Commission, Peirce had been dangerously marginalized in the Survey. Peirce had offered to resign under Thorn, but Thorn refused to accept it—since Thorn was not a rival of Peirce. Mendenhall was. He had been doing gravity research with pendulums since teaching in Ohio in the 1870s, and he had swung pendulums in Japan. And Mendenhall had a concept for smaller, lighter half-second pendulums, in contrast to

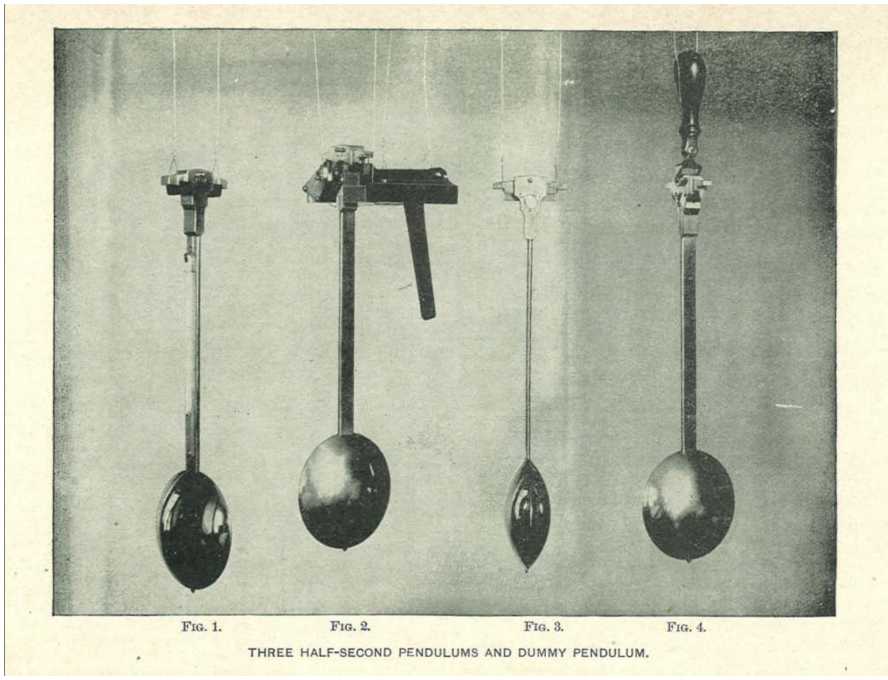
[26] Mendenhall, 1892, App. 8, Prefatory Note, p. 329.

Peirce's larger one-second pendulums. Peirce pointed out what he saw as insurmountable problems with Mendenhall's concept. Essentially, there wasn't room in the Survey for two rival gravity programs. Mendenhall forced Peirce to resign. Then Mendenhall's new concept was developed. His subsequent description of the program is revealing. Peirce is entirely unmentioned. Various Survey personnel are fully credited for their work, but Mendenhall himself is invisible in the account, even though this was Mendenhall's project entirely.

As Mendenhall described the history of gravity work in the Survey:

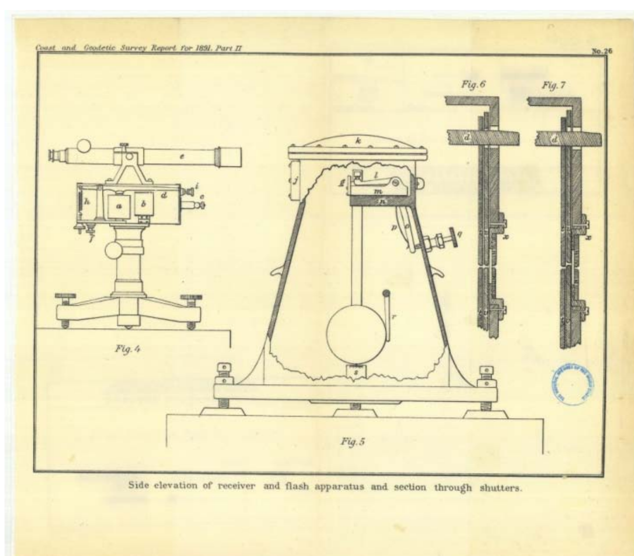
> "The active interest of the Survey in this subject began about 1873. The numerous and often extensive discrepancies between geodetic and astronomical positions indicated the importance of and necessity for the investigation, and the bearing of the results upon geological problems adds additional interest to it. Much valuable experimental work was done and a number of stations occupied, including several in the old world, from the beginning of the work up to 1890. Some form of pendulum whose period was approximately one second was used, together with a clock having a seconds pendulum; the method of coincidences and, for a few years, that of chronographic registration having been adopted in determining the period of the gravity pendulum. Reversible pendulums were generally made use of, but the measurements were in the main differential and not absolute. A serious difficulty in the way of continuing the investigation on this basis was its cost, when considered in connection with the number of stations occupied. The instrumental outfit of a party was large and not easy to transport; much was required in the way of preparation of a station, and thus a single determination involved the expenditure of so much time that it was extremely desirable to devise some means of more rapid working, especially if this could be done without material sacrifice of the accuracy which the nature of the problem demanded. It was agreed that a great reduction in the magnitude and complexity of the instrumental outfit of a party could be made by using a pendulum vibrating in a half second, and substituting a chronometer for the clock… It seemed altogether wise to make use of the method of coincidences in measuring the period of the pendulum, and also that some optical method of doing this was preferable to any other. It was determined that invariable non-reversible pendulums should be used, except at a limited number of base stations, where absolute values of the force of gravity should be obtained by the use of reversible pendulums or by some other method. In the elaboration of the plans for the work many valuable suggestions were secured from Mr. C.A. Schott, Mr. Edwin Smith, and Mr. E.D. Preston, assistants, the latter two having had large practical experience in gravity work; and in the designing and constructing the apparatus the services of Messrs. Smith and Preston, together with Mr. E.G. Fischer, chief mechanician, and Mr. G.R. Putnam, aid, U.S. Coast and Geodetic Survey, were invaluable in securing the

realization of the proposed improved devices, as well as the suggestion and invention of many of them".[27]



Three half-Second period Pendulums and a Dummy counterweight Pendulum
Nos 1-4, 1891

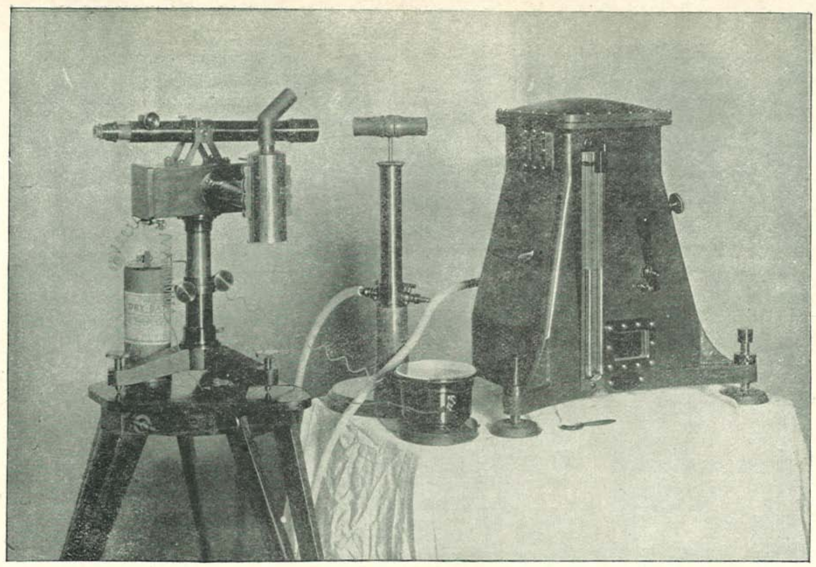
Mendenhall (and the others) developed the concept of swinging the pendulums in an enclosed case under partial vacuum, and also using an optical flash system to time the pendulums' swings.



[27] Mendenhall, 1891, Part II, pp. 503-504.

Side elevation of the system concept
No 26, 1891

The entire system, as built, was relatively compact and light-weight, especially compared to Peirce's apparatus.

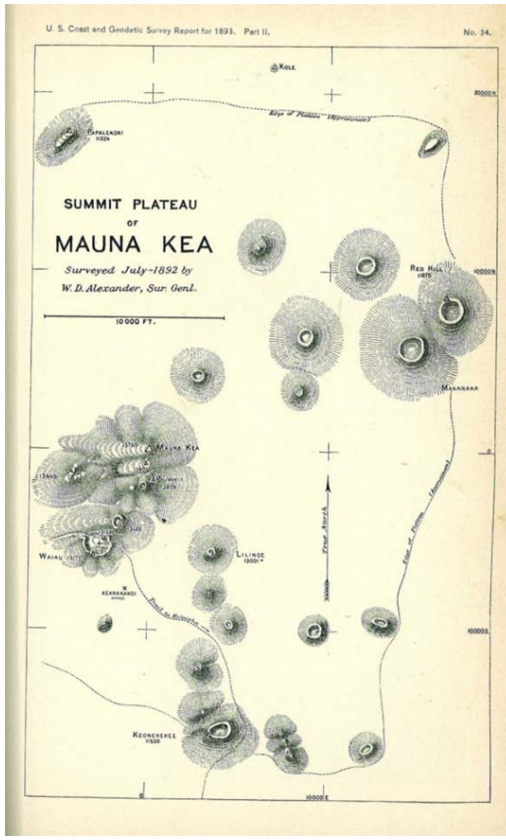


HALF-SECOND PENDULUMS.
Side view (right) of receiver, flash apparatus, etc.

The full pendulum system, with pendulum case, optical flash monitor, battery, and air pump for the partial vacuum. No 23, 1891

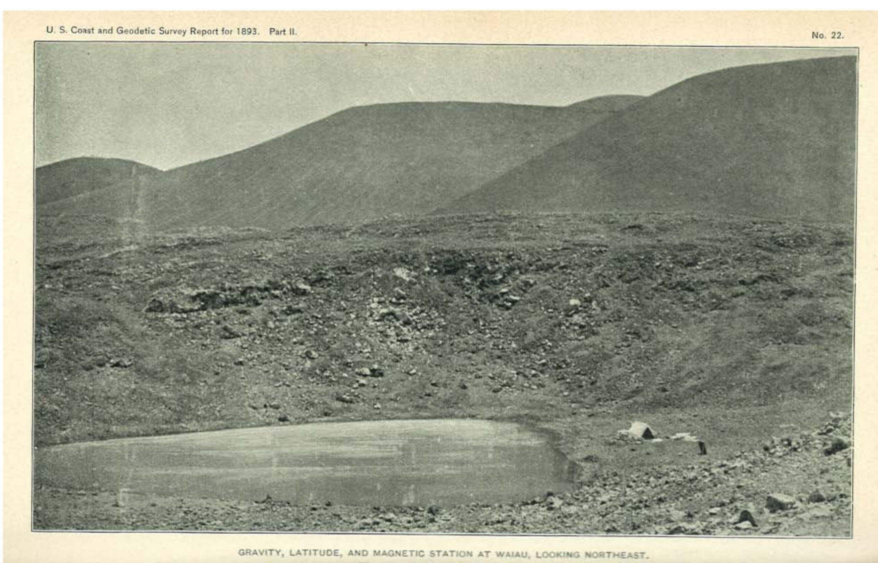
The Mendenhall pendulum system measured the relative value of gravitational force at a site to be compared to that of another site, but not the absolute gravitational force. Mendenhall compensated for this by taking his system to sites previously and laboriously occupied by Peirce's apparatus in order to at least partially calibrate his system. Then the Mendenhall pendulums traveled widely, taking advantage of their smaller size and rapid use. Mendenhall and his party made observations along the Pacific coast and Alaskan coast and islands when he went to the Bering Sea to investigate the fur seals, and also when he returned to Alaska in 1892 as the lead American delegate to organize the joint US-British survey of the Alaskan-Canadian boundary. Assistants Smith and Putnam swung the pendulums in various locations in the United States.

And Assistant Eramus Darwin Preston took a set to Hawai'I, where he conducted gravity research, in addition to the astronomical and magnetic work already discussed. His most extensive research was on the big island of Hawai'i.



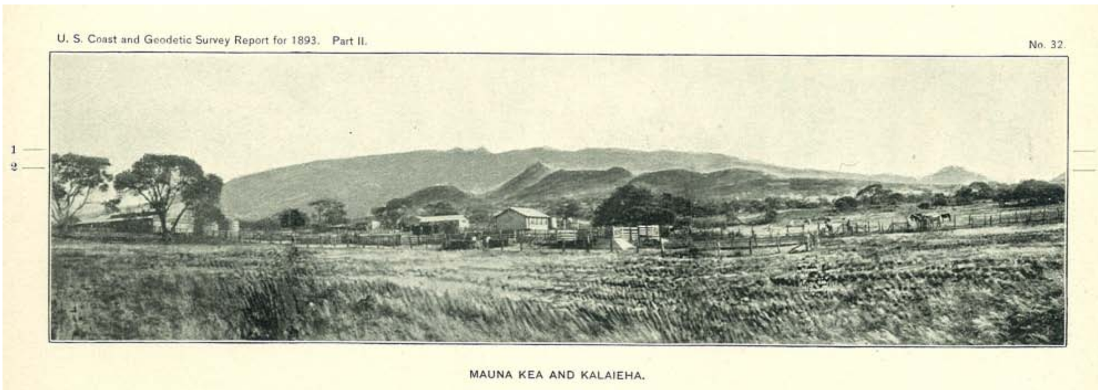
The Summit Volcanic Plateau of Mauna Kea surveyed by W.D. Alexander of the Hawaiian Geodetic Survey and later the US Coast and Geodetic Survey No 34, 1893

Preston made numerous gravity observations in transects crossing from sea level up and over the volcanic summits of the big island and several others.



Station at Weiau looking northeast No 22, 1893

Preston documented his gravity stations by positioning them geodetically with theodolites and other instruments, and also took photographs of the stations in context. These photographs are now considered quite valuable to Hawaiian researchers studying changes in vegetation and landforms since Preston's expeditions.



Mauna Kea and Kaleiha as seen from a plantation-ranch where Preston's party camped
No 32, 1893

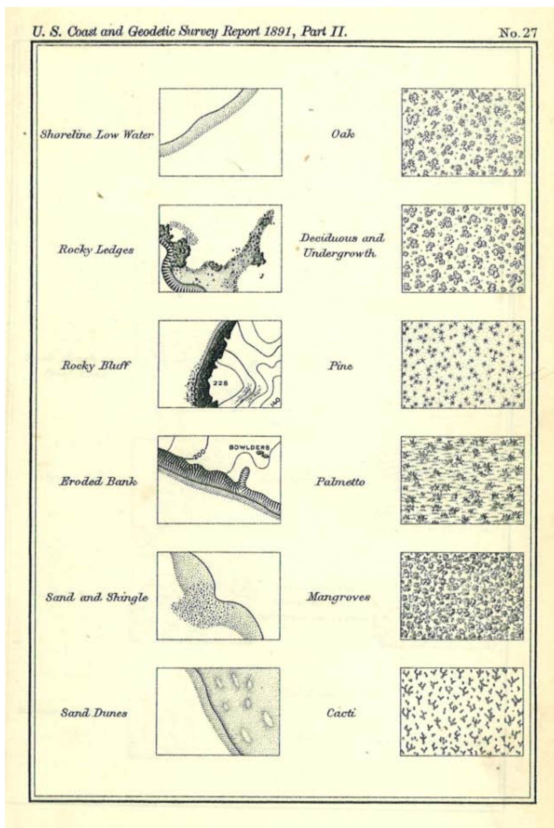
Mendenhall was only with the Survey about four years, but his pendulum system survived his exit; Mendenhall pendulums were used as long as the Survey continued to use any pendulums at all. Their fatal flaw—and also those of Peirce—was that the pendulums balanced and swung on a conceptual 'knife-edge' beam that was never as thin as the concept, and that inevitably introduced errors that skewed the measurements, precluding the kind of accuracies that Peirce in particular spent his life attempting to achieve.

Scaling and Mapping the Topographic Heights

Mendenhall was brilliant and enthusiastic and organized, but he was also rather small and delicate, and easily subject to ill health when under stress. He therefore never attempted any field work that couldn't be carried out from a beach or headland reached by a Survey vessel on his various travels as Superintendent. Nevertheless, the topographic work and research methods advanced strongly under his tenure, induced as Mendenhall could by the methods he was most familiar with as an educator and specialist in metrology and the naming of things.

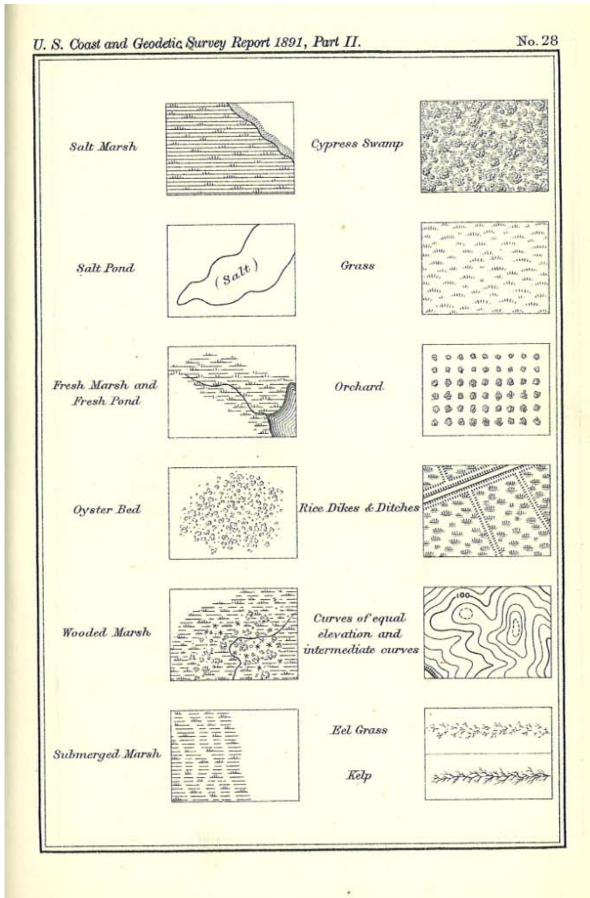
Early in his tenure, he took on the challenge that there was no consistent schema for naming geographic features on the many maps and publications of different government bureaus, even though correct naming could be, for example, in the case of nautical charts and navigation, a matter of life and death. He decided to remedy this. "A correspondence with the heads of Departments and chiefs of Bureaus especially concerned in the production of charts, maps, and other geographical publications was undertaken by the Superintendent of the Coast and Geodetic Survey, in which it was proposed to organize a Board consisting of representatives from such Departments and Bureaus, to which might be referred all questions arising in any of them relating to geographic names, the action of such a Board to be accepted as final, to the end that uniformity of nomenclature might be secured in all Government publications." The suggestion received favorable consideration in all quarters and resulted in the organization of the US Board on Geographic Names in April, 1890. [28]

In 1892, Mendenhall organized a conference of many of the most experienced topographers in the Survey—Henry Whiting, R.M. Bache, Augustus Rodgers, W.H. Dennis, Cleveland Rockwell, John W. Donn, C.T. Iardella, Herbert G. Ogden, D.B. Wainwright, W.C. Hodgkins, and J.A. Flemer—at Survey headquarters in Washington. They met daily from January 18 to March 7, 1892—with full pay, by the way—considering many topics of topographic surveying, accuracy standards, survey costs, etc., and also considering responses to circular letters submitted by many senior Survey scientists, draughtsmen, and cartographers and printers in the Survey. The resulting voluminous report was published in Appendix 16 of the 1892 annual report.[29]



Conventional Topographical Symbols, No 27, 1892

[28] US Board on Geographic Names, Prefatory Note, 1890, p. iii.
[29] Proceedings of the Topographical Conference held at Washington, DC January 18 to March 7, 1892.



Conventional Topographical Symbols, No 28, 1892

The Topographical Conference included J.A. Flemer, who was the Survey's specialist and first early adopter in the new discipline of photogrammetric topography, which used sets of stereo-pairs of photographs, with cameras aimed horizontally, and careful measurements and mathematical models, in order to determine three dimensional landscape forms and positions and elevations photogrammetrically. The technique originated with mapping bureaus in the European countries which shared the Alps, and was particularly useful in such areas of high relief, which were so difficult to map by plane table and spirit level. From there, the modified technique came to Canada. Flemer further modified the Canadian camera system to create the first American photogrammetric mapping system. He published several comprehensive appendices on the theory and methods of photogrammetry in annual reports.

PHOTOGRAPHIC INSTRUMENTS AND METHODS EMPLOYED FOR TOPOGRAPHIC SURVEYS IN THE DOMINION OF CANADA.

The phototopography of the Rocky Mountain region in the Northwest Territory of the Dominion of Canada proved a success, and several of the Dominion topographic and land surveyors (J. J. McArthur, W. S. Drewry, etc.), under the direction of the surveyor general, Capt. E. Deville, have acquired skill and valuable experience in this branch of surveying, as is well proven by Deville's topographic map of the Rocky Mountains along the Canadian Pacific Railroad, based on triangulation and phototopography, plotted on 1:20000 and published on 1:40000 scale, and which was on exhibition at the Columbian World's Fair.

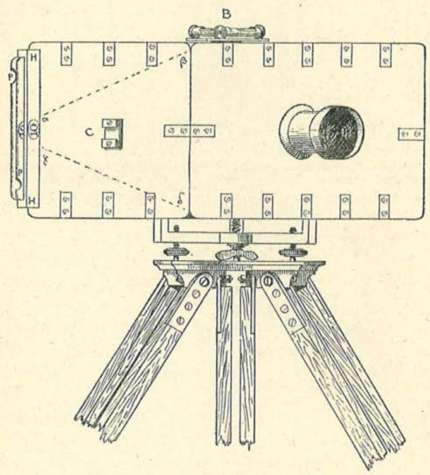


FIG. 16.

Under the direction of Dr. W. F. King, Alaskan boundary commissioner to Her Majesty, phototopography has been successfully employed for the topographic survey of southeastern Alaska, as far as this topographic reconnaissance has been executed under the Government of the Dominion of Canada.

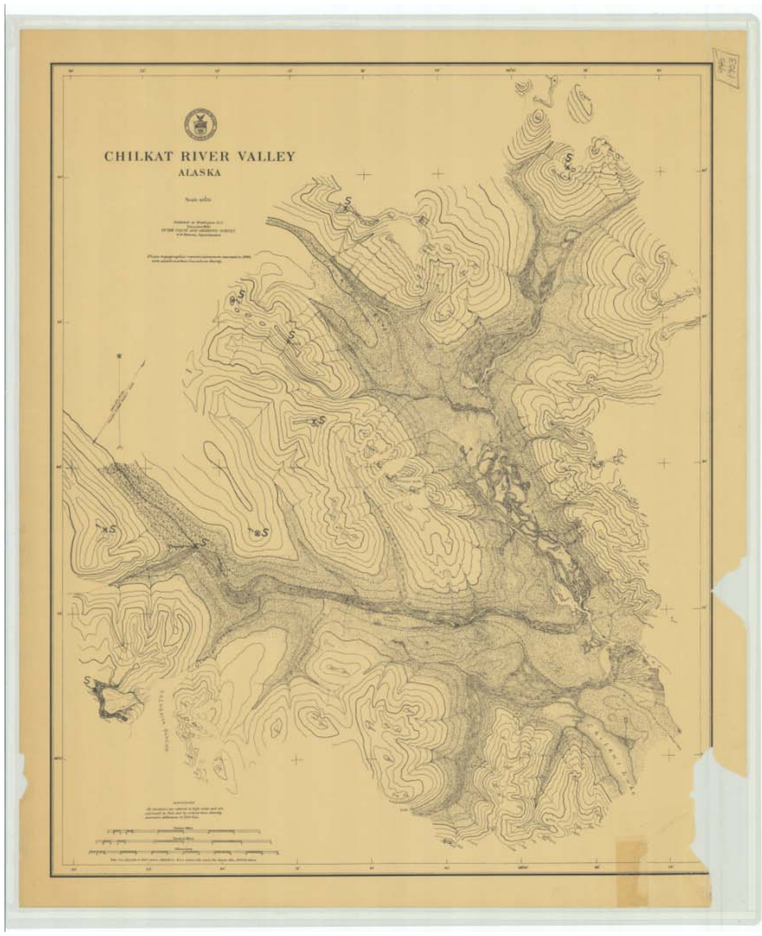
Canadian photogrammetric camera and context of its uses
No 16, 1893

It is interesting to note that the Coast Survey had used photography extensively since the late 1840s, as Superintendent Bache had then noted: "But above and before all other reasons, photography was to be introduced as a regular part of office detail, and great changes were necessarily consequent. I determined therefore to have a thorough revision of the whole system…"[30]. Nevertheless, almost half a century later, Flemer's appendix shows the very first cameras ever depicted in an annual report.

In 1892, the U.S. and British and Canadian governments decided to jointly determine an actual boundary line between Alaska and Canada along the south east "panhandle" portion of Alaska, which had been only vaguely indicated in the Russian documents when the U.S. bought Russian America in 1867. The topographic work was divided between the American parties, which worked from the Pacific coast up into the glacial valleys of southeast Alaska, and the British-Canadian parties which worked from the mountain heights down. This difficult work took many years, and the disputes over where to put the boundary line segments even longer. The first Survey map to be produced based on "photo-topographic reconnaissance' was published in 1903, based on surveying done in 1898. Ironically, the map is a portion of the Chilkat River Valley,

[30] Bache, 1860, Annual Report, Superintendent's Report, p. 19.

including Kohklux' village of Klukwan (here spelled Klookwan) where George Davidson had observed the solar eclipse in 1869, on the second Survey voyage to Alaska.



Chilkat River Valley, 1903

Mendenhall was, in some ways, above all else an educator. Despite the many problems and challenges the Survey faced, and despite its many enemies, Mendenhall managed to fund and execute a series of conferences that allowed virtually all the top scientists of the Survey to assemble in Washington for reasonably lengthy periods of time to address certain topics—and at full pay. There was the topographers' conference, several geodesists' conferences, and a gathering early in 1893 related to the preparation of exhibits for the Coast and Geodetic Survey's entry at the World's Columbian Exhibition in Chicago. The resulting staff photograph was only a partial view of the Survey, as it excluded all the Survey personnel other than Assistants. Nevertheless, it would be decades later, under the populist patrician E. Lester Jones, that the Survey ever attempted a mass photograph of its working staff.

George Davidson, Thomas C. Mendenhall, and Charles A. Schott cropped from the 1893 photograph of Mendenhall and the Survey's Assistants

"An Epoch in Metrology"

"The fiscal year 1890 has been marked by a steady and systematic development of the operations of the Survey in both field and office, and by advances so notable in the closely allied work of the Office of Weights and Measures as to constitute an epoch in metrology."[31]

Probably Mendenhall's signal achievement in the Survey, or at the least the achievement that he himself would have valued most highly, was the process by which the Coast and Geodetic Survey became situated more centrally in the organizations and mechanisms of international science and technology. He accomplished this by insistence on definitions and standards. These included the metric standards, and also the foundation and processes of the Board on Geographic Names.

His finale, perhaps, was the development and approval of the definitions and standards of the fundamental units of electricity. He did this by the International Congress of Electricians, which met in August, 1893 in Chicago in conjunction with the World's Columbian Exposition. There were unexpectedly large delegations, and many famous scientists among them, chiefly Dr. H. von Helmholtz, who served as honorary

[31] Mendenhall, 1890, p.1

president of the gathering. According to Mendenhall's own account of the Congress and what transpired:

> "It is true that the science of electrical measurement had been thoroughly explored; excellent methods and instruments have been devised and constructed, and the most perfect system of units of measure ever conceived has been developed during the last quarter of a century. These units being continually in use among scientific men, had come to be recognized as in some degrees authoritative among those engaged in commercial applications of electricity. But in general no legal values were attached to these untis, and in reference to two or three of them scientific men were not yet in entire accord in their nomenclature and definition…
>
> "The results of these investigations, and the general progress of the science of electricity during the past decade, were such as to justify the belief that the time had now arrived when an international agreement could be reached upon definitive values of the units desirable and necessary in electrical measurement, as well as upon the names they should bear… As already stated, it is not the purpose of this article to discuss the conclusions reached by the Chamber of Delegates from a scientific standpoint, but it will be desirable to name the units selected, and explain in a general way their technical significance. In the order of their adoption by the Chamber they are: the ohm, the ampere, the volt, the coulomb, the farad, the joule, the watt, the henry".[32]

Characteristically, Mendenhall left out of the account the fact that he had written the basic definitions, which were then approved by the small, elite Chamber of Delegates, and then approved by the full Congress. After the Congress and the Exposition, Dr. von Helmholtz made a triumphant tour across the United States, culminating in Washington, DC, where Mendenhall was his host in the city. Ironically, it was Von Helmholtz' finale as well, as he fell aboard ship on his return to Europe, and died of his injuries.

[32] Mendenhall, 1894, p. 606.

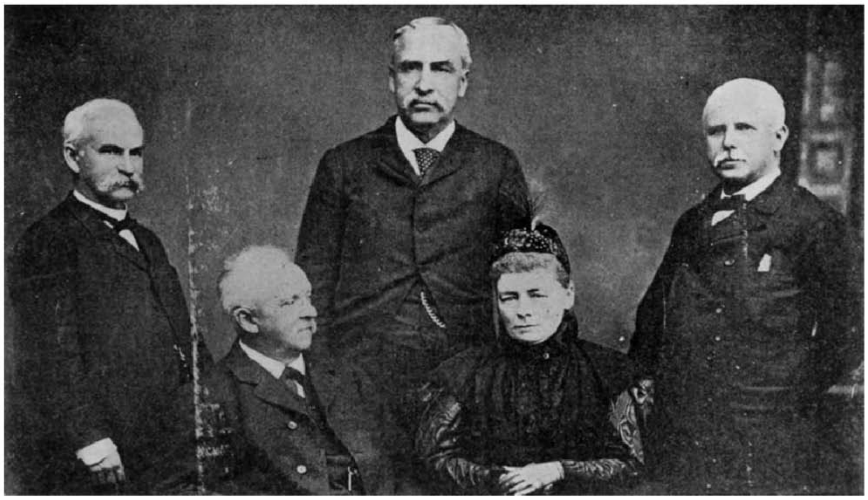


Figure 3. Helmholtz in Washington, DC, 1893. Hermann and Anna von Helmholtz are seated in the centre. Standing on the left is the German physiologist Hugo Kronecker; in the centre is Henry Villard; and on the right is Thomas Corwin Mendenhall. Source: *Popular Science Monthly*, 85 (1914), 517.

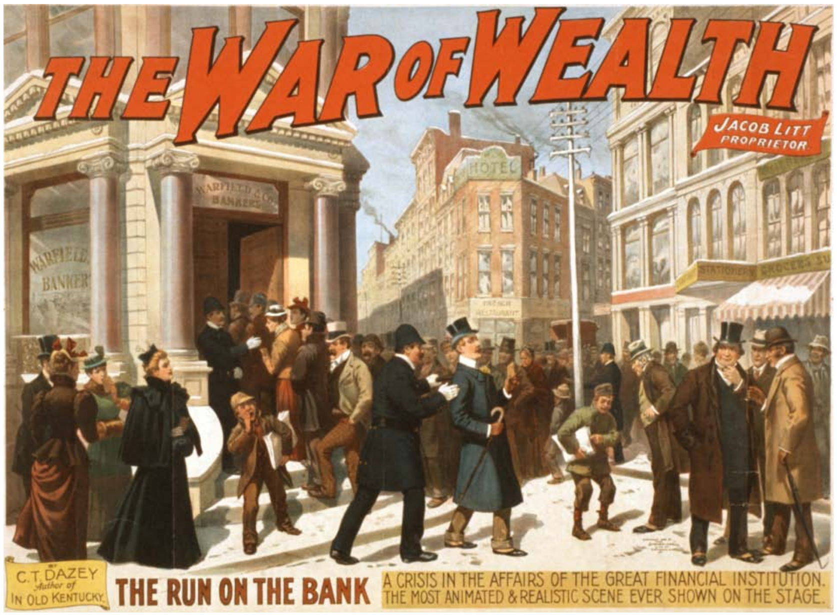
Dr. von Helmholtz (seated, left) and Mendenhall (standing, right). Standing in the middle is Henry Villard, the financier, who, interestingly enough, was the first cousin of Julius Hilgard, the former Superintendent

The convergence of all these activities was the publication of a set of Bulletins of the Coast and Geodetic Survey in Mendenhall's favored octavo format. These included: Bulletin No. 26 Fundamental Standards of Length and Mass; Bulletin No. 29 The Methods and Results of the U.S. Coast and Geodetic Survey, as illustrated at the World's Columbian Exposition, which itself had 14 different sub-divisions covering the full array of Survey work and its many publications, including a unique physical model of the United States and Alaska "as if they were cut out from sphere about 42 feet in diameter"[33]; Bulletin No 30 Units of Electrical Measure; and Bulletin No 31 Legal Units of Electrical Measure in the United States.

The End of the Epoch

The year 1893 encompassed both the World's Columbian Exposition and the Panic of 1893. The Philadelphia and Reading Railroad went bankrupt in February, only 10 days before Grover Cleveland was inaugurated to an unprecedented second separate term as president. A cascade of bank and railroad failures soon led to the biggest depression the country had ever faced. That, and the increased Democratic majority in Congress, spelled trouble for the Survey and Mendenhall.

[33] Bulletin No. 29, Model of United States and Alaska, p. 95.



"The Run on the Bank" from *The War of Wealth* by Charles Turner Dazy (1895)

The Survey's congressional foes used the familiar combination of attempts to cut Survey funding, and attempts to once again dismantle the Survey into the Navy Hydrographic Office. But the final straw came through actions from the Executive branch. Cleveland appointed James G. Carlisle as Secretary of the Treasury, who appointed his son Logan s chief of the division within Treasury that appointed people to positions. They wanted patronage positions from the top to the bottom of the Survey, and they used tactics that were almost impossible for the placid and mild-mannered Mendenhall to successfully oppose. On top of all this, Mendenhall's health began to deteriorate, as it had done in certain critical periods of his life previously.

Whatever else, Mendenhall had other options. In April, 1894, he quietly took a position to become the president of the Worcester Polytechnic Institute in Massachusetts, although he would stay as head of the Survey long enough to complete various obligations. In June, he went to President Cleveland in the White House with a letter of resignation. Cleveland asked him not to resign and say nothing about the matter. Mendenhall agrees, but rumors flew about Washington that he had resigned. This became front page news in Washington. The Washington Times addressed the rumors that he had written the letter of resignation: "It was stated further that he assigns as a reason for resigning that the force in his bureau, which is under the Treasury Department, has been greatly changed, and inferior men selected in the place of men of experience who had formerly held the places. At this point, Mendenhall failed. He was accosted at his house at a late hour. When asked about the rumors of his resignation, "after some urging, he said this: 'I will say this. For all I know, I am still in charge of the Coast Survey Department, and for all I know I will be for a long time to come. I am ignorant as to where this report originated, but can say frankly that it never came from me."[34] Unfortunately, apparently the only people who believed this account were the senior staff of the Survey. This limited their abilities to organize some defense against the coming onslaught.

In late June, 1894, Mendenhall left Washington, nominally for a three week vacation in Europe. His plan for the Survey was for Assistant Colonna and Henry Whiting, the senior topographer and last Survey scientist who had worked under Hassler, to jointly run the Survey in his absence. The plan was hopeless. "It is reported that Professor Mendenhall, of the Coast and Geodetic Survey, has accepted the presidency of Worcester Polytechnic Institute, but the story cannot be confirmed". [35] That same day, Henry Whiting arrived in Washington from the field, to be the acting Superintendent. He found a note waiting from Secretary Carlisle, that Mendenhall's action "was illegal and of no effect".[36] Whiting used connections to appeal to President Cleveland. Cleveland told him that any acting Superintendent should have his appointment confirmed by the Senate, just as the actual Superintendent was confirmed. On July 13, the staff of the Survey learned that treasury tax officer named William H. Pugh had been appointed Acting Superintendent of the Survey. The Survey's nadir had begun.

Mendenhall's later life

In the first half of the Survey's existence, superintendent's served until they died, and they were so busy while alive that their only memoirs were represented by the Survey's achievements under their direction. With Hilgard's disgrace and resignation, another era began, in which Superintendents might survive the Survey. Thorn survived many decades, and wrote a memoir, in effect, in preparation for the Survey's centennial. Mendenhall had virtually an entire new career after the Survey. He was director of the Worcester Polytechnic Institute, and eventually returned to Ohio and Ohio State University. There he assembled a 900 page autobiographical manuscript.[37] He also edited the multi-volume project of the history of Ohio State University.[38] And in 1922, three years before his death in 1925, he published a reminiscence of events back in his young Quaker abolitionist days as his community celebrated the end of slavery and the surrender of General Lee. He had been, all his life, a man who accentuated the positive. That accounted in no small way for his many accomplishment sin the Survey, and also his abrupt and sad departure.

[34] "Is Mendenhall In or Out" Washington Times, page 1, June 23, 1894.
[35] Washington Times, July 8, 1894, p. 8
[36] As cited by manning, 1988, pp. 120-121.
[37] Mendenhall, Autobiographical Notes, in the Mendenhall Papers, Center for the History of Physics, College Park, MD.
[38] Mendenhall (ed), 1920.

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A Change in Direction by Successive Change in the Points of Direction:
The Nadir of the Coast and Geodetic Survey under Gen. W.W. Duffield (1894-1897)

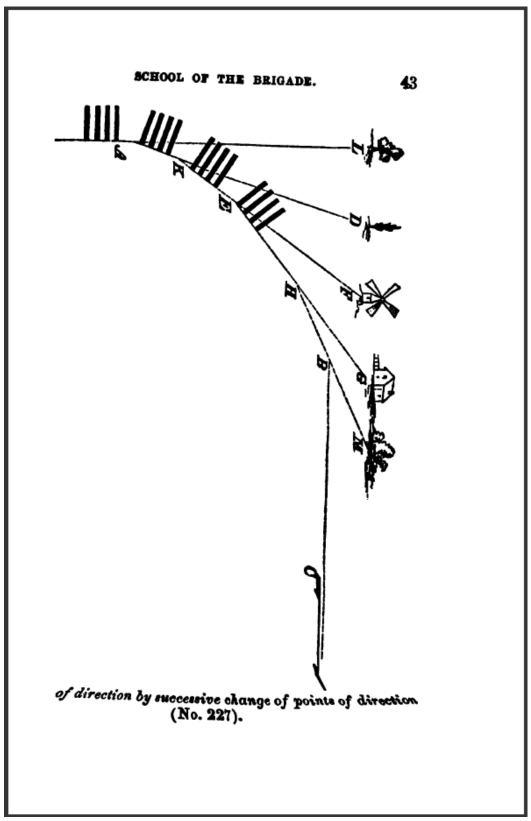
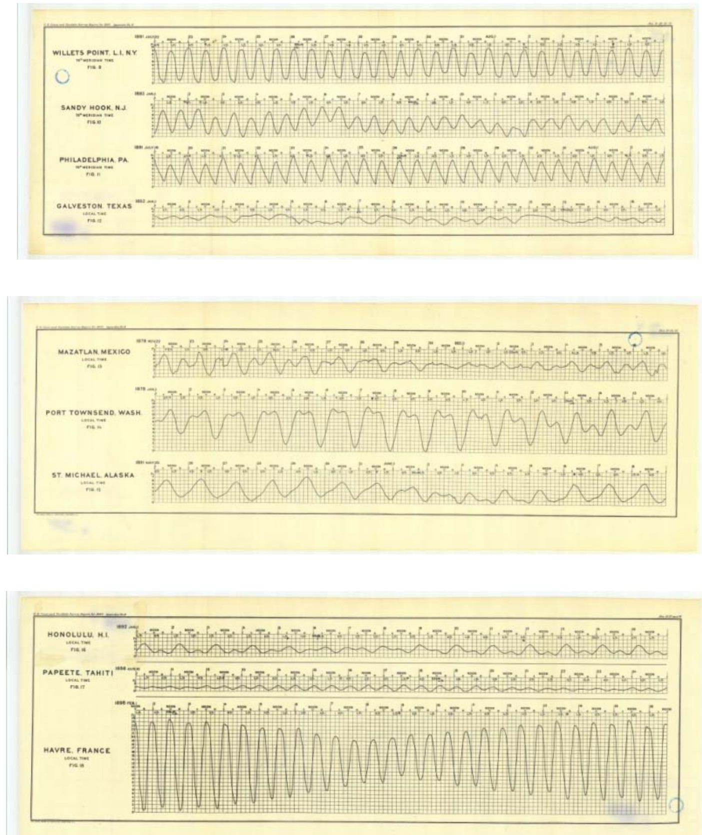


Diagram from *School of the Brigade, and Evolutions of the Line*
By William Ward Duffield (1862)

In retrospect, one of the most important achievements of the Coast and Geodetic Survey during this era was accretion, appendix by appendix, of the disparate sections of what was to become the *Manual of Tides,* under the direction of Rollin Harris, one of the greatest mathematicians in a bureau that had employed some of the finest mathematicians in the country. The Manual will be described later; its presence here sets the tone for the discussion of the nadir of the Coast and Geodetic Survey.



Tidal Curves at various US and foreign tide stations
From Appendix 8, Annual Report for 1897

In essence, the Presidential administrations of Grover Cleveland, Benjamin Harrison, and William McKinley were a series of tides that ebbed and flowed through and over the offices of the Coast and Geodetic Survey. In conjunction with related but somewhat different changes in the composition of Congress, the era of these Presidential tides was like no other in the entire history of the Survey. And even though Presidential tides, by their nature, must both ebb and flow, the recurrent theme of this period was an ebbing away of the leadership, personnel, and integrity of the Survey.

Historically the Survey's annual reports were always carefully neutral, brief, and discrete in discussion of personnel changes. For the annual report of 1895, a new Assistant in Charge of the Office, the first in over a decade, carried on in the classic Survey manner:

"At the beginning of the fiscal year Superintendent T.C. Mendenhall was absent in Europe, and Hon. William H. Pugh, Commissioner of Customs, was designated by the President as Acting Superintendent, and served in that capacity until October 1, 1894.

Dr. Mendenhall's resignation was accepted on September 20, 1894, and the appointment of his successor, Gen. W.W. Duffield, the present incumbent, bears the same date.

"At the close of the fiscal year, Assistant Davidson was relieved of the charge of the sub-office [in San Francisco], and was succeeded by Assistant A.F. Rodgers.'[1]

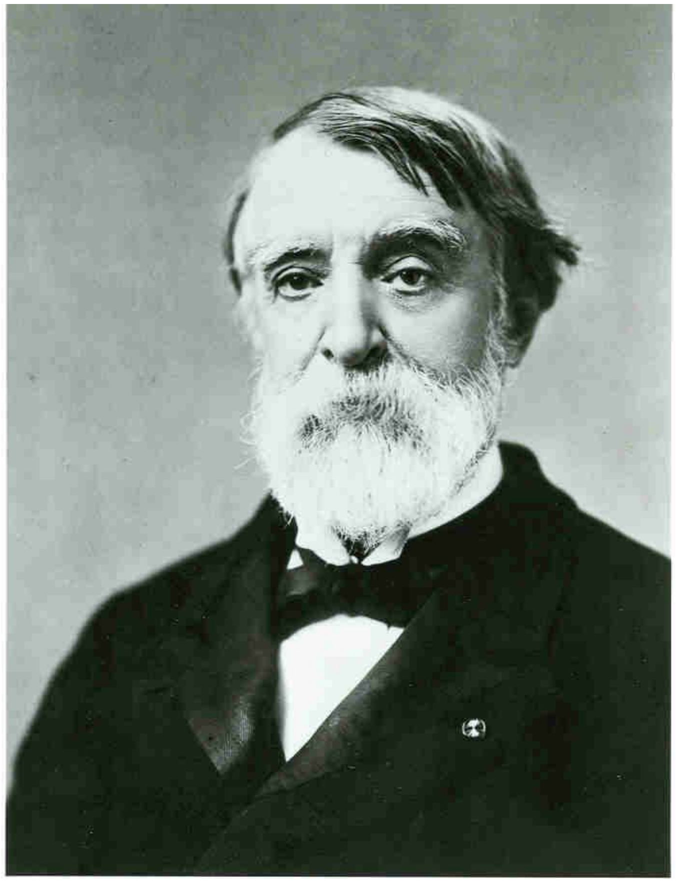
"Assistant B.A. Colonna served as Assistant in Charge of the Office from the beginning of the fiscal year until March 11, 1895, when he tendered his resignation to take effect April 10, leave of absence for the intervening time being granted him. By your instructions of March 11, I was detailed to act as Assistant in Charge of the Office during this interim, and on its expiration was duly appointed to the position by the Honorable Secretary of the Treasury and also directed to act as Superintendent during your absence."[2]

"Mr. Ogden resumed duty as chief of the [engraving] division for the remaining few days of the year and was succeeded on July 1 by Assistant Will Ward Duffield, the consolidation of the drawing and engraving divisions being effected on that date.

"The changes in the personnel of the office due to deaths, resignations, and dismissals have been unusually numerous, but being given in detail in the reports of the various chiefs of divisions, need not be enumerated here.[3]

For the second time in its history, a non-scientist was appointed to lead the bureau. The first such person, Frank Thorn, had become a valued leader of the agency. The second, William Ward Duffield, was another story entirely. Although there had been a tradition of nepotism throughout the Survey's history, never before had a leader installed his own son, a person without any experience in the work involved, as a division leader. There were numerous division slots available to be filled, as the new Superintendent attempted to dismiss most of the leading scientists in the Survey for one reason or another, and he succeeded in several cases. Who was this new leader, and why did he act that way?

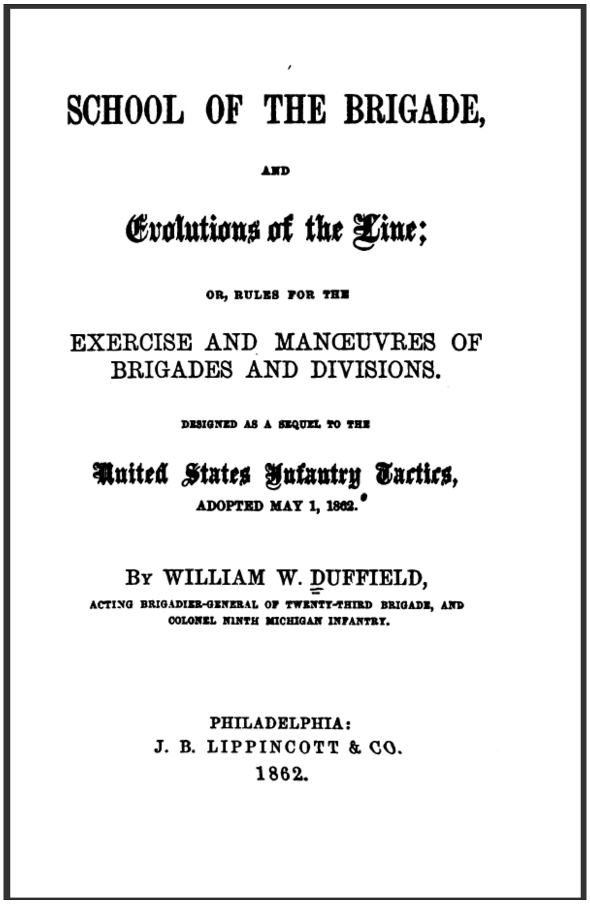
[1] Assistant Andrew Braid, Report of the Assistant in Charge of the Office, Annual Report for 1895, pp. 69-70.
[2] Ibid, p. 90
[3] Ibid., p. 91.



William Ward Duffield (1823-1907)

Duffield was born in Carlisle, Pennsylvania to a prominent family. He graduated from Columbia College in New York in 1842 with a degree in engineering, which was essentially his field for the rest of his life, although he also acquired a law degree in Michigan, his adopted state, and also traveled widely in the United States and the world. He had many talents useful in the military, and he also displayed conspicuous bravery, being wounded as an officer at the front in both the Mexican War and the Civil War. In the Mexican War his talents were recognized, and he ended as a staff officer of General Pillow, and fought at the battle of Chapultepec, the fabled "Halls of Montezuma". He later was sent to California as paymaster for US troops stationed there. He then left the military, and worked as an engineer and superintendent of several railroads in New York, and then later in Michigan and Illinois.

When the Civil War began, he joined an infantry regiment from Michigan as a lieutenant-colonel. His troops fought at the first battle of Bull Run. He transferred to another unit as a colonel. While serving as the commander of the 23^{rd} Brigade of the Army of the Ohio in 1862, he wrote a marching drill text that was widely used in training troops for combat.


SCHOOL OF THE BRIGADE,

AND

Evolutions of the Line;

OR, RULES FOR THE

EXERCISE AND MANŒUVRES OF
BRIGADES AND DIVISIONS.

DESIGNED AS A SEQUEL TO THE

United States Infantry Tactics,
ADOPTED MAY 1, 1862.

BY WILLIAM W. DUFFIELD,
ACTING BRIGADIER-GENERAL OF TWENTY-THIRD BRIGADE, AND
COLONEL NINTH MICHIGAN INFANTRY.

PHILADELPHIA:
J. B. LIPPINCOTT & CO.
1862.

Later he was appointed as the acting military governor of the state of Kentucky. In July, 1863, he arrived in Murfreesboro, Tennessee as commander of the 9th Michigan Regiment. The next day, Confederate forces under General Nathan Bedford Forrest surrounded and defeated the federal army in what became known as the First Battle of Murfreesboro. Duffield was wounded in battle and captured. A month later, he was exchanged for Confederate prisoners. His wounds were serious and long-lasting. He resigned from the military as a Brigadier General in 1863 and returned to Michigan. He resumed his railroad engineering work, which was his profession for most of the rest of his life, although he served as a Michigan State Senator in 1879-80.[4]

In September of 1894, at the age of 71, he was appointed by Grover Cleveland as Superintendent of the Coast and Geodetic Survey. It is not entirely clear why Cleveland made this appointment. In his first term Cleveland had appointed Frank Thorn. Thorn had no background in science, but he was decades younger, was a capable manager of municipal government, and was well known personally by the President, as they were both part of the Democratic party leadership in Buffalo, New York. After his tenure,

[4] See Connolley and Coulter, 1922.

Thorn returned to the Buffalo area, a myriad of civic interests, and his experimentation with potato harvesting machines.[5]

In Cleveland's second administration, he appointed William Ward Duffield. A possible clue to why this happened was the incident of the Lighthouse Bureau. Traditionally, the Coast and Geodetic Survey was represented on the Lighthouse Board. The previous Superintendent, Thomas C. Mendenhall, had resigned in response to the change in administrations, and under medical stress, but he had retained his seat on the Lighthouse Board. The Board and its duties appealed to his professional career in electricity and metrology, and his new position as President of the Worcester Polytechnic Institute afforded him the time to serve on the board. However, on October 29, 1894, Cleveland removed Mendenhall from the Lighthouse Board, and replaced him with Duffield. The New York Times speculated as to why this occurred.

"This change, occurring just at this time, is believed to bear upon a subject that is exciting much speculation in the navy, that of the next duty of Admiral John G. Walker, who was recalled from Honolulu a few months ago by Secretary Herbert, with the intention of placing him in charge of the Naval Academy, which he declined, without giving his reasons for the refusal. For ten years Admiral Walker has exercised great influence in naval affairs, and it is now believed that the reason he declined the much-coveted position was because he is now championing the cause of the navy in a struggle with army officers to secure the control of the Lighthouse Board after the retirement of Admiral Greer as Chairman.

"The lighthouse establishment, in addition to its board of two civilians and two naval and two army officers, consists of a staff of sixteen naval officers as Lighthouse Inspectors and sixteen army officers as engineers. Secretary [of the Treasury] Carlisle is an ex-officio President of the board. Since its organization, with the exception of seven years, the board has been invariably dominated by the navy in recognition of the patent fact that mariners have more to do with lighthouses than the landsmen. There is an impression now that Secretary Carlisle and the President are convinced that lighthouses should be controlled by the Engineer Corps of the army. This, taken in connection with the detail of Col. John M. Wilson, as the chief army member of the board, has warned the navy of impending dangers to its interests.

"General Duffield's sympathies are presumed to be with the army, as he is an ex-army officer. If it is true that the army has captured the board, it is impossible for Admiral Walker to become a member, as he could not serve with a Chairman whose rank was below his. Naval officers stated to-day, with considerable positiveness, that Col. Wilson had declined to be a candidate for the Chairmanship of the board, and had stated as his opinion that the navy ought to continue in control".[6]

Was Duffield appointed Superintendent of the Survey as well as the Lighthouse Board because the President and the Secretary of War wanted to strengthen the power of

[5] See the Thorn chapter for additional information.
[6] "Control of Lighthouse Board" New York Times October 30, 1894.

the Army relative to the Navy? The answer will never be known. However, it would be more than ironic if the Survey's darkest period occurred as part of a maneuver by the US Army against the Survey's nemesis for almost a century, the US Navy[7].

Duffield was in office only a few months when the new all-Democrat 53rd Congress took office in 1895. Congress was hostile to pleas for adequate funding for the Survey, and actually reduced the Survey budget. Further, Secretary Carlisle's son Logan Carlisle served as Clerk of the Secretary, with great powers to affect the hiring and firing of personnel in the Survey. Duffield's major response to belt-tightening of the Survey was disastrous: to save funds, he would dismiss people at the top. Duffield attempted to dismiss virtually the entire leadership of the Survey, although he was only partially successful at this. Those with long experience in the Survey, especially if their work had been based in the home office, a block from the Capitol, could appeal to allies in the government to save themselves. Those who worked farther afield were less lucky. And so it was that, on June 20, 1895, Secretary Carlisle wrote a letter telegraphed to George Davidson consisting of a single sentence:

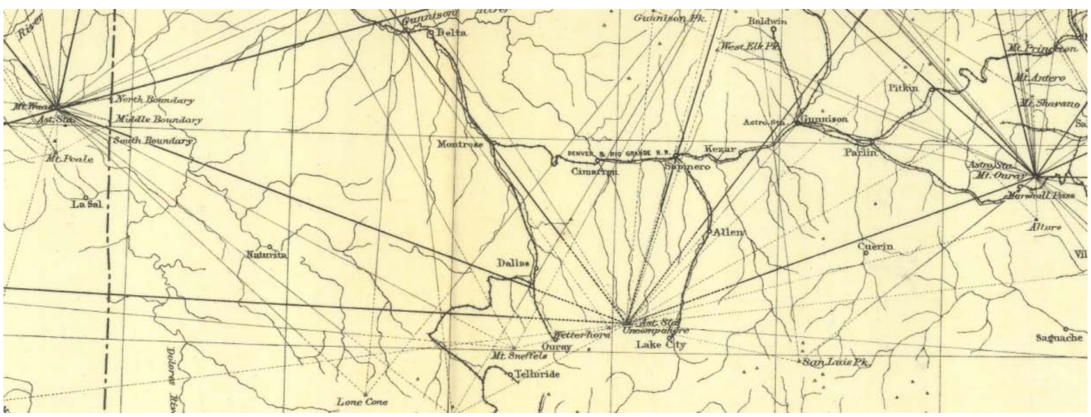
"Your services as an Assistant in the Office of the United States Coast and Geodetic Survey will not be required from and after the 30th instant."[8]

The telegraphed letter was delayed, for whatever reason. Davidson noted on a copy of the letter that he received it only 3 days before the terminus of his position, after 50 years and one month working for the Survey. [9]

Assistant Colonna was forced to resign, as did Frank Parsons, head of the Library and Archives Collection. John E. McGrath, who had commanded so much of the rigorous surveying work on the Alaska/Canada boundaries, was fired. William Dennis, the head of the drawing division, was removed. Duffield attempted to dismiss Henry Odgen as head of the engraving division. Ogden had enough allies to escape dismissal, but the engraving division was taken from him and combined with drawing into one division—so that Duffield's son, William Ward Duffield, Jr., could have a job as head of the division of drawing and engraving. In all, eight assistants were dismissed or forced to resign in the spring and summer of 1895. In a final indignity, \$500 of the son's \$3,000 annual salary was provided for by taking it out of the salary of William Eimbeck, who had guided the epic triangulation surveys of the Great Arc of the 39th Parallel. [10]

[7] For which, see Manning, 1988.
[8] Carlisle to Davidson, Davidson Papers, Box 18. Quoted in King, 1973, p. 278
[9] See King, p. 278.
[10] See Manning, pp. 122-126.

Party of William Eimbeck breaking camp, Uncompahgre Peak, Colorado, 1895



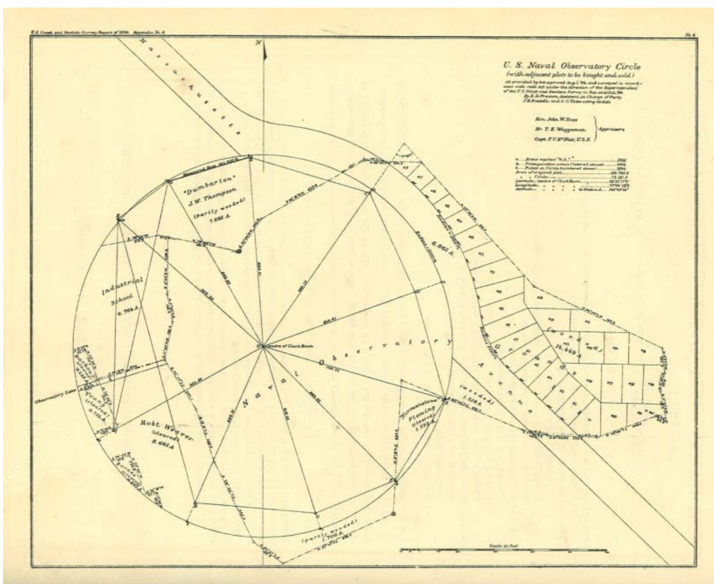
Triangulation theodolite lines from Uncompahgre Peak (lower center)
From the annual report for 1895

Successive Change in the Points of Direction

Duffield became Superintendent on September 20, 1894, and resigned on December 1, 1897, serving slightly more than three years in office, the shortest stint in the history of the Survey. Morale plummeted, some of the most experienced and skilled Survey personnel resigned or were fired, and the budget of the agency was reduced. In some ways, it is a miracle how much work was accomplished during his tenure. To be sure, much of the work was the semi-automatic functioning of very traditional activities in the Survey in the field and in the office, and the completion or expansion of projects begun well before Duffield's arrival. But there were two very different creative triumphs during the Duffield era, created by the draughtsman and oceanographer Adolph Lindenkohl and the mathematician and tidal scientist Rollin A. Harris. As if by main force of intellect alone, these men managed to make dramatic advancements in their science and its presentation to the world. The chapter will end with their signal achievements.

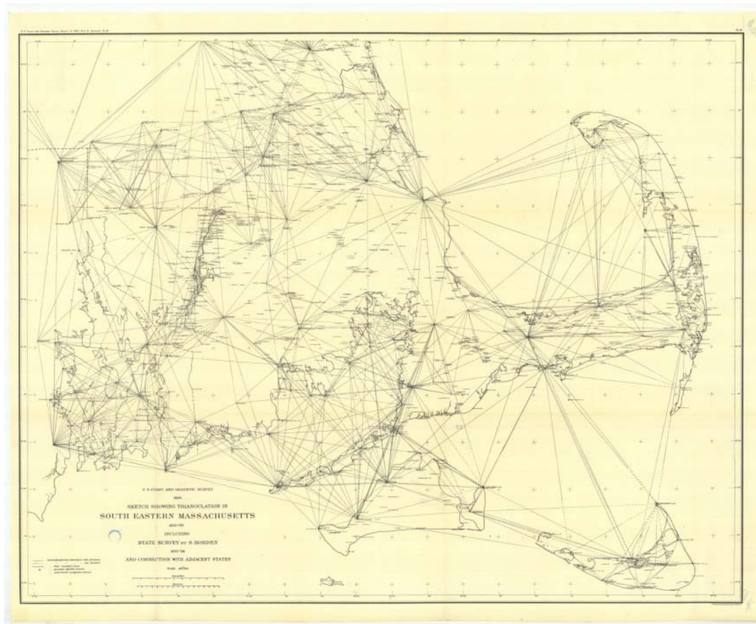
For more than a decade before Duffield, the Survey had been directed by the U.S. Congress to play a major role in the regional development and planning of the Capital. After the City of Washington and the County of Washington had been united, forming the present jurisdiction of the single unified District of Columbia, the Survey was assigned the task of developing a geodetic framework for the District, and then mapping the District's topography at extremely large scale (1:10,000). The Survey also tied the positions of many federal research observatories and labs into the emerging national geodetic network based on the Arc of the 39th Parallel system and its expansions north and south to form the geodetic foundations for state mapping and land ownership systems.

During Duffield's tenure, the Survey assisted the Navy to plan and precisely position its new Naval Observatory off Massachusetts Avenue, in what was then a rustic area outside the city. Since the Naval Observatory would conduct observations of terrestrial magnetism, the Observatory grounds were developed as an almost perfect circle centered on the site of the magnetic observatory, in the hopes, unfortunately unsuccessful, that the protective radius would shield the Observatory from electro-magnetic interference.



The site of the new Naval Observatory, Washington, DC, as surveyed by Survey personnel in 1894-95. No. 4, Annual Report for 1896.

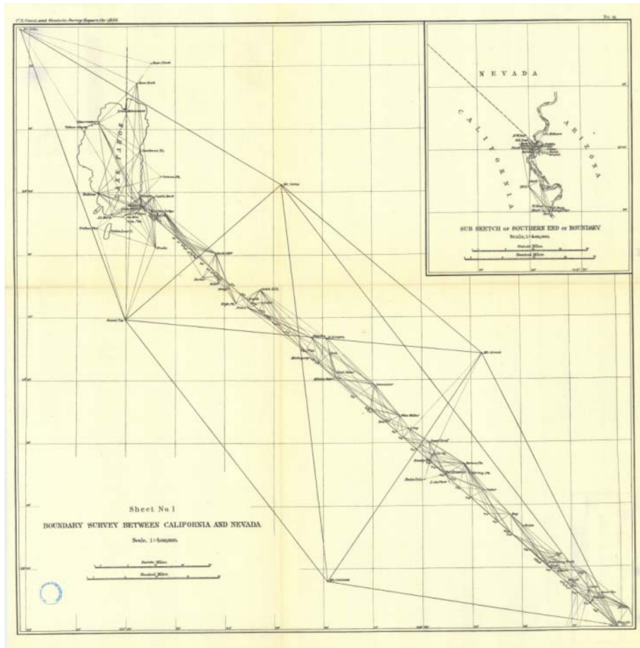
The state of Massachusetts had traditionally had rigorous state surveying programs inter-linked to the Survey's geodetic network. Geodetic data from surveys dating back to 1843 and the very beginnings of Survey work in Massachusetts following the death of Hassler and the ascendancy of A.D. Bache that very year were compiled and corrected, and errors distributed, to create the most rigorous state-level geodetic network extant in the country at that point.



Triangulation Stations in South-Eastern Massachusetts, 1843-1890, including ties to state surveys and stations in adjacent states. No. 10, Annual Report for 1894

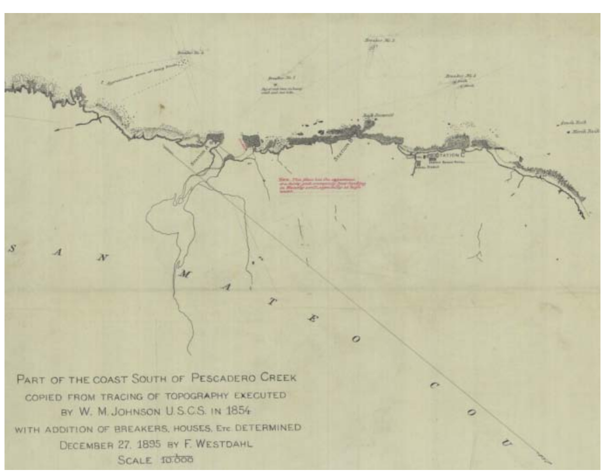
Another long-running project of the Survey was the re-survey of the oblique boundary line between California and Nevada. The straight line segment was a unique boundary segment in American history, as it was defined verbally as a “straight line between two points”, the points in question being in or on water (Lake Tahoe and the middle of the Colorado River). The initial field work was completed during Duffield’s tenure, although re-surveys and error corrections delayed the final description and completion of the project for several additional years[11].

[11] See Sinclair, 1901.



Sheet 1, Boundary Survey between Nevada and California.
Sketch 16, Annual Report for 1896

On the Pacific Coast, a major re-survey of San Francisco Bay continued, under the direction of Augustus Rodgers, who had succeeded George Davidson as Assistant in Charge of the Survey for the west coast. The Bay re-surveys were triggered by the state and rate of changes in the bay and its harbor and navigation systems. Many areas of the California coast were also changing rapidly. Assistant Ferdinand Westdahl made many small "spot" re-surveys of specific places, as the request of coastal agencies and enterprise owners. One of his projects was a re-survey of a section of the Pacific coast very near Monterey, being developed as part of the Pebbly Beach Hotel (now Pebble Beach Resort and Golf Course).



Shoreline and Breakers near Pebbly Beach Hotel based on a tracing of the 1854 t-sheet and re-surveying by Ferdinand Westdahl in December, 1895.

One can only imagine Westdahl's sadness in his labors, as he had worked productively with and for George Davidson for decades. In particular, Westdahl had collaborated with Davidson to create hundreds of coastal views that were reduced and re-worked by Cleveland Rockwell and others, and engraved for Davidson's magnum-opus, the Pacific Coast Pilot, 4th revised edition. In 1894, some sort of submarine earthquake and possible tsunami had occurred at Cuyler Harbor on San Miguel Island in the California Channel Islands. Westdahl and a crew were dispatched to re-survey parts of the island and the reconfiguration of the bottom of Cuyler Harbor after "The Upheaval" as it was called. Westdahl did a number of sketches from specific points. At the end of the work, he requested the ship captain stand offshore from the northern edge of the island and steam parallel to the island coast past the other end of the island as they returned to Santa Barbara. As though it were a final run for old times' sake, Westdahl used the cruise to sketch what became the very last coastal view, taken from life, ever produced by the Coast and Geodetic Survey.

View of Cuyler Harbor, San Miguel Island by Ferdinand Westdahl.
Sketch No. 3 on T-2211 (1895)

The gravity of gravity research in Duffield's tenure

Gravity research in the Survey had begun under the mercurial genius Charles S. Peirce. Peirce had many enemies and a few significant allies in the Survey and the larger American scientific community. As it happened, he was finally pushed out of the Survey by one of its best leaders, Thomas Mendenhall. There was an element of professional disagreement to his ouster, as Mendenhall had invented his own pendulum system, different than Peirce's, and Mendenhall had his own approach, favoring rapid observations of relative gravity at many points, as opposed to meticulous observations to determine absolute gravity at a very few points. Peirce's successor in the gravity work was Eramus Darwin Preston, who, possibly in response to the controversial political context of Peirce, appeared to prefer doing his gravity work as far away as possible from Washington DC. Hence, Preston worked in Hawai'i, Africa, and a host of remote islands far from the Potomac's fragrant shore. However, when Duffield ascended in 1894, he fired or forced to resign a major part of the office leadership in Washington, including Assistant in Charge B. Colonna, who had been a particular friend and protégé of George Davidson. Colonna was only too glad to leave the sordid politics of the office behind him in his active retirement in Washington.[12] Duffield chose E.D. Preston to succeed

[12] See Sharle, 1999.

Colonna as Assistant in Charge of the office, possibly because his gravity work in the far tropics had isolated him more than any other of the long-term personnel in the Survey.

With Preston now confined to the capital, the major part of the gravity work fell to George Rockwell Putnam. Putnam completed a series of gravity observations at stations situated in a belt of latitude across North America along, and above and below the major Arc of the 39th Parallel network. Further, the stations differed deliberately in terms of their relationships to elevation above sea-level, to the coasts on both the Atlantic and Pacific, and to large masses of mountains, with many of the stations situated on isolated peaks. The gravity values acquired at each site were then corrected and adjusted by various types of corrections designed to allow gravity values to be compared to each other in light of their local and regional geologic contexts. The USGS geologist Grove King Gilbert then "followed behind" Putnam, creating a local mass model for each observation site, using the new USGS contoured topographical maps, in a method pioneered two decades earlier in 1873-74 by Charles S. Peirce at Hoosac Mountain. Putnam and Gilbert co-released their data and analysis in 1894.

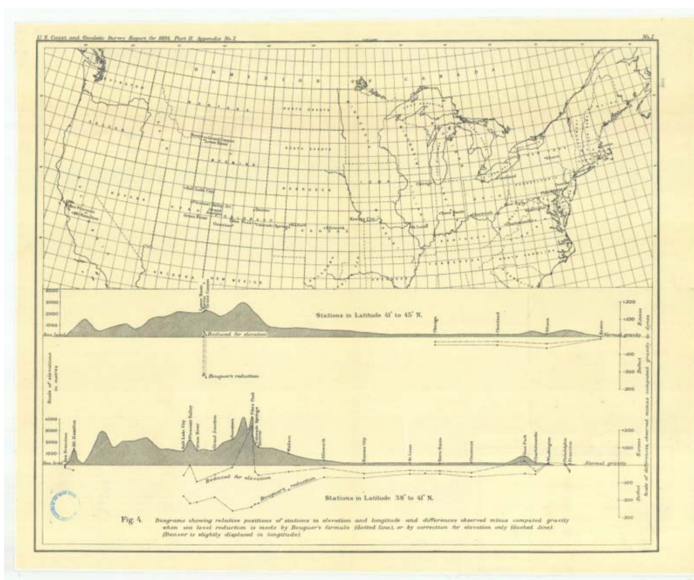


Diagram showing relative positions in elevation and longitude and the differences observed minus computed gravity based on sea-level reductions made by Bouguer's formula, of gravity stations between 38 to 45 degrees latitude. Figure 1, Appendix No. 1, Annual Report for 1894.

Putnam determined, after making various compensations, that the data showed a clear pattern of relative excesses of observed gravity, compared to computed gravity, for observations made on or over the Atlantic and Pacific Oceans, while on the continent of North America there was a clear pattern of observed gravity deficiencies, compared to computed gravity for these terrestrial locations.

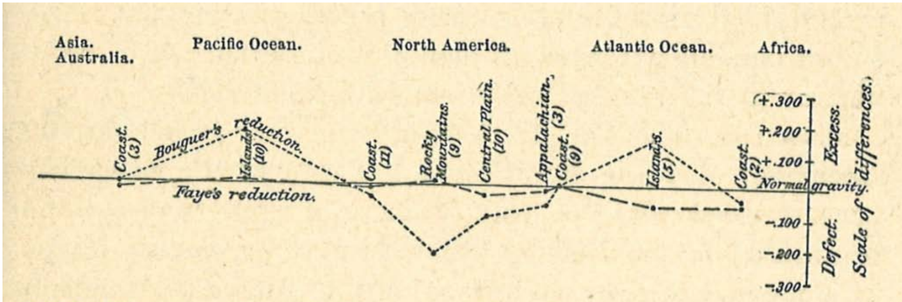


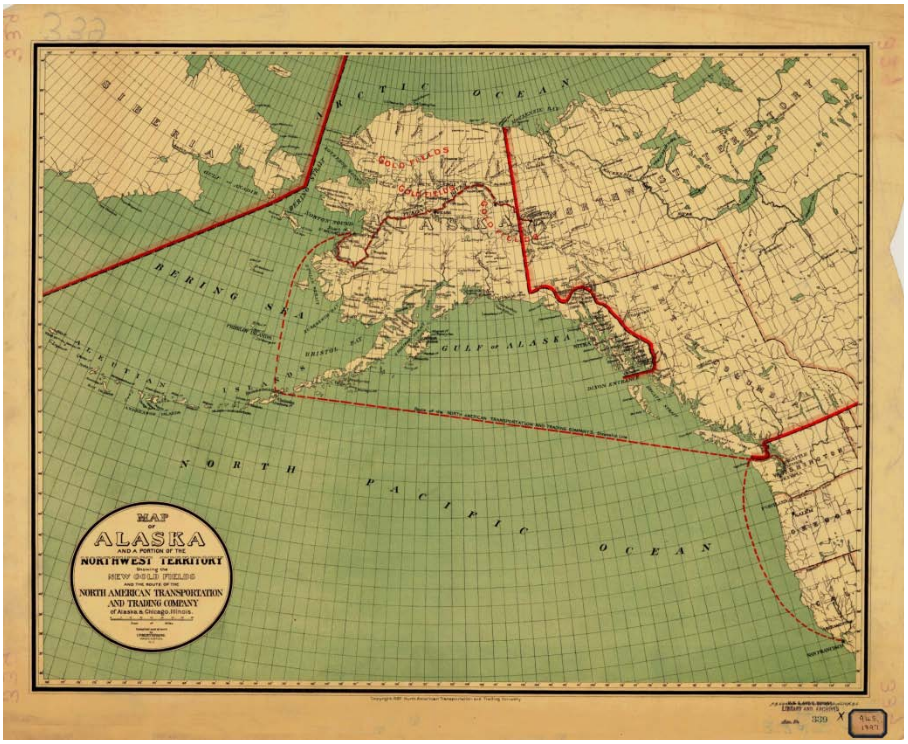
Fig. 2.—Differences observed minus computed gravity (in dynes) from C. and G. S. observations. The figure in parenthesis show the number of stations included.

Differences observed in gravity measurements minus computed gravity based on Coast and Geodetic Survey stations occupied on the Pacific and Atlantic Oceans and North America, from George Rockwell Putnam's 1895 paper on the transcontinental series of gravity measurements.

Soon after this, Putnam's gravity work ended, as he was assigned to survey work in Alaska, and then the Philippines, after the Survey acquired responsibilities there after the Spanish-American War. The gravity work would fall to major Survey scientists like John Hayford and William Bowie, and later on Nicolas Heck. It would be many decades before the gravity observation patterns secured and identified by Putnam would be explained through a new model for earth structure and dynamics now summarized in the shorthand of plate tectonics.

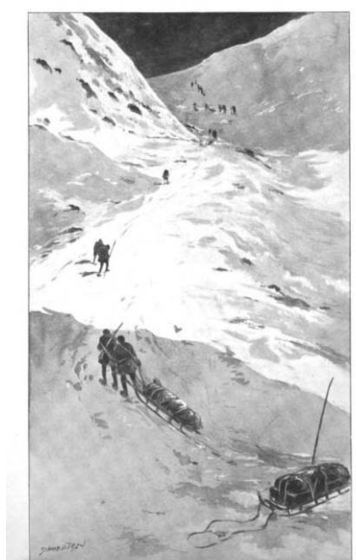
The Call of the Wild North

There was one major exception to the general contraction of the personnel and work of the Survey under Duffield—Alaska and the Yukon and approaches to it. Gold had been discovered in British Columbia in 1882, and every succeeding year had seen other discoveries further north. The largest discoveries yet were found in the region of the Klondike River of northern British Columbia. The name "Klondike" was soon expanded to cover a vast area centered on the Yukon River watershed in Alaska and the Yukon Territory of Canada. Within a few years, the small deep-water port of St. Michael on the Bering Sea became one of the busiest harbors on the west coast of the Americas, while the ancient Indian trade trails from the southeast coast over the mountain passes to the Yukon were re-purposed for vast migrations of would-be gold seekers.



Map of Alaska and Routes to the Gold Fields showing the routes
of the North American Transportation and Trading Company (1897)

The ancient routes from the Chilkat River to the Yukon shown on the Coast Survey's maps made by the Tlingit leader Kohklux and his wives were now displaced by other trails leading to other destinations.

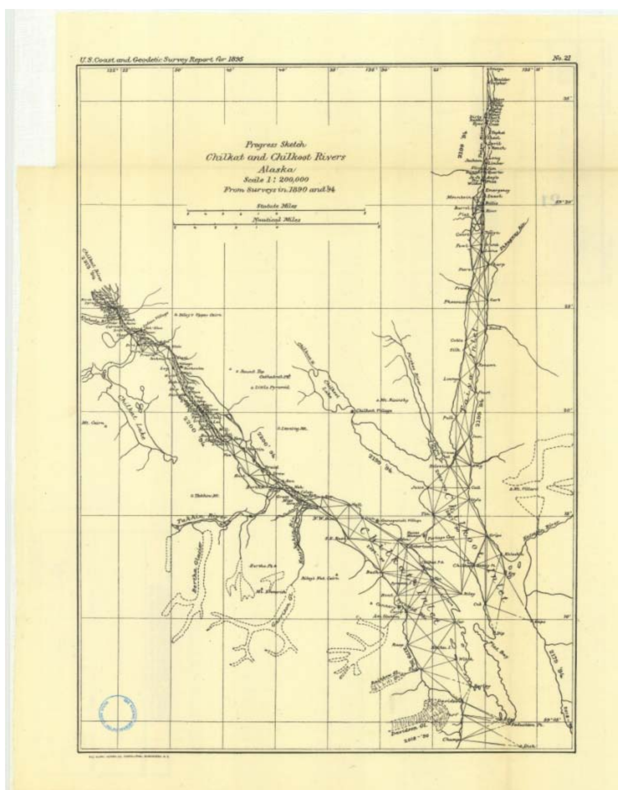


CHILKOOT PASS.

Chilkoot Pass, Alaska, from the Chicago Record's Book for Gold Seekers, 1897

Duffield had merged the Drawing and Engraving Divisions in order to provide a leadership position for his son, William Ward Duffield, Jr. The son wanted in on the Klondike excitement, so Duffield dispatched him to Alaska as nominal leader of the surveying expeditions. As a result, Duffield, Jr. is listed as one of the "Alaskan explorers" in Marcus Baker's Geographic Dictionary of Alaska.[13] Duffield Senior even shows up as a peninsula. "Duffield peninsula, forming the northern end of Baranof island, Alexander Archipelago. So named by Moore, 1895, after Gen. William Ward Duffield, Superintendent of the Coast and Geodetic Survey."[14]

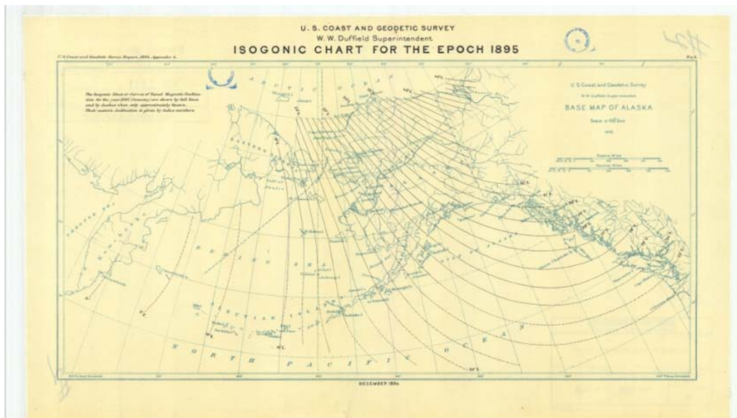
The Survey responded to the great push to Alaska by sending parties to establish geodetic control for mapping the new routes and transportation infrastructure, like railroads, that would eventually parallel the new routes. The surveys of the Chilkat and Chilkoot river valleys are instructive. Pre-Gold Rush, the land trail systems over the mountains to the interior were essentially equivalent. However, the Chilkoot system offered a deep water port at Skagway, at the head of the Chilkoot fiord, and almost all the miners would come in by ship from the south to try their luck. So Skagway on one side of the trail system, and Whitehorse on the other end, at the main stem of the Yukon, became cities almost overnight.



[13] Baker, 1906, pp. 29-30.
[14] Baker, 1906, p. 227.

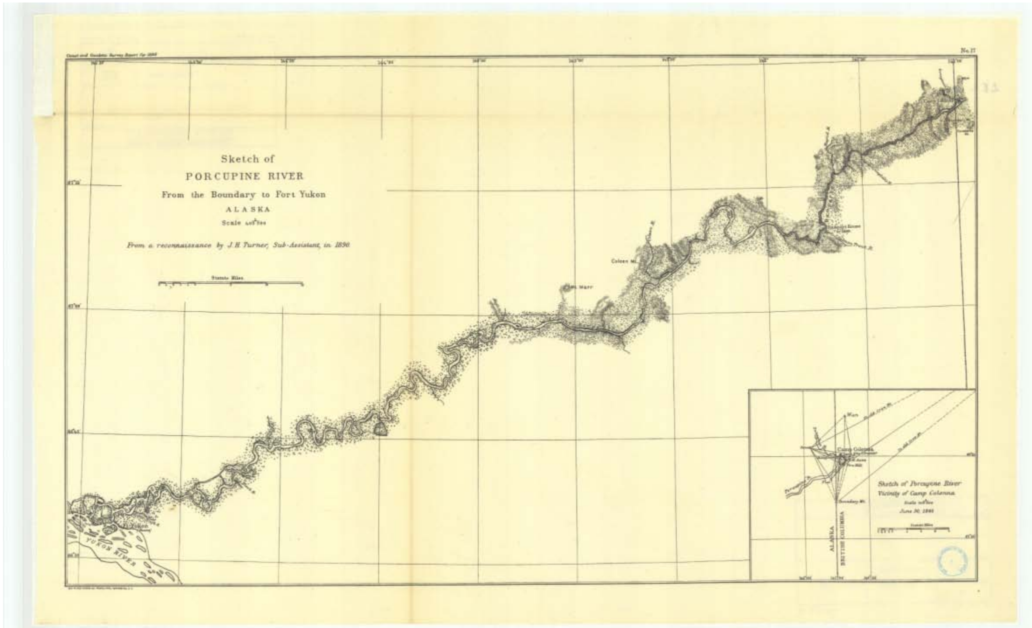
Chilkat and Chilkoot Rivers, showing triangulation stations occupied.
Sketch 21, Annual Report for 1895

The Gold Rush involved travel by land and by sea and river, over large areas of uncharted water and terrain. A series of temporary magnetic observatories were set up in various areas to acquire sufficient data to upgrade new isogonic charts of magnetic declination covering vast areas of eastern Siberia, the Bering Sea, and Alaska and the Yukon.



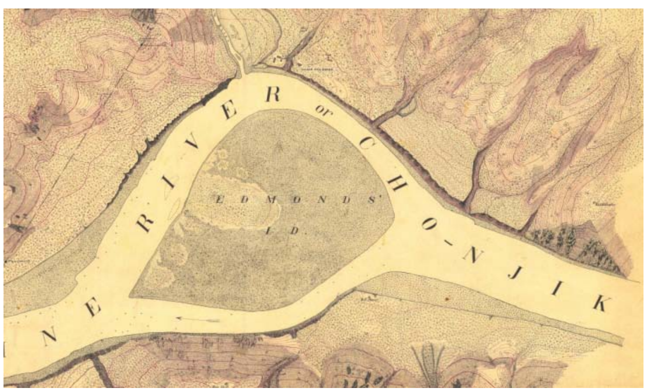
Isogonic Chart of Magnetic Declination for the Epoch 1895
No. 2, Annual Report for 1894

During the Thorn superintendency, American and British and Canadian teams had occupied observatory sites near or at the 141st meridian to finally determine with great accuracy the vast boundary segment running from near Mt. St. Elias north to the Arctic Ocean. In Duffield's tenure, maps related to the journeys and explorations made in conjunction with the boundary observatories were developed and published as essential field guides for those bound to the gold fields. An excellent example was the map of the Porcupine River from where it emerged from Canada, the site of the 1890 base Camp Colonna, down to that river's intersection with the main Yukon River at Fort Yukon.



Sketch of the Porcupine River, from the Canadian boundary to Fort Yukon, as surveyed by J.H. Turner in 1890. No. 17, Annual Report for 1895.

There were winners and losers in this enterprise. In 1890, the original Survey personnel were careful to map the river using both its English name and its Gwich/in name Cho-Njik, in the Athabascan language family. Only five years later, only the name Porcupine River survived.



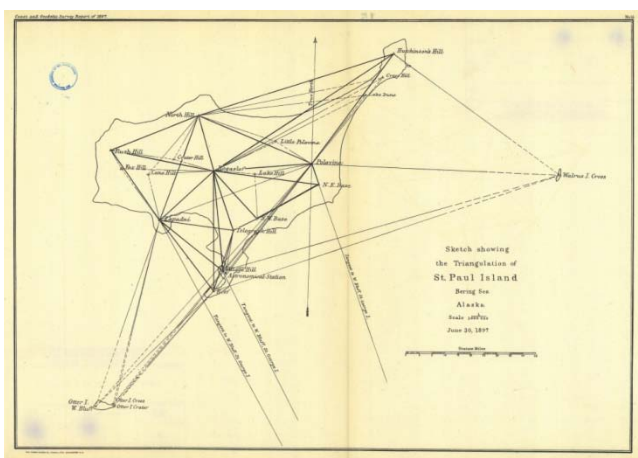
A section from T-2066, Camp Colonna (seen above the island near the final letter "R" in River), 1890

George Putnam, the gravity researcher previously discussed, was sent to Alaska for a combination of Survey work fulfilling various objectives. At the beginning of his work, in 1897, he and his crew re-surveyed St. Paul Island in the Pribilofs, along with the major outlier small islands around St. Paul, for updated mapping of the fur seal rookeries.

PHOTOGRAPH FROM COAST AND GEODETIC SURVEY, 1897.

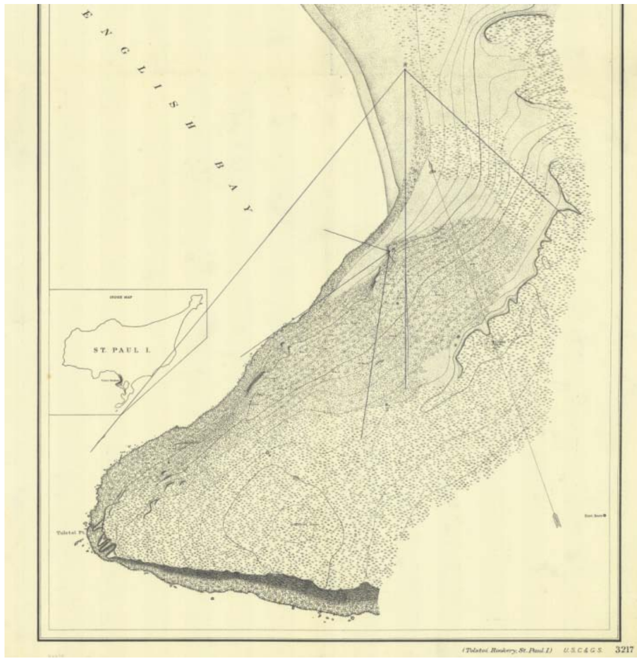
Topographic mapping party on St. Paul Island in Bering Sea. The author is at the plane table, with rod-men and recorder.

George Rockwell Putnam and party surveying on St. Paul Island in the Pribilofs,
Reprinted in Putnam's *Sentinel of the Coast*, 1937



Sketch showing the triangulation of St. Paul Island.
No. 15 in the Annual Report for 1897.

The Survey's 1897-98 maps of the fur seal rookeries was the third American enterprise to map the seal islands, after Henry Elliott's pioneering efforts in 1871-74, and the Stanley Brown map series created 1891-92. The third exercise, under Putnam, included the geometry of the system of permanent camera viewpoints created to monitor the fur seal herds by consistent repeat photography of the rookeries during their brief and chaotic breeding seasons.

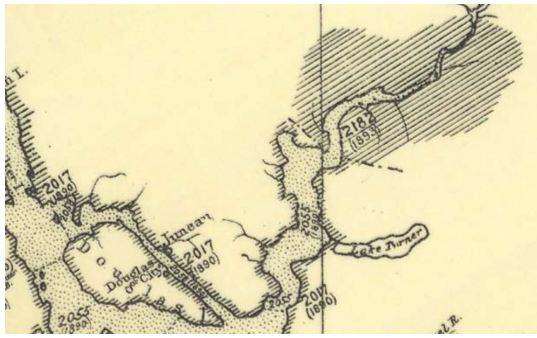


A portion of Chart 3217, the Tolstoy Rookery on St. Paul Island, the Pribilofs, with camera viewpoints and camera view angles, as published in 1898.

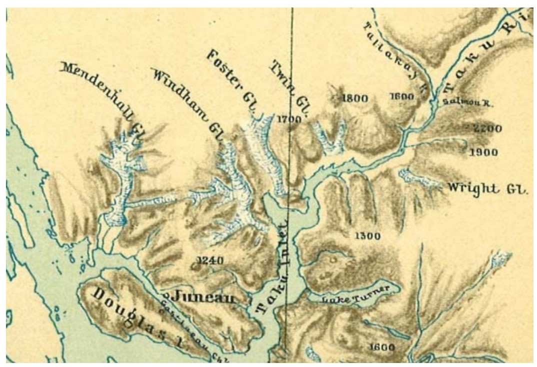
The Great Cartographic Collaboration and Experiment with Petermann's

Petermann's Geographische Mitteilungen was founded by August Petermann in Gotha, in what later became Germany, in 1854. It is unclear when direct connections between Petermann's and personnel of the Coast Survey began, but they quickly became extensive. Petermann's was for quite a long time probably the premier geographic/cartographic journal on the planet. Several of the specialty subject areas of Petermann's were oceanographic maps, and maps related to polar lands and seas. After the American acquisition of Alaska, the official cartographic subjects of the Survey developed in directions that closely paralleled those of Petermann's, although there were significant differences. Chief among these were the higher level of cartographic production in Petermann's, and especially Petermann's skills in chromo-lithographic production and printing.

In the era before, during, and after Duffield's tenure, there were numerous examples of publications of maps of essentially the same areas and themes in the Survey and in Petermann's, often involving the work of the same Survey personnel in both cases. Their similarities and differences are illuminating.



A portion of Sketch 4, the progress of surveys in South-East Alaska showing
Juneau to the Taku River estuary, from the Annual Report for 1897



A section from the Coast Districts of South-East Alaska showing Juneau
to the Taku River estuary by Adolph Lindenkohl, published in 1894
in Petermann's Geographische Mitteilungen

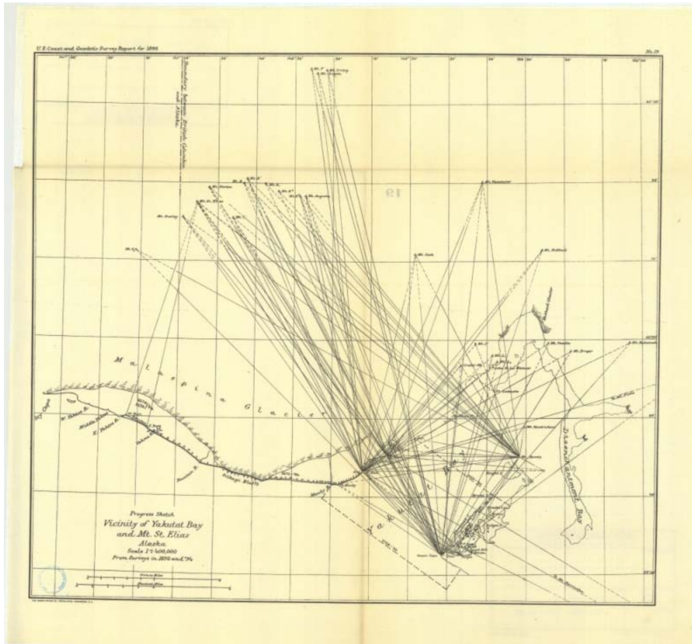
Adolph Lindenkohl and his brother Henry Lindenkohl were two of the best draughtsmen in the Survey, and they had many other cartographic and surveying skills. Adolph Lindenkohl created the Juneau to Taku map presented in Petermann's, but it is highly likely he also drew, or oversaw the drawing of, the comparable map in the Survey's 1897 Annual Report. On the one hand, the Survey map is rudimentary by design—it is a monocolor work progress map, showing areas initially surveyed in the Taku estuary by crosshatching, and actual registered and numbered t-sheets and h-sheets produced shown with their numbers and map extents. The Petermann's map is much more detailed in topographic relief and the nature of the glacier systems in the valleys. Could it be that the Survey did not feel compelled to publish Lindenkohl's detained topography because it was already extant in Petermann's? It is entirely unclear what the understanding was between the two enterprises, but a major pattern emerged in this era, in which the same Survey data was published in both venues, with entirely different production values and designs. Sometimes the Petermann's versions preceded the Survey versions, and sometimes the Petermann's versions came later.

One example of many is the critical convergence of Mt. St. Elias, the Malaspina Glacier, and Yakutat Bay, at the northern end of the "panhandle" of Alaska where the

US/Canadian border turned straight north at 141 degrees longitude. Lindenkohl first published this area in Petermann's in 1892.

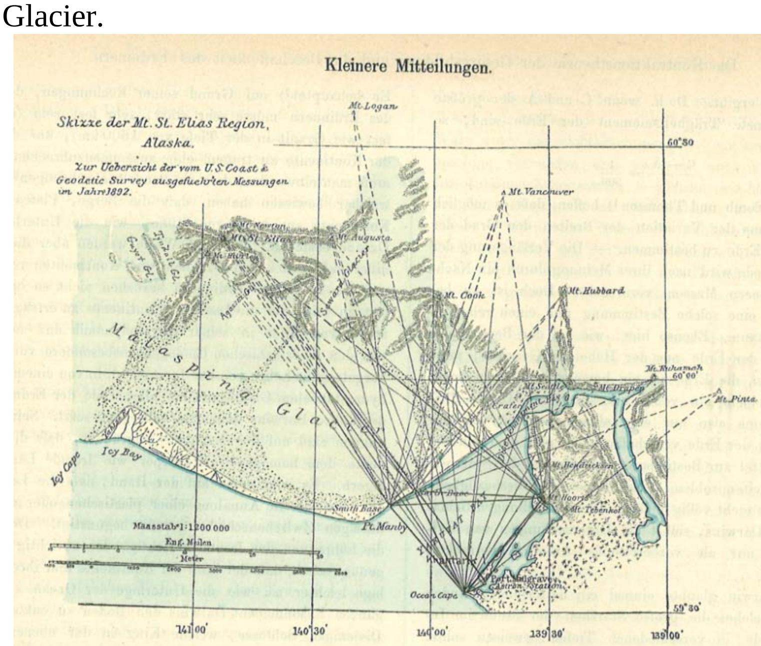
Mt. St. Elias and Malaspina Glacier, Adolph Lindenkohl, published
in Petermann's Geographische Mitteilungen, 1892.

In 1895, Lindenkohl published a progress sketch in the Survey Annual Report, with the same mapped area, overdrawn with theodolite azimuths from the triangulation surveys from the field seasons of 1892 and a re-visit during the 1894 season.



Progress sketch, vicinity of Yakutat Bay and Mt. St. Elias, from surveys
In 1892 and 1894. No. 19, Annual Report for 1895.

But in 1893, a year after the initial reconnaissance work, Lindenkohl published a map in Petermann's with exactly the same set of 1892 theodolite azimuths, but also much delineation of the complex glacier field and its relation to the mountain ridges and peaks that surrounded the glacier, as well as the moraines and post-glacial features adjacent to the Malaspina Glacier.



Sketch of Mt. St. Elias region, with an overview of measurements performed in 1892, by Adolph Lindenkohl, published in 1893 in Petermann's Geographische Mitteilungen.

It is possible that the superior production facilities and capabilities of Petermann's were in a sense an inspiration and laboratory for more sophisticated cartography in the Survey. These more elaborated maps of the Survey emerged as published, sellable maps and charts, rather than the more rudimentary and monocolor maps that were the staples of the Annual Reports. An example of this pairing is Lindenkohl's map published in 1892 in Petermann's showing an overview of modern research in Alaska. The multi-color map showcases exploration of the Yukon River going back to Dall and the Western Union Telegraph Expedition, and the line of monuments sited in along the 141st meridian boundary between Alaska and the Yukon Territory. There are many broad areas of blankness, representing lack of reliable data, but in other areas there is a clear depiction of the general terrain relief, the organization of river systems, and some of the major transportation routes in use at the time.

Overview of modern research in Alaska, by Adolph Lindenkohl, published in Petermann's Geographische Mitteilungen, 1892.

Five years later, in 1897, the Survey published a dramatic oblique multi-color chromo-lithograph map of the overland gateway to the new gold fields, from the coast along the Chilkat and Chilkoot Rivers over and down to the tributaries and main stem of the Yukon, down to and below the juncture of the Porcupine River with the Yukon. The map essentially summarizes what was by then over 30 years of exploration by Survey personnel, presented in a dramatically oblique format registered as a numbered chart in the 3000 series, the chart numbers the Survey reserved for unusual, experimental, and "one of a kind" maps. Could it be that Lindenkohl and the Survey had used Petermann's as an experimental platform to develop what was for them a completely new map type?

Chart 3100 Juneau to the Porcupine River, published in 1897

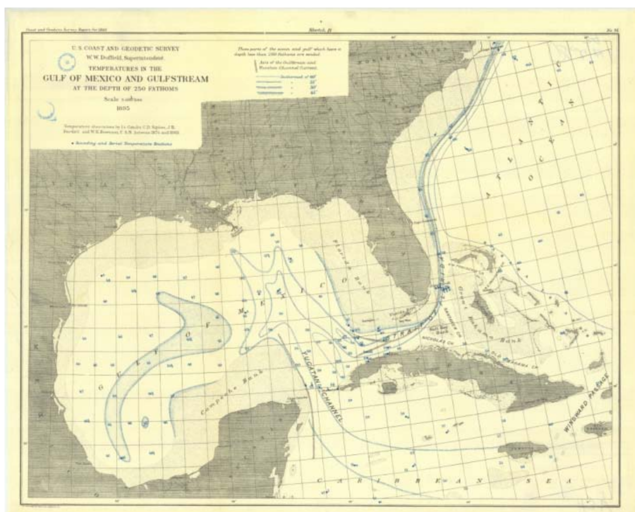
It certainly appears to be the case that Adolph Lindenkohl used Petermann's as a venue for his elaborated masterpieces of oceanographic mapping. Apart from his normal duties in the Drawing Division, and his field work and mapping during the Civil War, Lindenkohl over decades applied himself to analyzing the patterns and distributions of then relatively scarce oceanographic data, as had been acquired by Survey personnel on Survey ships like the Blake, and the Fish Commission ship the Albatross. This evolved process was beautifully described in a memoir written by his dear friend and colleague Henry Ogden in1905, after Lindenkohl died in 1904.

> "Mr. Lindenkohl was a man of marked ability in his profession. He was not only a draughtsman; his studies had led him through a range of subjects that prepared him for the discussion of data passing through his hands, but not always content with this, he would search independently for missing links until he might have sufficient facts to formulate a theory. It was the good fortune of the writer to have close association with him for many years, during which time he could observe his methods and realize what a vast fund of knowledge he had stored away and how oftentimes he

> had collected facts piecemeal through years of research with a definite object in view. *He spent much of his leisure time in studying the vast physical problems relating to the earth, devoting himself especially to physical geography, oceanography, and deep-sea temperatures, densities, and currents.* Numerous articles upon these subjects were written by him and have been published as appendices to the Coast and Geodetic Survey annual reports, in *Petermann's Mitteilungen*, and in the *American Journal of Science*".[15] (Emphasis added)

The process of initial description of the phenomena and their patterning in Survey appendices, and then their elaboration in Petermann's, can be seen over and over in Lindenkohl's papers and maps published during Duffield's tenure. I t was one of the very few bright spots in the history of the Survey in these troubled three years.

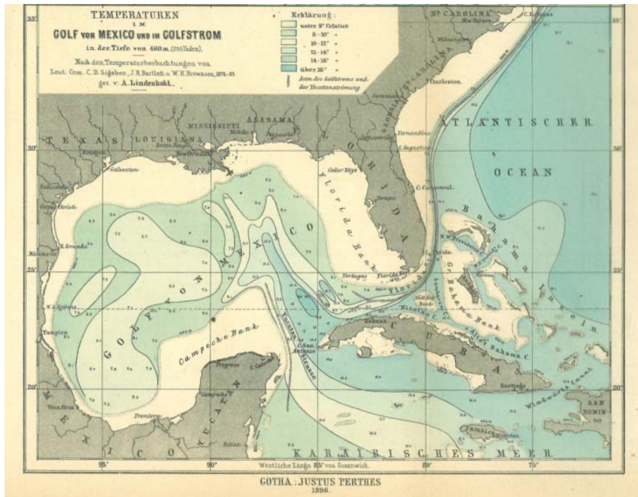
In 1895, Lindenkohl published this map on deep water temperatures in the Gulf of Mexico and the Gulf Stream, based on data that began with the very first work of the Survey onboard the Blake in the 1870s.



Temperatures of the Gulf of Mexico and Gulf Stream at the depth of 250 fathoms
From data acquired between 1874 and 1883, by Adolph Lindenkohl.
Sketch 34, Annual Report for 1895

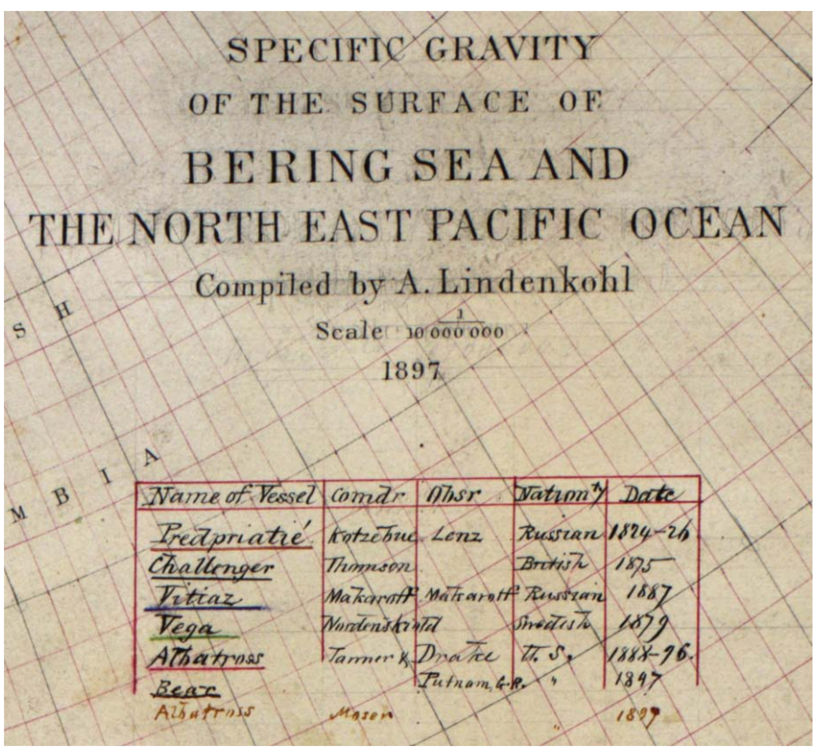
A year later, his Petermann's version was published. Apart from the chromo-lithography, the major change involves the differing class boundaries of the sets of seawater temperatures in the Lindenkohl maps, which are not just transformations between the Celsius and Fahrenheit temperature scales, but different data classes.

[15] Ogden, 1905, pp. 296-297.



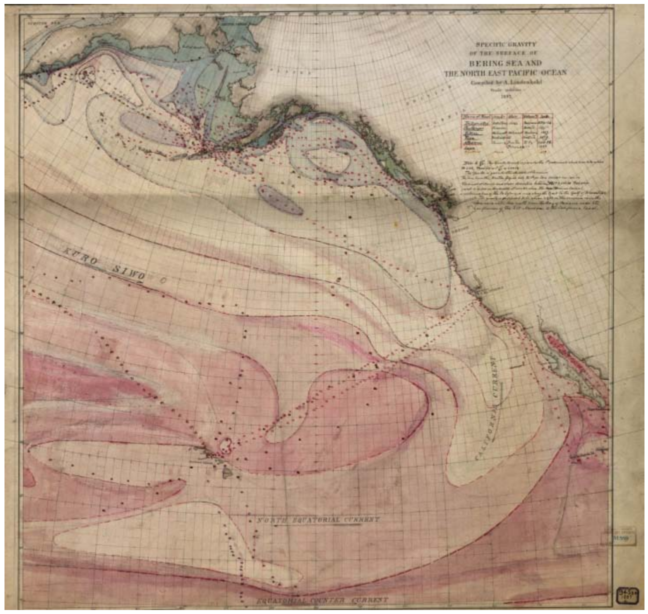
Temperaturen im Golf von Mexico und im Golfstrom in der Tiefe
von 460 meteren (250 Faden). Gez von Adolph Lindenkohl,
published in Petermann's Geographische Mitteilungen in 1896.

A final example gives a vivid demonstration of Lindenkohl and his personal synthesis of an entire generation of ocean deep sea data and the real beginnings of modern oceanography. In 1897, he completed a hand-drawn and colored manuscript map of data on the specific gravity (density) of surface seawater obtained in the entire North-east Pacific and the Bering Sea by cruises of some of the most legendary foundational research ships and scientists in 19th century oceanography.



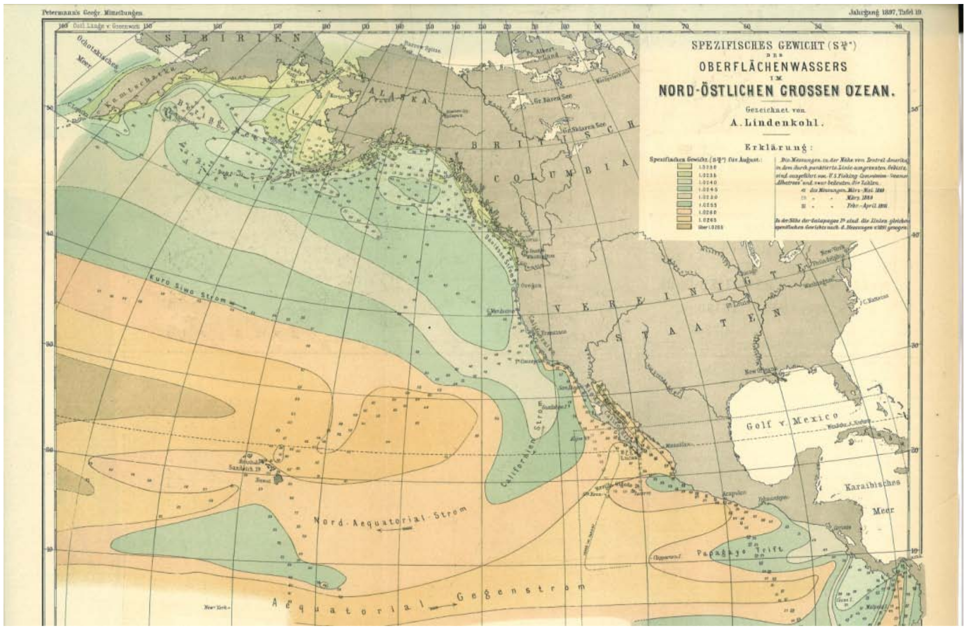
Title and list of ships, commanders, observers, nationalities, and dates, for data on the specific gravity of surface seawater, obtained between 1824 and 1897. Compiled (and drawn) by Adolph Lindenkohl.

The data from specific cruise lines was then analyzed and synthesized by Lindenkohl into color-coded chloropleth regions in his manuscript map.



Specific Gravity of the surface of the Bering Sea and the North-East Pacific Ocean, compiled by Adolph Lindenkohl, 1897. Manuscript map from the Survey Library and Archives Collection, now in the Library of Congress Geography and Map Room.

Later that same year, the same data set, with additional data for the eastern tropical Pacific Ocean, using the same data classes but a very different color-coding scheme, was published in Petermann's.



Spezifisches Gewicht des oberFlächenwassers im Nord-Őstlichen Ozean, gezeichnet von A. Lindenkohl, published in 1897 in Petermann's Geographische Mitteilungen.

Lindenkohl's map is a tour de force of 19th century oceanography. His works, and that of one other scientist in the Coast and Geodetic Survey, are the forlorn jewels in the troubled tenure of General Duffield.

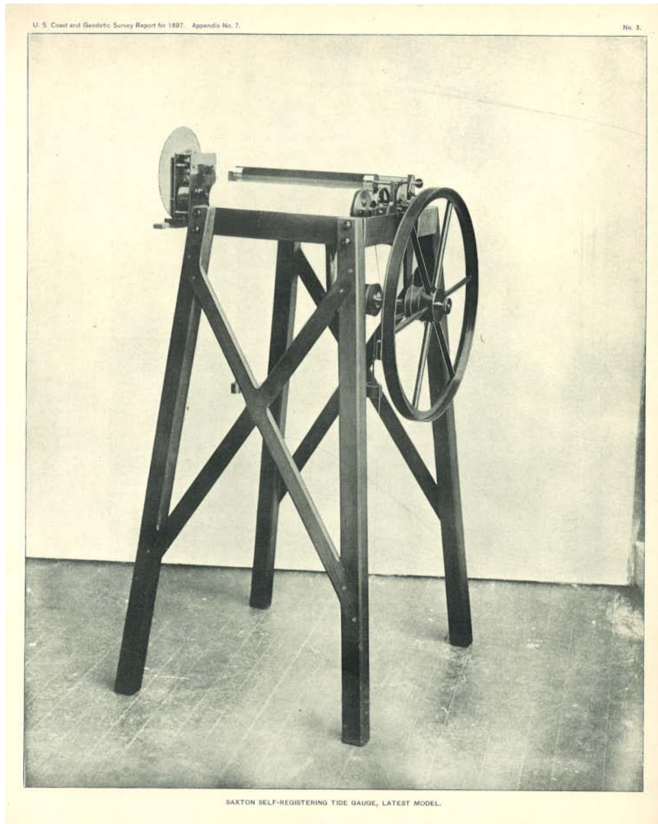
Rollin A. Harris and the Manual of Tides

One of the most important intellectual achievements of the Coast and Geodetic Survey, considering its entire existence, was the gradual accretion of a body of work that came to be called the *Manual of Tides*, by Rollin A. Harris, originally published as eight separate appendices to the annual reports of 1894, 1897, 1900, 1904, and 1907. Thus the work really began under Duffield's tenure; although it is likely he had no real knowledge or understanding of Harris' work at all.

Tidal observation and research had been a part of the Survey since its foundation under Hassler. But the great era of Survey tidal work began in the 1850s, under Alexander Dallas Bache. Bache established the Tidal Division in 1854, about the same time that the Survey adopted Joseph Saxton's self-registering tide gauge design. Bache pursued serious research on tidal theory and empirical tides along the North American coasts, which were quite distinct from the tidal regimes of European coasts which had been the foundational data for modern tidal theory. Bache also created cotidal maps "in the spirit of Whewell", referring to Reverend William Whewell (1794-1866) who began the initiative of mapping High Water times in areas of ocean basins based on empirical data from coastal tide gauges, either Saxton's design or others.[16] Forty years later, the

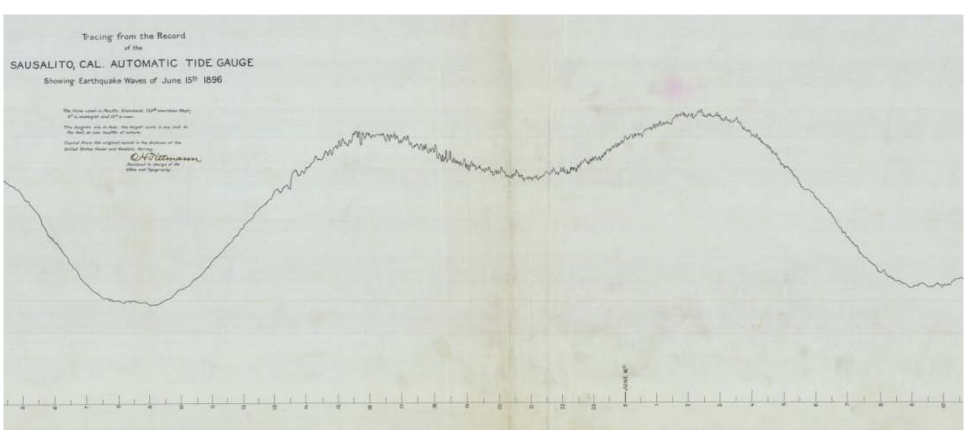
[16] Cartwright, 1999, pp. 110-118.

annual report for 1897 presented the latest model of Saxton's machine, improved but substantially unchanged since before the Civil War.



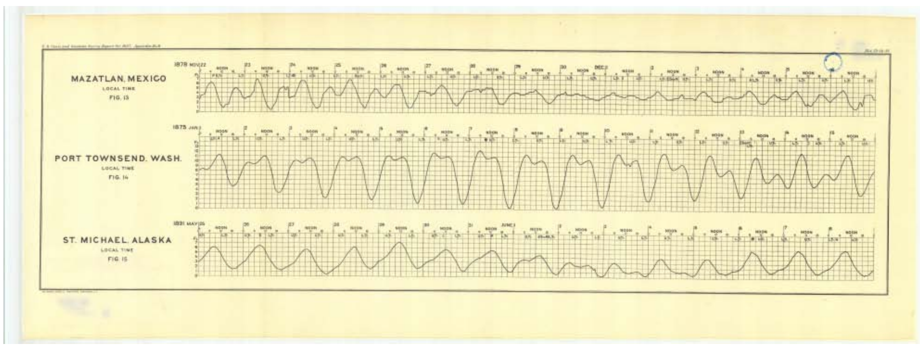
The latest model Saxton Self-Registering Tide Gauge.
No 34 in the Annual Report for 1897

The machine provided an automatic recording of the rise and fall of the tides at a station, needing only occasional changing of the paper rolls of tidal curves, and maintenance and care of the machine. From the very beginning, the machines captured evidence of major earthquake waves and other dynamic ocean phenomena.



Tracing from the record of the Sausalito Automatic Tide Gauge
showing earthquake waves of June 15, 1896.

But the most important quality of the machines was that they allowed the accumulation of vast quantities of continuous data, so very different from the previous data sets of tidal observations at discrete moments. In addition to the vast increase in tidal data recorded continuously, the continuous nature of the tidal curves made their analysis and decomposition by harmonic analysis potentially possible.



Tidal Curves at 3 North American stations. Nos. 13 to 15, illustrations
to accompany Appendix No. 8, Annual Report for 1897

Some of the best mathematicians in the Survey, including Charles A. Schott and William Ferrel, devoted themselves to harmonic analysis of the tides, and Ferrel created the first American tide prediction machine, using the design concept pioneered by William Thomson, later Lord Kelvin. The machines and their tide table output were sufficiently accurate to provide useful aids to navigation in all major American ports and channels.

Fig. 5.—Tidal indicator, Delaware River, Delaware.

At the time shown in the figure, the tide is 1¼ feet above mean low water and is still falling, as indicated by pointing of the arrow.

The Tidal Indicator at the mouth of the Delaware River
Figure 5, Annual Report for 1897

Yet even Ferrel's machine was not very accurate in many cases, and comparisons of tidal data between ports and harbors that were relatively close to each other sometimes revealed disparities in the times and heights of tides that could not readily be resolved by any available explanation. Into this context came Rollin A. Harris (1863-1918).

Harris was born and educated in upstate New York. He graduated from Cornell University, and remained there for graduate studies in mathematics and physics. He received a PhD in 1888, and then spent two years as a Fellow in mathematics at Clark University. In 1890 he was hired by the Tidal Division of the Survey, where he worked until he died. "After becoming familiar with the work, he began the preparation of a publication into which would be gathered the tidal information scattered in various journals and memoirs and in which the methods of tidal reduction and prediction would be coordinated. Dr. Harris threw himself into the work with enthusiasm".[17]

The tasks were daunting, particularly since the most important conceptual problems were beyond the recognition or even perception of most of humanity. As Harris noted:

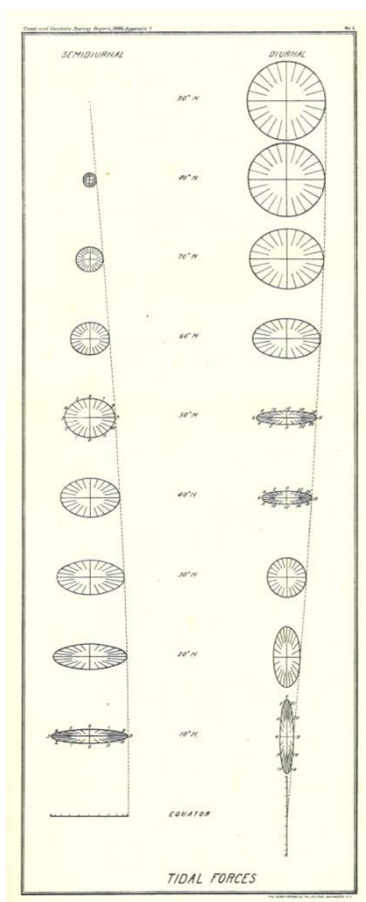
> "Since it has been universally recognized that the tides result from the attraction of the moon and sun, the popular mind has taken little interest in the manner in which these forces operate in order to produce the tides. The apparent hopelessness of the task has doubtless deterred many

[17] Science, 1918, p. 162.

investigators from devoting to it a full measure of their attention. In fact, as will be shown below, there is no such thing as “the tidal problem” analogous to the astronomers’ “problem of three bodies”. The tide involves a number of problems, and to even discover what these problems are requires a good knowledge of the forms, sizes, and depths of the oceans, together with knowledge of the tide-producing forces. The observed tides themselves render great assistance in this matter; for their times and ranges indicate the ways in which the various oceans probably oscillate, and so, in a measure, the underlying tidal problems requiring solution”. [18]

Harris’ contributions to tidal theory were created on a foundation of the most comprehensive history yet written on the evolution of ideas about the tides from antiquity to the end of the 19th century.[19] From this he proposed a new concept and theory to ocean cotidal maps

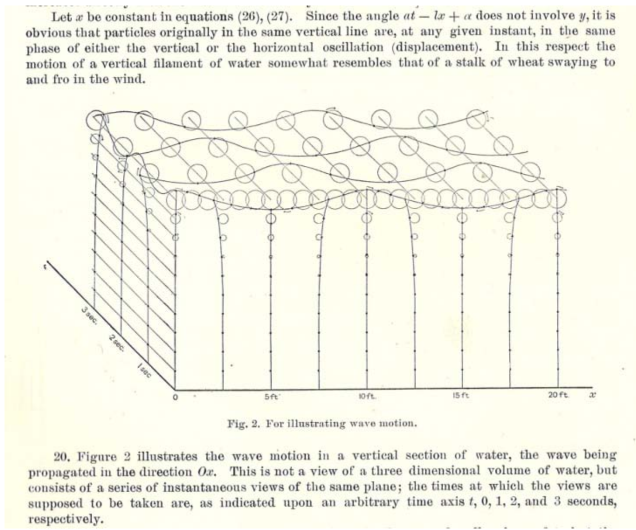
Harris analyzed the problems involved at every conceivable scale, at one end of the range concerning the Sun-Moon-Earth system and planetary geometry.



[18] Harris, 1909, p. 522.
[19] Cartwright, p. 4.

Tidal Forces symbolized for Diurnal and Semi-Diurnal Tides from the Equator to the Pole. No 1, Appendix 7, Annual Report for 1900.

At the other end of the scale, Harris analyzed the complex physics of individual waves on the ocean.



Let x be constant in equations (26), (27). Since the angle $at - lx + \alpha$ does not involve y, it is obvious that particles originally in the same vertical line are, at any given instant, in the same phase of either the vertical or the horizontal oscillation (displacement). In this respect the motion of a vertical filament of water somewhat resembles that of a stalk of wheat swaying to and fro in the wind.

Fig. 2. For illustrating wave motion.

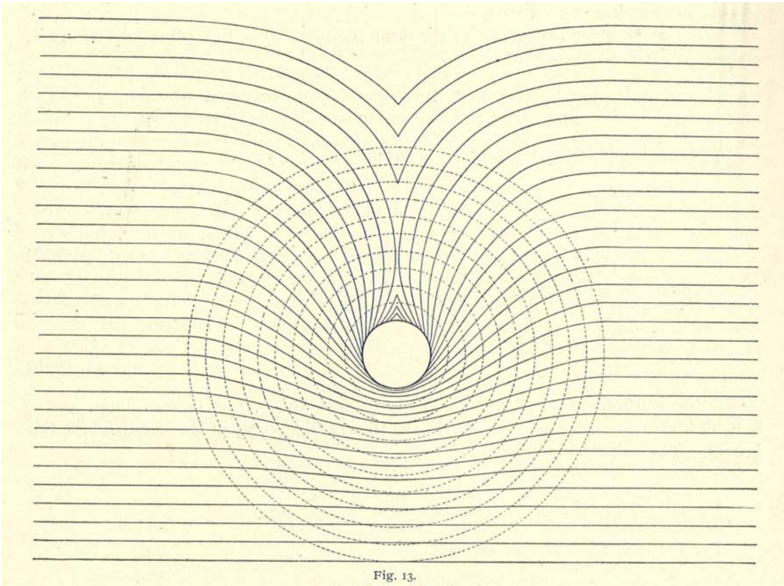
20. Figure 2 illustrates the wave motion in a vertical section of water, the wave being propagated in the direction Ox. This is not a view of a three dimensional volume of water, but consists of a series of instantaneous views of the same plane; the times at which the views are supposed to be taken are, as indicated upon an arbitrary time axis t, 0, 1, 2, and 3 seconds, respectively.

Diagram illustrating wave motion. Figure No. 2 to accompany Appendix No. 8, Annual Report for 1897

In the end, his greatest contribution was made in the middle scale, concerning the systems of tidal waves between ocean continents. The Manual as such was never consolidated into a single volume during Harris' lifetime, which was cut short in 1918 when he died of heart disease, at the age of 55. Four years later, H.A. Marmer, who succeeded Harris as a major authority on tides and currents within the Coast and Geodetic Survey, published a short history of the mighty challenges overcome to develop the modern theories of the tides. Marmer contrasted the next-to-most-current theory of tides, based on the concept of progressive waves, which had their origin in the great southern ocean. Succeeding that was a theory of stationary waves.

> "This newer theory is diametrically opposed to the ideas advanced in the Southern Ocean theory of the making of the tide. It does away with the conception of a single world phenomenon and substitutes regional oscillating areas as the origin of the dominant tides of the various oceans. It may be of interest to note here that the older theory is due to European mathematicians and tidal workers, while the newer theory is the outgrowth of American genius. Almost entirely, the stationary wave theory is the work of one man, the late R.A. Harris of the United States Coast and Geodetic Survey. .. Now to come back to the tides, the Stationary Wave theory states that the dominant tides of the world are caused by stationary waves that are set up and maintained in various portions of the oceans by the periodic tidal forces of the sun and moon. According to this theory

therefore, the tides do not constitute a general world phenomenon, but a local phenomena, the tides of any given region being due primarily to the stationary wave oscillation of that region".[20]



Effect of a Circular island on Cotidal Lines from Harris' "Outlines of Tidal Theory" from Appendix 7, Annual Report for 1900, p. 602.

Harris' work included delineations of partitions of ocean basins with resonating strips, which overlap and interact in complex ways. Where the nodal lines of overlapping strips intersect or come close together, no-tide points result, around which the cotidal lines rotate through all directions. Harris called these amphidromic systems, from the Greek words amphi (around) and dromos (running).[21]

[20] Marmer, 1922, pp. 217-218.
[21] Cartwright, pp. 120-121.

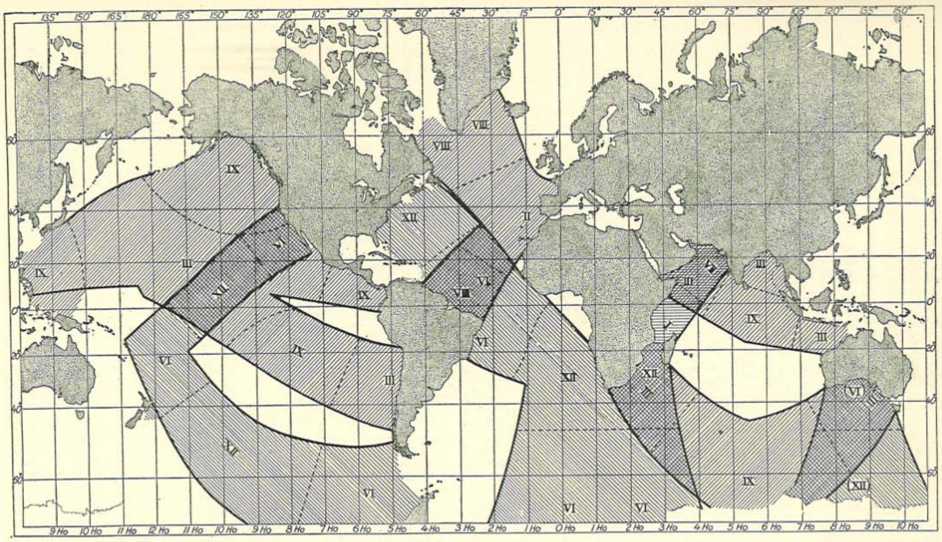


FIG. 4. Systems for the Semi-daily Tides. The shaded portions of this chart represent the regions most concerned in the production of tides, together with landward dependencies which possess tides simultaneous with those of the systems proper. The Roman numerals refer to Greenwich lunar time of high water. The values upon Fig. 4 are nearly those which would result from theoretical considerations. The values upon Figs. 5, 6, 7 and 8 are made to agree with observation as nearly as possible. The Arabic numerals on Figs. 5, 6, 7 and 8 denote mean ranges in feet of the observed semi-daily tide. The Roman numerals are placed upon that side of a cotidal line towards which the wave appears to progress.

Systems for the Semi-Daily Tides, by Rollin A. Harris, from his Manual of Tides, Annual Report for 1900

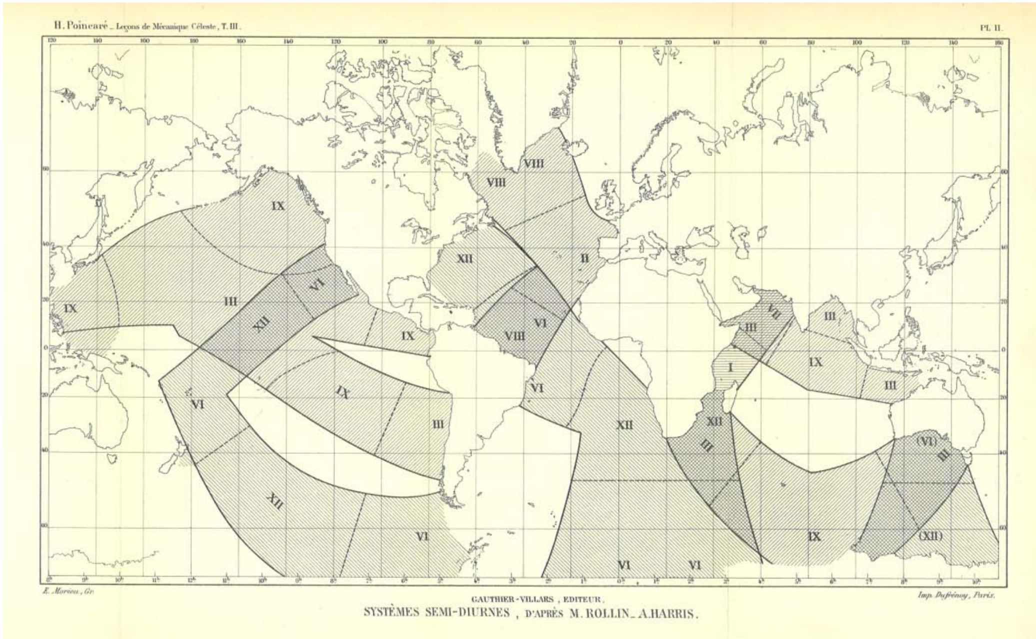
Harris' many contributions to tidal theory were uneven in strength. His major critic was Sir George Darwin, a son of Charles Darwin and major tidal mathematician. Darwin was polite, but thoroughly dismissive of Harris' theory: "I venture to express my admiration at the courage of the attempt, and although, as I think, it is a failure, yet it may inspire others to more successful attacks."[22]

However, Harris' work was acknowledged immediately by the small subset of mathematicians and tidal workers who could comprehend it and its significance. These included the distinguished French mathematician and polymath physicist Henri Poincaré. His lectures on topics in celestial mechanics addressed tidal theories, noting that:

> …"His [Harris] way of seeing things differs greatly from that of Whewell and his general principles do not run into the same objections. It is very likely that the definitive theory will take a large part of its outline from the theory of Harris".[23]

Poincaré's essential agreement with Harris is reflected in Poincaré's own map of resonating basins.

[22] Darwin, 1902, p. 445.
[23] H. Poincaré, 1910, translated and quoted in Harris' obituary, Science, 1918, and in Cartwright, 1999, p. 123.



Systèmes Semi-Diurnes, d'après M. Rollin A. Harris.
From Leçons de Mécanique Céleste, by H. Poincaré, 1910.

Harris' work was known and appreciated within the Survey, and certainly his theories were made manifest in the second Tide Prediction Machine. But the Manual as such was never published as a single work. As the Army Corps of Engineers Committee on Tidal Hydraulics noted: "Thus, the Manual is hidden in its intimate association with the official records of the Coast and Geodetic Survey, and understandably it has not received the attention that it so richly deserves from other scholars…". To rectify that, the same Committee prepared and published an abridged, condensed synthesis of Harris derived from the more than a thousand pages of Harris' appendices in five volumes of the Annual Report. The opening sentence to their introduction to Extracts from the Manual of Tides states: "The Manual of Tides, by Dr. Rollin A. Harris, has been considered by students of tidal phenomena as an extraordinary contribution to the fund of knowledge in that domain of science".[24]

The Tide Finally Turns

Perhaps the two highest achievements of Duffield's short tenure were those produced by Adolph Lindenkohl and Rollin A. Harris. Appropriately, their major intellectual domains were ocean currents and ocean tides, complex phenomena that change and change again. The tide in the Superintendent's office on New Jersey Avenue eventually turned.

[24] Committee on Tidal Hydraulics, 1966, p. iii.

Duffield had attempted to remove almost all the most experienced officers in the Survey at one point or another. In1897, he attempted to remove Otto Tittmanm head of the Office of Weights and Measures (and later Survey Superintendent), John F. Pratt, overseer of many of the Alaskan surveys and now head of the Instrument Division, and even Charles A. Schott, the head computer of the Survey for almost half a century. He had finally gone too far. Senator Henry Cabot Lodge called the situation outrageous, Gerald Hubbard, the father-in-law of Alexander Graham Bell and co-owner of the journal Science, called Duffield "an enemy of science" and former Superintendent Mendenhall called Duffield insane[25]. The new Republican President McKinley demanded a change. Once again, dramatic events in the Survey headquarters became short neutral sentences in Annual Reports. The next Annual Report notes:

"Ths Superintendency of the Coast and Geodetic Survey at the beginning of the fiscal year was held by Gen.W.W. Duffield, and upon his resignation taking effect, the duties were assumed by the present Superintendent on December 1, 1897".[26]

Henry S. Pritchett, who became one of the very best Superintendents, succeeded the man who was undoubtedly the very worst, by any measure. The lowest tide the Survey had ever experienced had finally turned, and a spring tide rushed in.

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[25] Manning, 1988, pp. 122-128.
[26] Henry S. Pritchett, 1898, p. 106

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Henry S. Pritchett and the Great Reorganization of the Coast & Geodetic Survey

In 1897 the astronomer and mathematician Henry S. Pritchett succeeded the retired Civil War General William Duffield as the ninth superintendent of the US Coast and Geodetic Survey.

Before attempting more complete discussion of what took place between 1897 and 1900, and what these new orderings and activities of the Survey meant, it is important to discuss the various reasons why any re-organization of the Coast and Geodetic Survey was necessary, or at least desirable, in the first place. The first great era in the history of the Coast Survey ended with the death of Alexander Dallas Bache in 1867. Bache, the second superintendent and successor to Ferdinand Hassler, the founder of the Survey, left an organization which had begun to realize the potential that Hassler had foreseen but never fully realized in his own tenure. The Coast Survey had been thoroughly mobilized for service in the Civil War, and the transition back to peacetime authority and peacetime budgets was not an easy one.

There were two great sources of problems for the Survey, one of them military and the other civilian. The military problem was that, since the beginning of the realized Survey, Army and Navy officers had been deployed to service with the Coast Survey under conditions that were never optimized for the Coast Survey. The Coast Survey served as a training academy in geodesy, surveying, and cartography for military officers, and some military men served significant lengths of time with the Survey, but most came and went with a frequency that did not enrich the Survey sufficiently for its investment. Further, many of the ships deployed to the Survey were Navy vessels, and all of the most important and largest ships were Navy ships, which presented problems to the civilian organization which was the Coast Survey. In fact, authority for the Survey had shifted between civilian control in the Treasury department and under the Navy department several times.[1] Further, the Naval Hydrographic Office, founded in 1866 to provide charts for foreign ports and the seas outside American territorial waters, became in

[1] See Theberge's history of the Coast Survey 1807-1867 at the NOAA History website for the definitive account.

various senses a rival organization and a source of a variety of problems for the Coast Survey for the remainder of the 19th century.[2]

The other great source of problems was civilian in nature. The Coast Survey in the 19th century, apart from episodes of control by the Navy, was a small agency within the Treasury department entirely dependent on Congressional appropriations for its entire budget, apart from the occasional philanthropy of wealthy men to provide ships and access to ships. The Survey, unlike the Smithsonian Institution, had no endowment. Survey personnel were paid salaries commensurate with both university scientists and government scientists in general, which were quite low. From the time the Survey was working continuously as an organization, meaning the 1830s, in the many decades that followed there were many important Survey personnel who spent their entire working lives with the Survey, meaning that they had were paid salaries that provided little opportunity to prepare themselves for retirement. And, for civil servants in the late 19th century, there were no federal pensions for civilian service (as opposed to military service) so many Coast Survey personnel worked literally until they died, if they could.

Despite these problems, in the 30 years between Bache's death, and the beginning of Henry S. Pritchett's term as superintendent in 1897, a remarkable amount of work in many areas was accomplished. Three particular developments, out of many that could be described, will convey the expanded scope and agenda of scientific work and maritime service in that time.

First, in 1867 the Coast Survey acquired responsibility for charting the coastal waters of Alaska, and also determining the Alaska-Canadian boundary, in conjunction with the government of Great Britain. This enlarged mission of the Coast Survey had fortuitous consequences that survive into the 21st century, because work in Alaska "opened up" the entire Northeastern Pacific Ocean, as well as the Bering and Arctic Oceans, to the ships and personnel of the Coast Survey. Since the very beginning of active Survey work in Alaskan waters, the Coast Survey traveled to and from Alaska by what may be called "the scientific route". This means that Survey ships took many different routings, and Survey scientists and crews acquired a wide variety of oceanographic data, not directly related to their nominal duties for coastal charting. The full significance of much of it was not necessarily apparent in the 19th century, but it became readily apparent in the next.

Second, under the tenure of Benjamin Peirce, who succeeded Alexander Dallas Bache as third superintendent in 1867, Peirce's son Charles Sanders Peirce was hired by the Coast Survey. C. S. Peirce made voluminous contributions to the Survey, and American society in general, but in particular it was Peirce who began serious Survey research on the earth's gravity fields and instruments to study gravity. This was a substantial enlargement of the scientific agenda of the Survey, beyond the scope of both Hassler and Bache. The gravity work brought the Survey into the forefront of international geodetic research, and also further connected Survey personnel and the Survey as an institution to

[2] The definitive source on these matters is Manning (1988).

international scientific associations, with ramifications that carried on into the next century.

Third, the Coast Survey connected the previously separate Atlantic and Gulf Coast Surveys to the Pacific Survey, and in doing so created the foundation for the United States Datum, which the Survey then expanded to the continent, as the North American Datum. The initial transcontinental connection between the Atlantic and Pacific coasts was the great arc of the 39th parallel, a first-order geodetic triangulation network begun in 1871, but not completed until almost two decades later. The long march overland gave the Survey a terrestrial focus, and a rationale for new methods and instruments appropriate to the vast plains and mountains along route. Midway in that journey, in 1878, in order to signify its greatly expanded scope, and also to help differentiate the Survey from the nascent US Geological Survey organized under the new Department of the Interior, the US Coast Survey became the US Coast and Geodetic Survey, the name it would carry for almost a century.

Towards the end of the 19th century, then, the US Coast and Geodetic Survey had responsibilities that spanned the continent of North America, and embraced the American coast lines and coastal waters of the Atlantic, Pacific, and Arctic Oceans and the Bering Sea. The publishing technologies developed and used by the Survey were amongst the most sophisticated in the nation. The Survey maintained the official standards of weights and measures and scientific metrics for the US government, represented the nation on a variety of international scientific bodies, and served as the defacto national training academy for geodesy without rival in the entire western hemisphere.

At the same time, towards the end of the 19th century, the Coast and Geodetic Survey reached its nadir. The tenures of Superintendents Hilgard, and Duffield, in particular were mired in major political scandals. Hilgard, a German immigrant and talented instrument designer, was eventually forced to resign from the Survey in response to allegations of inappropriate behavior in his office. Duffield, a retired Civil War general without the slightest knowledge or interest in geodesy, was a particularly disastrous leader, whose most signal achievement was to dismiss as many of the most distinguished and long-serving scientists in the Coast and Geodetic Survey as he was able to discharge. But eventually the tide turned, Duffield retired a final time, and, in 1897, a 40-year old astronomer with a doctorate in mathematics from the University of Munich, Henry S. Pritchett, was named the ninth Superintendent of the Coast and Geodetic Survey. With his entrance, the Great Re-organization of the Survey began.

Pritchett served in that post only three years, before moving on to become the President of MIT, where he unsuccessfully attempted another great re-organization, a proposed merger of MIT and Harvard.[3] During his administration, a major reorganization and revitalization of the Survey took place, which created the “modern” 20th century Survey that eventually became a major component of NOAA. During Pritchett’s administration, the following signal activities were either begun or accomplished:

[3] From the Pritchett biography, MIT Archives.

- The scientific components of the Survey were re-ordered into three great divisions, Hydrography and Topography, Geodesy, and Terrestrial Magnetism.
- Permanent astronomical observatories were established at Ukiah, California and Gaithersburg, Maryland as American components of the International Latitude Service, which in turn was a component of the International Polar Motion Service, both established by the International Geodetic Association.
- Permanent observatories for terrestrial magnetism were established at Ewa, Ohau, in Hawai'i, Sitka, Alaska, and Cheltenham, Maryland, with the latter developed as the national standard facility.
- A permanent port facility was established in Seattle, Washington, as a home base for the Alaska Survey and, by extension, all Survey activities in the Pacific Ocean.
- Work began to create a new national datum, the United States Datum, based on the Hayford ellipsoid, integrating and correcting data from all extant transcontinental geodetic arcs and surveys.
- The Office of Weights and Measures began the move out of its original home in the Coast Survey to a new independent position, eventually to be re-named the National Bureau of Standards.
- A complete reordering of the production of hydrographic charts was accomplished, triggered by the removal of US Navy officers and ships for service in the Spanish-AmericanWar, never to return to the roles they had played since the foundation of the Coast Survey. The Coast and Geodetic Survey gained the legal and budgetary authority to acquire large vessels of their own, under complete control of civilian sailing masters and crews. This was reflected in the creation of the first official flags of the Survey.
- As a result of the Spanish-American War and its consequences, Coast and Geodetic Survey personnel began work for the Philippines Survey, extending the domain of the Survey across the entire Pacific Ocean.

The achievements of 1900 were but dimly glimpsed in 1897. Several recently appointed superintendents had either been removed for scandal, or had so prosecuted their tasks as to provoke scandal. Duffield, in particular, had effected or attempted the dismissals of the most senior and most accomplished members of the Survey, with only partial success. Given this, the leadership of the department of the Treasury looked well outside both the Survey and the other sources of Survey leadership (mainly the military) for a successor to Duffield. They found the man they wanted in Henry S. Pritchett.

Pritchett grew up in Missouri in a family of modest means but far-reaching ambitions in education and research. Pritchett's father was a teacher and astronomer, who, when Henry was young, absented himself from the family to attend Harvard University for a full year. His father was a fervent Union supporter in a contested and confederate-leaning state, eventually leaving the family again to spend the bulk of the Civil War working in Washington for the US Sanitary Commission, whose Vice-

President was Alexander Dallas Bache, Superintendent of the Coast Survey. Henry Pritchett eventually attended Washington University in St. Louis, and then taught astronomy there for 16 years (1881-1897). The mathematical astronomy that was his predilection was perfect preparation for his tenure at the Coast and Geodetic Survey. Near the end of his life, Pritchett recalled his astronomical career in a letter to George E. Hale, director of the Mount Wilson Observatory in California:

> "I grew up in the astronomy of position, a field peculiarly attractive to the amateur observer. Thus a large number of persons got considerable satisfaction out of the work and passed on to other intelligent people a knowledge of astronomy and of the celestial bodies. Since that day, the old astronomy has become quite secondary to the fascinating developments in astrophysics; but the spectroscope is an instrument not so easily handled, and, as a consequence, the amateur astronomer has almost entirely disappeared. I think it would be of great value if some simple form of spectroscopic apparatus could be devised for the use of amateurs".[4]

In 1894, Pritchett traveled to Munich, Germany, to obtain a doctorate in astronomy under the celebrated Professor Seeliger. His studies began with elliptic functions and definite integrals, and the theory of planetary perturbations and photometry. In a little over a year and a half, he completed his thesis, entitled "Über die Verfinsterungen der Saturntrabanten" [On the Eclipses of Saturn's Moons]. He traveled widely, in and out of university circles, and made many connections and friendships in the community of European scientists, as he had earlier done the same amongst American scientists and political officials. These connections were about to pay off.

In 1897, two years back at Washington University, Pritchett received a letter from Lyman J. Gage, the Secretary of the Treasury, inviting him to come to Washington to discuss a matter. When Pritchett arrived, Gage remarked at his youthful appearance. The Secretary went on: "If you accept the job I am about to offer you, it won't take you so long to grow old". The offer was to become, effective immediately, the Superintendent of the US Coast and Geodetic Survey. Pritchett made inquiries amongst his friends in the Capitol, and also requested an interview with President McKinley. Pritchett explained that the Survey was a scientific institution, and that he must have a free hand to dismiss or hire personnel on every level based solely on scientific competency alone, regardless of political backing. McKinley and Secretary Gage agreed, and Pritchett accepted the position on the spot. That same day, he was called before a Congressional Committee concerned with the problems of the Survey. He was unable to answer many questions. A Congressman remarked: "You seem to know very little about questions under your jurisdiction. How long have you been Superintendent of the Coast Survey?" Pritchett pulled out his watch, and then replied: "About four hours and some minutes."[5] And so it came to pass that a widely-read and well-connected astronomer with no experience in the Coast Survey became its leader for three years. But, as his biographer stated: "When, for example, he was called to Washington as superintendent of the Coast

[4] Flexner (1943), p. 33.
[5] Ibid, pp. 50-54.

Survey, he seemed to see through the whole organization as though it was a piece of plate glass". [6] The major changes he effected to the Survey survive to the present day.

The Weight of the Office of Weights and Measures

The first significant project he attempted may seem counterintuitive—he advocated that the Office of Weights and Measures, the very essence of Hassler's legacy in government service, should be *removed* from the Coast Survey, its home since Hassler founded the office in 1836. But as Pritchett saw matters, the labors of scientific and material standards were burgeoning, and rightly so, but the Coast and Geodetic Survey, by virtue of its perennially constricted personnel and budget, was paying an increasingly high price to maintain the office. As Pritchett recounted the story in 1902:

> "On coming to the Coast Survey in 1897 I found the Office of Weights and Measures engaged in the work which I have just mentioned. In its service were two scientific assistants, an instrument maker and a messenger, and a small appropriation was made for office expenses. The work was under the charge of a field officer of the Coast Survey. The arrangement by which a field officer was in this way detailed temporarily for this duty did not seem to me good administration; it deprived the Coast Survey of the services of a much-needed officer, and in addition there was required for this duty not a surveyor but a physicist". [7]

Pritchett therefore asked Congress to appropriate sufficient funds to hire a physicist of high standing to accept direction of the Office, and eventually, he persuaded Dr. S.W. Stratton to leave the University of Chicago to accept the post. Stratton's job included the assignment to prepare a report recommending changes in the office; Stratton prepared a scheme for a National Bureau of Standards, which was evaluated within the Survey as well as without. Many of the Survey's best scientists, including then Assistant Superintendent Tittmann, were German immigrants or their children, quite familiar with counterpart European agencies. After their criticisms were digested, the final plan was revised and submitted to Congress. Pritchett noted that the new proposed bureau "as finally planned is not intended to be simply a copy of the Reichsanstalt [the German office of measures] but a standardizing bureau adapted to American science and to American manufacturers".[8] Congress accepted the proposal, and in 1901 the National Bureau of Standards was established under the Department of the Treasury. Both the Survey and the Bureau were later transferred to the Department of Commerce, where their successors remain, the Bureau now the National Institute of Science and Technology (NIST), and the Survey now the oldest element of the National Oceanic and Atmospheric Administration (NOAA).

The Spanish-American War, and the War with the Navy

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[6] Ibid, p. 196.
[7] Pritchett (1902) p. 281.
[8] Ibid, p. 283.

The Coast Survey and the American military services have always been as closely related as siblings, and at times in their histories they contended and fought as only siblings can. Officers, crews and ships of the US Navy were attached to service with the Coast Survey from the very beginning of actual field operations in 1816. US Army officers and occasionally enlisted men were also attached for service, and over the decades many hundreds of US military personnel spend tours of duty, including multiple tours over many years, working on hydrographic, topographic and geodetic surveys. There were disputes and turf battles, and the histories of contention between leaders of the various services and bureaus form much of the extant scholarship of the early Coast Survey. Long simmering disputes occasionally erupted in major crises, and these generally correlated with the advent of war. In 1861, on the eve of the Civil War, all Army and Navy officers were abruptly withdrawn from the Coast Survey, in anticipation of the mobilization against the emerging Confederacy. Post-war, Army officers never returned to service as they had before the war, although the US Navy once again resumed its traditional roles in support—and occasional competition—with the Coast Survey.

The second half of the 19th century was an age of western imperialism, global expansion of trade and colonialism, and the coal-fired gunboat and dreadnought. The United States was an emerging player, although still a minor one compared to the great naval powers, which were then the United Kingdom, France, Germany, Russia, Italy, and Japan.[9] As the size and reach of the US Navy expanded, so did the responsibilities—and ambitions—of the Naval Hydrographic Office. In theory, there should be little or no reason for competition between the Hydrographic Office and the Coast and Geodetic Survey, because they had distinctly different arenas of operation. The Coast and Geodetic Survey was responsible for charting the coastal waters and adjacent lands of the United States and its possessions, while the Hydrographic Office was directed to securing or publishing charts and sailing directions for the waters of the world ocean that were outside of and beyond American territory. But every war that expanded American possessions created a direct conflict between the two bureaus. Any foreign coastal waters were the domain of the Hydrographic Office so long as the United States didn't possess them—but as soon as the nation acquired them, they became the responsibility of the Coast and Geodetic Survey. The conflict between the two agencies was as inevitable as the potential for collision between two ships sailing for the same spot.

In 1895, rebellion in the Spanish colony of Cuba broke out, and was suppressed brutally by the Spanish Army and Navy. The United States took great interest in the conflict, unfortunately much less out of concern for the rights of the Cubans in revolt than for the consequences of the rebellion should it spread to the other Spanish colonies, particularly Puerto Rico and the Philippines. Nor was the United States greatly concerned about the rights of Puerto Rican and Philippine nationals on their own islands. The emerging objective of American concern was the possibilities for acquiring, at the least, more favorable resource access and trade relations, if not more direct control, of any colonies Spain might lose in the rebellion.

[9] See tables and graphs from the report to accompany H.R. 10450, submitted by Mr. Foss, from the Committee on Naval Affairs, committed April 5, 1900 to the Committee of the Whole on the State of the Union 956st Congress, 1st Session, Report No. 930).

On February 15, 1898, the visiting American battleship the U.S.S. Maine exploded and sank in the harbor of Havana, Cuba. The immediate consequence of that disaster was a complete mobilization for war by the American military. For the second time in its history, the Coast Survey experienced the abrupt withdrawal of all military officers and ships assigned to service with the Survey. This change triggered a crisis in the Survey, and responding to the crisis exercised fully the powers of Superintendent Pritchett and his small band of Congressional allies. And so it came to pass that the Coast and Geodetic Survey itself went to war, in response to an offensive attack—not by Spain, but rather by the Naval Hydrographic Office.

The expanded scope of American naval activities, some directly related to the war with Spain or some not, had greatly increased the demands for Coast Survey charting, which meant commitments of ships and personnel to do the work. In August, 1898, the Navy asked the Coast and Geodetic Survey to chart the south side of the island of Puerto Rico. Later that same year, the Survey signed an agreement with the newly created Territory of Hawai'i to incorporate W.D. Alexander and his staff, who were once the Hawaiian Government Survey, then the Hawaiian Territorial Survey, into the Coast Survey itself. In 1899, the new ship Pathfinder sailed to Hawai'i to begin surveys of what were now American coastal waters. These changed mandates were made legal by Congressional language authorizing the Survey to work in the Atlantic and Pacific on "coasts of outlying islands under the jurisdiction of the United States".[10]

The Naval Hydrographic Office, in this same era, had been re-vitalized and expanded by Commander Royal B. Bradford and John D. Long, the Secretary of the Navy. By 1898, they had secured authority to construct "a series of charts of the coasts and waters between the state of Washington and the territory of Alaska" (i.e., the Pacific coast of Canada). In 1899, they secured authority to chart "the imperfectly known parts of the coasts and harbors of the Philippine Archipelago"[11]—which meant the Hydrographic Office was attempting to secure control of mapping the very same territory of "the coasts of outlying islands under the jurisdiction of the united States" that had been given to the Coast and Geodetic Survey.

The conflict between the two agencies soon expanded in 1900, as now-Admiral Bradford attempted to secure legal authority—and substantial budgets—to chart the coastal waters of the United states itself, thereby essentially displacing the Coast Survey. Bradford and his allies mounted a public relations campaign, built around nationally circulated copies of a pamphlet that made a series of claims that cut to the heart of the history of the Coast Survey and its whole engagement with science and the government. The Navy advocates argued that all maritime nations used charts made by their militaries, and not civilian agencies; that the bulk of the charting work of the Coast Survey had in any case been done by the military officers assigned to it; that the Survey had failed in its long history to complete its fundamental assignment of mapping the American coastal

[10] The Sundry Civil Act of March 3, 1899, in U. S. Statutes at Large, 30, 1082.
[11] Ibid, pp. 302, 374.

waters; and that in large part this was because its major efforts in recent decades had been overland geodetic surveys far from the coastal areas that were its mandate.[12]

The Navy's assault was eventually repulsed by the strenuous defense mounted by a handful of major Congressional allies of the Survey, in conjunction with the spirited testimony of Henry S. Pritchett. In March and April, 1900, he demolished the Navy's specific arguments, and forged the foundations for the next great era of the Coast and Geodetic Survey. He noted that Navy officers' service in the Survey generally assisted them more than their work assisted the Survey, by virtue of the fact that, in the average three years' posting each had, they could only begin to learn the scientific skills that modern geodetically-grounded charting required. He noted that the Survey's mandate to chart American territorial waters had expanded continuously through its history, but that even so the Survey always dropped other work to answer urgent requests from the American military command to chart new territory or harbors should these be required. He defended both the trans-continental geodetic networks and scientific activities like research in gravity and terrestrial magnetism as central to the core mission of charting coastal waters, due to the nature of the constraints of the physics of the earth. And finally, he argued that the very potential for success of the Survey was ultimately grounded in its status as a rigorous civilian scientific agency that would work best situated in a department of commerce:

> The Chairman: "I suppose they have to have a separate corps?"
>
> Mr. Pritchett: "Certainly they do. The Navy would have to have a separate corps and provide the machinery for doing the work; the experience of all nations has shown that, and our experience has shown that. When you have done that you will practically have the Coast Survey. If you think it wiser to have the Coast Survey under the Navy Department it would be better, possibly, to transfer our bureau there, but really the place I believe it should be is under a bureau of commerce, because its relations with commerce are so much closer than with the work of the Navy; but wherever you do put it, it does not matter, the work must be done by a corps of men who spend their whole time at it. This is the day of specialists, the time has gone by when men could do a half dozen things well, and as for the statement as it is here, that the Navy in ten years could make the charts of the whole world, that could not be made by any man who knew what he was talking about".[13]

And so the battle raged—Pritchett was convinced there must be one integral Coast Survey, regardless of where it was situated, although some homes were much better than others. In anticipation that, unless other changes were made, after the hostilities of the immediate war diminished naval officers would once again be assigned to the Survey, perpetuating a potential conflict that had plagued the Survey for the better part of a century, Pritchett and his Congressional advocates urged instead that the Survey should acquire control of its entire operations, and henceforth not be dependent on military

[12] The definitive source for the 1900 disputes and Congressional battles remains Manning (1988).
[13] Committee on Naval Affairs, March 19, 1900, statement of Mr. Henry S. Pritchett, Superintendent Coast and Geodetic Survey. p. 8

support at all. While fending off further attacks by the Navy during the remaining months of the Congressional session in spring and early summer of 1900, Pritchett urged approval of an authorization, through the Sundry Civil Act bill, that would switch the pay and subsistence of the navy crews of Coast Survey ships over to the budget of the Survey. He further negotiated with Navy Secretary Long to transfer jurisdiction of these men, not just their salaries, to the Survey. The changes were implemented piecemeal, as specific Survey vessels had already sailed away for the summer hydrographic season, but by December, 1900, the Navy Department closed its enlistment records for sailors and men on Coast Survey vessels. Those men now didn't just serve the Coast Survey—they were in the Coast Survey. It has been said that Ferdinand Hassler created the foundation upon which Alexander Dallas Bache built the house. But it was Henry S. Pritchett who finally realized Hassler's dream of scientific civil service—for the first time in its history, apart from the years of the Civil War, and for the rest of its existence, the Coast and Geodetic Survey was finally an entirely civilian organization. This change was signified by the competition, within the Survey, to create designs for nautical flags and pennants to signify to the maritime world that the ships flying them were under the command of the Survey.[14]

The Survey in the Philippines: "War is God's way of teaching Americans geography"—Ambrose Bierce

The involvement of the Coast and Geodetic Survey in the Philippines began in the earliest stages of the Spanish-American War. The Survey had, by 1898, spent almost half a century exploring and charting the waters of the Pacific, but solely in the eastern Pacific: along the west coast of the country, the coasts of Alaska and the Aleutians and their surrounding seas, and Hawai'i, based on cooperative research with the Hawaiian Government Survey of the Kingdom, over a decade before the islands were annexed to the United States. The north-east quadrant of the Pacific Ocean that includes all these coasts was also explored progressively, by Survey ships and crews taking "the scientific route" between different destinations. However, the greater part of the western Pacific had never been explored or even visited by the Survey at the time that war broke out between the United States and Spain.

Nevertheless, the Survey was the premiere earth science agency of the country, and the earth sciences are thoroughly international. The Survey maintained productive relationships with English and especially German oceanographic research and mapping enterprises and agencies, the latter based in good part on the fact that for many decades after the failed German liberal revolution of 1848, wave after wave of superbly trained German scientists immigrated to the United States and worked with the Coast Survey.[15]

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[14] See frontpiece, Superintendent's Report of 1899 for a display of all the flags and pennants. The NOAA Central Library holds a collection of other flag designs submitted to the competition.

[15] Spurred by research that began with work on the career of the German immigrant Adolph Cluss, who worked with the Coast Survey 1849-50 upon his arrival in the US, before becoming a celebrated architect in Washington, DC, the NOAA Central Library has developed a web-based directory of other German immigrants who worked with the Coast Survey, accessible at: http://lib.noaa.gov/edocs/cluss/sciences.html

Thus it was that Superintendent Pritchett had access to recent English Admiralty charts that had been re-scaled and printed by the Survey cartographic division. On May 2, 1898, the day before the battle of Manila Bay, on impulse, he took an enlarged chart of Manila Bay to the White House, thinking it would be useful to President McKinley. The chart was far superior to any other map McKinley had. McKinley was suitably impressed. He remarked "I see I must learn a great deal of geography before the war is over, and I am going to ask you to help me".[16] Pritchett returned to the Survey headquarters on New Jersey Avenue, a block from the US Capitol, and ordered his cartographic staff to ransack the archives for the best available charts, and to create new ones if necessary. Thus the war in the Philippines, as it was fought from Washington, was fought with charts created by the civilian Coast and Geodetic Survey. As the Superintendent's report of 1899 noted: "Miscellaneous drawings were also furnished: San Juan [Puerto Rico], Hawaiian Islands, Guam Island, Ladrone Islands [the Marianas Islands], and a new chart of the Philippine Islands".[17] The next year, it published the very first American Atlas of the Philippines, which was based on a revised, re-scaled, and corrected version of a Spanish-language atlas of the islands originally published by the Jesuit Observatory of Manila, with the cooperation and assistance of various Jesuit scientists working in Manila and in Washington.[18]

With American success in the war, the United States found it had inherited colonies, and not territories, for the first time in American history—and also it inherited the liberation struggles within the colonies. The war in the Philippines turned into what the Americans called the Philippine Insurrection, which lasted for many years. The Coast and Geodetic Survey did its best to avoid direct involvement in the conflicts, squaring off instead with its old adversary—the US Navy Hydrographic Office.

The dispute was the by-now familiar question of which agency should receive authority for coastal charting, this time for the specific coasts that were now under US jurisdiction as a result of the war. These included Puerto Rico and surrounding waters in the Caribbean (but not Cuba, which is another story) and a variety of Spanish-ceded island possessions in the Pacific, of which the greatest was the 7,000 island archipelago of the Philippine Islands. The Navy Hydrographic Office demanded responsibility for the Philippines, so once again Pritchett was called to Capitol Hill. The Navy had suggested that Navy war ships could be used for surveying in between military duties. Pritchett wasted no words.

> "That is exactly the fallacy that I suggested. If you take any navy officer who is accustomed to survey work—take such a man as Captain Moser—he will tell you that the business of a man-of-war in patrolling work can not be done together with coast-survey work. The work takes men to a large extent out of naval discipline. The men turn out in the morning, say at 5 o'clock, in order to

[16] quotation from Pritchett's 1929 memoir of his service as Superintendent, quoted in Flexner (1943, p. 56-57).
[17] Superintendents Annual Report for the year 1899, p. ___
[18] *The Atlas of the Philippine Inlands*, UC C & G S Special Publication No. 3, 1900.

get the advantage of the smooth water, and work as hard as they can when the weather will allow them, and the regime of the ship is totally different from the duty of patrolling. If you have a half dozen small vessels in the Philippines, why should you not turn them over to the use of the Coast Survey, and let the naval officers cooperate, as they have always done?" [19]

Eventually, Pritchett prevailed over the Hydrographic Office, but then he prudently attempted to avoid conflict with the populace in the Philippines. When asked, before the same Congressional committee, about his plans, Pritchett noted "We are authorized to survey the Philippines. We have a report prepared but we cannot survey the Philippines now without a gun, besides I really prefer to wait until the matter is settled".[20]

With the initial truce in the Philippines, American mapping of the islands began. The chief administrative authority for the Philippines was the Philippine Commission, which created a Committee on Surveys to direct a wide variety of scientific and cartographic initiatives. Their major report to the Commission describes seven types and levels of investigations presented in the order of their importance and foundational place relative to the other survey types.

1- The needs of the public service in regard to surveys may be grouped under the following heads:

1st. Coast & Geodetic Surveys,
2nd. Topographic Surveys,
3rd, Surveys of the Public Lands, Mining Claims, etc.,
4th, Surveys of those private properties for which the issuance of certificates of ownership may be sought in the Court of Land Registration,
5th, Surveys, in detail, for special constructive purposes,
6th, Sanitary Surveys,
7th, Geological, Biological, Ethnological, and other scientific studies.[21]

The sequence of types of surveys presented crystallizes the aims and means of American science and technology at the turn of the 20th century. Geodesy is paramount, then all else. The reasons for the emphasis on nautical charts before topographic maps was indicated clearly by Charles B. Elliott, who had also been a member of the Philippine Commission, along with Worchester.

"For the Philippines, water transportation will always be of even greater importance than land transportation. The Archipelago is separated from the American continents by the broad Pacific and from the coasts of Asia by the turbulent waters of the China Sea. It is a maritime country in the strictest sense of the word... Marine surveys are of general as well as local importance, and it was only reasonable that the United States government should bear a portion of the

[19] Testimony before the Committee on Naval Affairs, March 19, 1900. pp. 11-12.
[20] Ibid, p. 13
[21] Committee on Surveys (1904, p. 1)

> expense of a complete coast and geodetic survey. An arrangement was therefore made under which the coast waters were to be resurveyed and recharted. The work was placed under the general control of the superintendent of the Coast and Geodetic Survey at Washington, who detailed an officer to act as director of a bureau in the Philippine government. Under this arrangement, which has proved quite satisfactory, the United States government has paid about fifty-five percent and the Philippine government forty-five per cent of the cost of the work".[22]

And so the mapping of the Philippines began, not on the islands, but at sea level. Soon enough, though, the great triangulation networks began to march across the mountain peaks of the larger islands and then across straits and channels between the islands. In anticipation of a myriad of hydrographic and other charts, the Coast Survey established the 4000 series of numbered charts, devoted exclusively to Philippine charts. The Insular Government of the Philippines created a Bureau of Coast and Geodetic Survey which worked in tandem with the US Coast and Geodetic Survey, with particular emphasis in both agencies in nurturing local specialists in all phases of the work. By 1923, the Philippine government had requested a 3-D relief model of the archipelago "as an invaluable aid, not only in the teaching of physical geography in the schools of the Philippines but as a help to the Scientific staffs of the various Philippine Government bureaus in their studies along the lines of seismology, geology, mineralogy, meteorology, etc".[23]

And so the work progressed in the Philippines, for four decades, until the day after Pearl Harbor in the Hawaiian Islands was attacked, and the Coast and Geodetic Survey went to war. That mobilization will be discussed in its time.

"The Variations of the Needle must be Shown"

Pritchett directed a Survey dedicated to cutting-edge science, but funded by legislative processes that preceded the invention of photography, the telegraph and the telephone. In December, 1899, the US Senate directed there be furnished a report on the present status of the Survey, with particular regard to the status of "surveys which may have been inaugurated on the islands now under the possession of the United States"—those being, of course, the Caribbean and Pacific islands gained through the Spanish-American War. Pritchett's reply was couched in language that sounded even older than that of Ferdinand Hassler, dead some 66 years at that point.

> "The object of surveys of the coast, as defined by existing law, is to furnish the information needed to commerce and in defense. A survey sufficiently complete to furnish this information requires a hydrographic development showing the depths of the water in the approaches to the coast, on the bars, and in the harbors and estuaries frequented by navigators, a careful location of hidden dangers, whether they be rocks or shoals, and whether they are permanent or shifting. There is also required a

[22] Elliott (1917, pp.326-327).
[23] Bureau of Coast and Geodetic Survey, 1923, p. 5.

> knowledge of the tides and currents whose bearing on the needs of the navigator is patent to everyone. A topographic survey of the shores is needed in order that the sailor may identify the locality through natural and artificial aids to navigation on shore, for defensive purposes, for showing the facilities of commerce, and for the study of harbor improvements. The triangulation is the mensurational part of the survey on which the correctness of the hydrographic and topographic representations depend, and which properly connects in distance and bearing the features of the map. Last but not least in importance, the variations of the needle must be shown and data must be at hand for predicting it in advance".[24]

The reality of Survey science, as opposed to the archaic formalized language of Congressional reports, was based on investigations and instruments that were increasingly sophisticated and international. Survey earth science was, necessarily, *global* science, whether or not this was necessarily explained to Congress on all occasions.

Two initiatives of this globally-networked science from Pritchett's tenure will give the range of endeavors the Survey was pursuing. The first was the establishment of two permanent stations, at Ukiah, California, and Gaithersburg, Maryland, that were the American components of the International Latitude Service. They were part of a new global network, under the International Geodetic Association, designed to answer one of the most important challenges in the theory of the earth system.

In 1765, Leonhard Euler (1707-1783) the great mathematician and physicist, proposed that there was a disparity between the earth's axis of rotation, and its axis of figure, the latter being the principal polar axis of inertia. One axis should rotate around the other, and the earth therefore should wobble, with a period of rotation to be determined. For the next century, this theory, and attempts to prove it or disprove it, occupied an important place in the concerns of those whose profession it was to observe the complex relationships between the terrestrial and celestial spheres. . By the late 19th century, a combination of new and sensitive instruments, coupled to a network of increasingly global cooperative scientists, demonstrated Euler to be correct. The Coast and Geodetic Survey was at the heart of the exercise.

> "The crucial test was made in 1891 by the International Geodetic Association and the United States Coast and Geodetic Survey. Observations for latitude were made by the former at Berlin, Strassburg, and Prague, and at Waikiki in the Sandwich Islands; and by the Coast and Geodetic Survey at Rockville (in Maryland), San Francisco, and also at Waikiki. The last station was especially important because its longitude is about 180° different from those of the German stations. Consequently, if the latitudes of the latter are found to increase during a certain period then that of Waikiki must be expected to simultaneously decrease by the same amount. As this was found to be the case, we may say that the two independent series of Marcuse and Preston, at Waikiki, firmly established the fact that the earth's axis of figure was slowly revolving around its axis of rotation.

[24] Pritchett (1900) pp.2-3.

"Meanwhile Chandler, of Cambridge Mass., had already begun his investigations upon the law of variation. The results obtained by him mark an epoch not only in this subject, but the whole progress of precise astronomy. For he was able to trace variations of latitude as far back as the time of Bradley (1750), and to show that many of the discouraging discrepancies encountered since that time were due to fluctuations in the latitude".[25]

The convergence of Euler's theory and Chandler's variations together with an increasingly cooperative international scientific community and increasingly accurate and precise instruments indicates how the Survey's concerns were evolving in ways not necessarily apparent to, say, a Congressional committee budgeting nautical charting. Erasmus Darwin Preston, of the Survey, had worked even earlier than 1891 in Hawai'i, performing gravity measurements on the slopes of Mauna Kea on the big island of Hawai'i. Note that Preston arrived before the islands were annexed to the United States, so his presence wasn't dictated by the demands of charting the coastal waters of the United States and its possessions. He was there because the science demanded it.

As the Survey's contribution to the International Latitude Service, the Ukiah and Gaithersburg stations, part of a global network of similar observatories located at 39° north latitude, were equipped with a variety of standardized instruments, operated under standardized protocols, and reported and analyzed by international committees.

International geophysical scientists were linked by increasingly similar objectives, but their work was also threatened by similar phenomena. Those whose profession it was to attend to 'the variation of the needle', meaning the fluctuations of terrestrial magnetism, found themselves menaced, in the late 19th century, by the latest products of advanced urban life. Edison's electric lights and the whole cascade of electrical utilities had provoked a crisis in the study of terrestrial magnetism. As Louis Bauer, who became the first head of the Division of Terrestrial Magnetism of the Survey, and later the founding director of the Division of Terrestrial Magnetism of the Carnegie Institution of Washington, noted:

"The selection of a suitable site for a magnetic observatory to be continuously and uninterruptedly in operation for a period of fifteen years, at least, is a most difficult matter in view of the rapid spread and development of electric car lines and electric power and lighting establishments. Nearly every prominent magnetic observatory over the entire globe has suffered more or less in recent years from stray industrial electric currents. Thus the two principal observatories in England, Kew and Greenwich, in operation for half a century and more, have been affected by the London electric car lines. Kew is at present making preparations to move to another site. Nearly every magnetic observatory in France has suffered, and its principal observatory has been moved... By the decree of the Emperor, forbidding a closer approach of electric car lines than 16 kilometers, the Germans have been able to keep their principal observatory at Potsdam free from disturbance. Considerable pressure

[25] Schlesinger (1900) p. 503.

has been exerted, however, on the part of the inhabitants of the district where electric car lines are excluded for better rapid-transit facilities than now existing, and there has been some talk of placing the observatory in a more isolated site..."[26]

The crisis of electrical interference had been developing for some years, although organizations varied in their recognition of the problem. At the height of the conflicts between the Coast Survey and the Navy, it possibly gave Mr. Pritchett some satisfaction to note that the Navy had been quite slow to recognize the problem.

The Chairman. "In your general investigations touching the various scientific work and various scientific departments about Washington, has your attention been drawn to the astronomical work being done by the Naval Observatory?"

Mr. Pritchett. "Naturally I have had a good deal of interest in that, having been at one time assistant astronomer in the Naval Observatory, and being more or less connected with astronomical work all my life...

"In reply to the request of the Chairman of the Committee, the following statement has been prepared relative to the equipment, standing, and organization of the United States Naval Observatory:

This observatory is one of the best equipped astronomical institutes in the world, and is the most expensive one. It includes also a complete magnetic observatory, which, however, is useless on account of the nearness of the trolley lines, a state of affairs which was foreseen before the erection of the magnetic instruments. The output of the work of the Observatory for many years past has been so meager as to bring upon it the constant criticism of astronomers in this country and in Europe".[27]

The magnetic crisis triggered by trolley cars added impetus to change the ways that the earth's magnetic field was observed, but addressing the phenomena of terrestrial magnetism, as it was then called, has been a constant in the Survey since its conception. The three primordial instruments of surveying are the plumb bob, to establish the vertical, some standard of measure, to measure distances, and the compass, to establish directions relative to north. Of the three, the compass is almost always wrong, in that it almost never points directly north, due to the disparity between the earth's magnetic field and its geographic organization by rotation around its axis. Hence, establishing magnetic deviations, both in place and over time, has always been a central preoccupation of the Survey, or any other survey. By the late 19th century, the Survey had established programs to determine, for all county seats in the United States, the paired azimuths of true north, derived astronomically, and magnetic north for that moment (since magnetic deviation changes steadily over time, a process called secular variation) for specific points, laid out with sets of monuments. The monuments and their alignment allowed surveyors or others who needed confident use of their compasses to note the local variations of the geomagentic field and correct for them.

[26] Bauer and Fleming (1903), p. 308.
[27] Pritchett (1900B) p. 417.

Compass readings vary over space and time, and also in response to local conditions, such as mountain ranges full of iron ore. Over time, the goal to determine magnetic deviation for specific spots evolved to embrace projects to make much more finely-tuned continual measurements from specific observatories, with correction factors determined to allow those results to be interpolated elsewhere. These observatories were directed to conduct precise observation of the three magnetic elements, as they are called: the first element is the absolute intensity of the magnetic field as sensed at that spot; the second is the azimuthal direction of the field, equivalent to the way the compass needle points relative to true north, which was determined astro-geodetically; and third the dip of the magnetic field, because the earth's magnetic field is organized around the magnetic poles in such a way that lines of magnetic attraction are curved from pole to pole, and so, from any given spot, the field dips at an angle to the horizontal parallel to theslope of the field at that point.

Three sets of instruments have been developed to measure, in concert, the three magnetic elements: the magnetometer (see illustration from Bauer, 1902), which measures magnetic deviation; the dip circle (see illustration from Bauer, 1902) which determines the dip of the field, and the earth inductor (see illustration from Bauer, 1902), which, in concert with the magnetometer, gives the absolute intensity of the field. The instruments were extremely delicate and quite sensitive to air temperature variations, which introduced error in the measurements. As a result, a proper magnetic observatory, as the facility used to house these instruments came to be called, was expensive to build and maintain. During the dark times of the Survey in the late 19th century, there was but one magnetic observatory, which was moved repeatedly, in response to changing constraints of the Survey's work, and also the new problem of electrical trolley cars. The discontinuity of observations from any one site impacted progress in any national program of magnetic work.

Once again, Pritchett had a solution. He proposed elevating the magnetic work to the status of a specific division of the Survey (along with the other two divisions, Geodesy, and the combined division Hydrography and Topography). After beating back the attempt of the Navy to take over the Survey, in order to replace the services of the Navy officers, now permanently withdrawn from the Survey, Pritchett had acquired authority to hire 30 new, permanent assistants. A good number of these positions were reserved for the newly expanded magnetic observatories. In Pritchett's final round of budget negotiations with Congress, he requested, and received, funding for:

> "For continuing magnetic observations and to establish meridian lines in connection therewith in all parts of the United States, and for making magnetic observations in other regions under the jurisdiction of the United States, including the purchase of additional magnetic instruments, and the lease of sites where necessary and the erection of temporary magnetic buildings;"[28]

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[28] Public—No. 158, An Act making appropriations for sundry public expenses, etc. Under the Treasury Department, 1902, p. 13.

After thorough and rigorous hunting for potential observatory sites that would not be susceptible to electric contamination, three observatory sites were first selected: a site on the extensive grounds of the Reform School for Colored Boys, in Cheltenham, Maryland, about 15 miles from Washington, DC, was to be the national standard observatory, to which all instruments were to be calibrated; an isolated hill on a peninsula outside Sitka, Alaska was to be the high latitude station; and a site on a non-magnetic uplifted coral plain at Ewa, on the coast of the island of Oahu, in the Hawaiian Islands, was to be the tropical site. Additional sites were planned for the middle of the continent, near Baldwin, Kansas, and a site in Puerto Rico, originally on the island of Vieques, the latter situated in "a region recommended as a desirable one for a magnetic observatory by the International Magnetic Conference held at Bristol, England, in 1898, and one which the recent volcanic eruptions on Martinique and concomitant magnetic storms have made doubly interesting and important for magnetic observations".[29]

The new era in terrestrial magnetism, with new permanent staff positions and new permanent national observatories[30] had far-reaching consequences for the Survey. The magnetic observatories, like the latitude observatories of the International Latitude Service, served national objectives and also international scientific goals as well. The demands for new instruments of sufficient sensitivity and reliability continued to expand the instrument designing and manufacturing capabilities of the Survey. And finally, the magnetic instruments themselves were sensitive enough, and the magnetic field faint enough, that additional instruments were acquired solely to assist in factoring out non-magnetic disturbances that might affect instrumental measurements. Bauer and Fleming, in discussing the original instrument arrays for the three original observatories, under accessories, note that each observatory would be "supplemented by a seismograph".[31] The original purpose of the seismographs was to filter out earth movements that might disturb the magnetometers. Hence, the contribution from earth tremors to the 'variation of the needle' of the magnetometer could be eliminated. However, eventually the seismographs would propel the Survey into the very heart of both the revolution of plate tectonics and the scientific Ground Zero of the Cold War.

After three years of adroit labor as Superintendent, Henry S. Pritchett resigned his post and accepted the position of President of the Massachusetts Institute of Technology (MIT). On his arrival, the Survey had been moribund, many of its most respected and longest-serving scientists had been dismissed, its very existence was threatened by the Navy, and its fundamental ability to survey the coasts was as dependent on Navy personnel as had been the case in the days of Hassler. During his administration, every one of those problems had been addressed. Pritchett left the Survey as a completely civilian scientific agency, participating on the most rarified levels of international earth

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[29] Bauer and Fleming, op. cit., p. 307.
[30] Postwar development in the Maryland suburbs eventually contaminated the Cheltenham site, so the national standard observatory was reconfigured at the Fredericksburg, Virginia Observatory, which is actually situated in a very rural location at Corbin, Virginia. The Hawaiian observatory had to be moved during the Second World War, because a newly constructed navy air base nearby interfered with the instruments; the observatory was relocated a few miles to its present site at Ewa on Oahu. The Sitka observatory is still situated in place, in the same non-magnetic building, constructed in 1902.
[31] Bauer and Fleming, op cit., p. 330.

science, and sailing its own ships under its own crews and sailing masters, not just to the expanding waters of the coastal possessions of the United States, but increasingly to every edge and corner of an ellipsoidal world.

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The More Things Remain the Same, the More Things Change: The Continents and Continuity, Isostasy and Otto Tittmann

After his three eventful years as Superintendent of the Survey, Henry S. Pritchett accepted an offer to become President of MIT and departed Washington. He was replaced by Otto Hilgard Tittmann (1850-1938), who served as Superintendent from 1900 to 1915. Tittmann's career embraced the old and the new. In a sense he was born in the Survey (he was actually born in Ohio) as he was the nephew of Julius Hilgard, the Survey's fifth Superintendent (1881-1885). He joined a Survey field party at the age of 17, in the year that Bache died, 1867. By 1900, when he became its leader, working for the Survey was the only job he had ever had. By the time he retired, he had worked for the Survey for 48 years.

Tittmann faced into the Survey, and he also faced out. His career emphasized the increasingly international nature of the Survey's burgeoning scientific work, as well as the opportunities that opened up for a person of his abilities and skills. He served on many international commissions, including the International Boundary Commission and commissions related to scientific standards, including the standards for substances assaayed by refractometer, including a refractometer originally invented by his uncle Julius Hilgard[1]. He was in charge of the Office of Weights and Measures in the Survey from 1887 to 1895, and in 1890 he was commissioned to bring the National Prototype Standards from Paris to Washington. Under his leadership in 1901, the Office of Weights and Measures separated from the Survey to become the National Bureau of Standards (NBS), as Pritchett had planned during his tenure. The physical meter has long been replaced by an optical standard length, but the one and only official kilogram of the United States, brought by Tittmann, still resides at the headquarters of the National Institute of Standards and Technology (NIST), the successor to NBS, in Gaithersburg, Maryland. Tittmann co-founded the National Geographic Society, and when he retired as Survey Superintendent in 1915 he became President of the Society until 1919. He also was a founding member of the Cosmos Club, an influential club of men of accomplishment in Washington, and served as the Club President in 1904. He was a member, and often a leader, of every major scientific society relevant to his subject areas,

[1] Garner, 1938, p. 394.

and served on the special committee of the NGS that evaluated Admiral Peary's claim to have reached the North Pole in 1909. Tittmann calculated that Peary had done so[2].

Tittmann's career and life were relentlessly straightforward that the only apparent drama in his life was a single episode, when he was a member of a field party of the International Boundary Commission. Tittmann and his crew were camped on a narrow defile above the Stikine River in Alaska. After a storm the water rose suddenly, and the men were able to scramble upwards to safety, but the entire camp and all their equipment and food were washed away[3]. In fact, Tittmann's career embraced many dramatic changes, but most of these occurred deep beneath the earth's surface. It was during the quietly productive tenure of Tittmann that the Survey acquired scientific missions, developed techniques and accumulated data that would, several decades later, lead to the most important upheavals in our understanding of the structure and functioning of the solid (or not so solid) earth itself. Tittmann's scientific life was coterminous with the rise and further rise of the calming concept of isostasy—but that same concept would eventually drive on relentlessly, like oceanic crust subducting, to create the great rift in the earth sciences that summoned the theory of plate tectonics itself.

The Survey in the US Government and the World

Apart from two short episodes when the Coast Survey was under the control of the US Navy, the Survey had been an agency in the US Treasury Department since Hassler's days. In 1903, the Coast and Geodetic Survey was transferred from the Department of the Treasury into the newly formed Department of Commerce and Labor, along with the National Bureau of Standards. In 1913, this Department was split into the separate departments of Commerce and of Labor, with the Survey and NBS remaining in Commerce. The Survey remained there the rest of its independent existence. In 1965 the Survey joined the Weather Bureau in forming ESSA (the Environmental Science Services Administration) in 1965, which became NOAA in 1970.

As the Survey had been the original scientific agency in the government, it was in many respects the template for other agencies as they developed. And all of these agencies were in turn affected by various attempts to standardize or regulate government bureaus as a part of specific administrations, particularly under periods of war. Perhaps the greatest cross-agency change in Tittmann's tenure was initiated by President Taft's 1910 President's Commission on Economy and Efficiency, which directed all non-military federal agencies to analyze their structures, and then strip away excessive infrastructure and expense. The Committee had a major impact, within the Survey, on the ways it administered its history and legacy. The Survey had generated vast quantities of data and information and charts, and also developed a major reference collection as well, particularly strong in several areas: historic maps and charts critical to resolve issues about boundaries and borders, and a premier scientific reference library, which formed around the core of the book collection that Ferdinand Hassler himself had assembled to conduct the Survey of the Coast. However, as a result of the 1910

[2] See Colton (1949) Garner (1938) and Tittmann (1916).
[3] Colton, p. 3.

Committee and its initiative, the Coast and Geodetic Survey removed thousands of its historic maps ands charts and other resources, and transferred them to the Library of Congress by 1914. This action probably “saved” and certainly better preserved much of the material, but it also dissociated the Survey from primary custodianship of its historical legacy, and it meant the loss of the “institutional memory” inherent in the existence of the major personnel with responsibilities for the Library and Archives Collection—when they left the Survey, their mastery of, or even knowledge of the existence of, the historical assets left with them.[4] This is an unfortunate theme that will arise again at various critical junctions in the history of the Survey and later of NOAA.

This attrition of maps and charts was accompanied by a parallel attrition in skilled members of the Survey, a seemingly constant problem since at least the demise of A.D. Bache in 1867. The Survey was the oldest scientific agency in the government, and as such was an important training academy for generations of scientists and skilled technicians, for computers and cartographers, for competent field party members and methodical librarians and catalogers. However—all of these personnel were necessary for other American scientific agencies and museums as they developed, and the Survey’s ability to retain many or even sometimes the best of their personnel was severely constrained by the low salaries and limited rates of advancement that seemed to be endemic with work on the Survey. The history of the Survey is characterized by only a very few Superintendents or Directors who were capable of making substantial changes in these matters during their tenure, and Tittmann was not one of them. And thus it was as well that the opportunity of celebrating or even noting the centennial of the beginning of the Survey, in 1907, was passed by on Tittmann’s watch.

In part this reflects the extraordinary advance in responsibilities for charting ever newer regions of the rapidly expanding American dominion. In part the Survey removed older maps from the Library and Archives Collection in order to make room for newer ones. The charting and geodetic responsibilities of the Survey continued to expand with the new territorial claims of the government. During Pritchett’s tenure, the US acquired the Philippines and annexed Hawai’i, and the Survey acquired major responsibilities in both places, particularly so in the Philippines. The Survey became responsible for mapping the Panama Canal Zone in 1903. The impact of the Klondike gold rush on American and Canadian management of the Yukon River and environs led to major bi-lateral (meaning the US and Great Britain) largely cooperative enterprises to determine or re-determine various parts of the border between Canada and the United States. There were major International Boundary Commission surveying exercises in 1901, 1902, 1906, and 1913. These will be discussed further under the section on the Division of Geodesy.

The very technologies of map production and printing were changing under the feet of the Survey, as it were. During the “golden decade” 1851-61, the Coast Survey was one of the most important innovators in engraving and lithographic technologies in the United States. By the end of the century, the Survey had lost the lead in printing innovation, although that would change again in the 20th century as the Survey prepared

[4] Committee on Economy and Efficiency in Government (1911), R.M. Brown (1911)

for and fought the Second World War through charts and maps. In Tittmann's time, major printing innovations were developed outside the Survey, but eventually migrated into Survey practices.

The use of engraved copper plates as the primary "permanent" bases for Survey charts, which began in the 1840s, ceased in 1905, replaced by a variety of photographic media used to maintain the information content of the plates. Electrotype copies from older copper plates continued, so that charts continued to be printed from "copper" (which really meant electrotype plates). Also in 1905, photolithograph plates and presses were introduced. These could be used to print lithographs in multiple color runs, using dry paper, as opposed to the wet paper used with "copper", greatly expanding the speed of chart production while decreasing the distortions from wettened paper shrinking and expanding. Finally, in 1903, offset lithography applied to printing on paper was independently invented twice in the US, in one instance by the Harris Brothers. Eventually, the Survey and the Harris Press Co. would form a relationship that survives into the 21st century, but that event required the brilliant bureaucratic skills of Tittmann's successor.

These are the highlights of the Survey during Tittmann's tenure, ordered according to the "modern" divisions of the Survey that Pritchett had established during his tenure:

The Division of Hydrography and Topography

- in 1903, under the direction of Nicolas Heck, the technique of wire drag for detecting rocks and snags and other intrusions in the water was developed substantially, a technique that in largely similar form would be used by the Survey, and later NOAA, for almost the rest of the 20th century.

- The first experiments with underwater acoustics for detection and distancing began, in collaboration with the Submarine Signal Corporation.

- The national vertical and horizontal networks expanded, the former particularly rapidly using the newly invented Fischer vertical precise level, one of the finest Survey instruments ever created.

- A new tide prediction machine, developed by Richard Harris and perfected and implemented by Ernst Fischer, through a development process that lasted 15 years, was finished in 1912. The Tide Prediction Machine No. 2 (No. 1 had been the Ferrel machine) was one of the most sophisticated analog calculators ever constructed, and was used by the Survey until the 1960s.

The Division of Terrestrial Magnetism (and Seismology)

• The national system of magnetic observatories developed by Pritchett was realized under Louis A. Bauer, the first head of the Division of Terrestrial magnetism, with observatories in Sitka, Alaska, and Ewa, on the island of Oahu, in Hawai'i, standardized to the national observatory in Cheltenham, Maryland.

• Bauer wanted to extend terrestrial magnetic observations worldwide, and persuaded the Carnegie Institution of Washington to establish, in 1904, a Department of International Research in Terrestrial Magnetism, later shortened to the Department of Terrestrial Magnetism, or DTM. DTM and the Survey collaborated from then on.

• With Bauer moved to DTM, Nicolas Heck shifted from Hydrography to become the head of the Division of Terrestrial Magnetism, which led to decades of important work in the earth sciences, although Heck continued an important role in developing hydrographic equipment and techniques, especially Radio Acoustic Ranging (RAR) in the 1920s, along with major instruments for seismology.

• In 1906, the great earthquake of San Francisco occurred. Survey magnetic observatories used seismometers as part of their instrument arrays to determine what component of apparent changes in magnetic intensity (i.e., the variation of the needle) was attributable to earth movements. The data their seismological equipment yielded about the earthquake on the San Andreas Fault was impressive, albeit secondary to their primary task. Nevertheless, this brought the Survey into a prominent role in seismology, in cooperation with the Carnegie institution of Washington, especially in California, where resurveys of geodetic monuments yielded important data on earth movements along faults.

Division of Geodesy

• Survey latitude observatories located in close proximity to the 39th parallel of latitude near Gaithersburg, Maryland and Ukiah, California were formally incorporated in the International Latitude Service. This was a significant milestone in the increasingly internationalized, outward-looking science of the Survey.

• Based on the integration of the major great geodetic arcs run in the late 19th century, the Survey established the first national datum, the U.S. Standard datum, in 1901. The Survey persuaded the nations of Mexico and Canada to cooperate on a unified datum for all three countries, particularly driven by the efforts to extend the 98th Meridian arc from Arctic Canada on the north to the southwest coast of Mexico on the south, and by the US-Canadian effort, to determine the 141st meridian as the boundary between part of Alaska and Canada. These collaborations led to the declaration, in 1913, of the North American Datum, the first great international datum.

• As a part of this continental geodetic integration, John Hayford of the Survey began to develop a new model of the Figure of the Earth, the Hayford Spheroid, which was subsequently adopted internationally in 1924 as the International Reference Ellipsoid.

• Hayford and William Bowie developed a topographic method to adjust gravitational anomalies, associated with calculated deflections of the vertical, particularly related to re-calibration of stations of the great arc of the 39th parallel run between 1871 and the 1890s. The Bowie method became a world standard technique. Further, the gravitational anomalies were yet further reduced by applying various corrections based on the theory of isostatic equilibrium. The great success for the corrections amounted to substantive evidence for the theory of isostasy, which had huge implications for the controversies to arise and subside in the next critical decades of debate in all fields of geophysics.

• A great explosion in geodetic instruments occurred, not the least of which was the first use by Survey personnel of one of the most important geodetic instruments of the 20^{th} century—the automobile.

Hydrography by Wire and Predicting Tides with Wire: The Division of Hydrography and Topography under Tittmann

The tools used for hydrographic and topographic surveying in this era were not radically different from previous technologies, but were improved over previous models. Much of this was due to the work of Ernst Fischer (1852-1934) and the personnel in the Survey's Instrument Division. Fischer was a child of German immigrants, born in Baltimore, who left with his family for Germany at 2, returning to the United States after a rigorous polytecnic school education and much work in engineering. In 1887 he joined the Survey, and very soon was chief of the Instrument Division, a position he held until his retirement in 1922. Fischer designed and improved many dozens of instruments used in every endeavor of the Survey on land and sea.

Two of these, from the Tittmann era, deserve mention. The first was the Fischer Precise Level, used in extending vertical control networks. It was cheaper, lighter, easier to use, and far more precise (hence its name) than any previous level model used in surveying and topography. Recognition of its significance requires some attention to vertical datums and how they differ profoundly from horizontal datums. The major work of the Survey, since the beginnings under Hassler, was to determine the specific positions of very specific important points, and then develop a triangulation grid radiating out from those points. The network was three-dimensional, in the sense that it followed the landscape, but the locations of the points in the network were the specifications of the horizontal positions of those points, relative to a specific reference ellipsoid and a specific datum. The vertical position of the points, as relative to mean sea level or its equivalent (the geoid) was a completely different matter, and a different kind of data, obtained by the use of completely different instruments. Vertical datams began at the seashore, with a zero level of mean sea level as defined by the average of years of tidal data to compensate for the influence of the Moon and sun and weather. Once mean sea level had been established, elevations above (and occasionally below) mean sea level marching inland were determined by spirit levels and calibrated rods. The vertical network could intersect the horizontal network, as when a spirit-level defined elevation was determined for a specific horizontal network point, but the determination of horizontal and vertical positioning for that single point were entirely distinct. Spirit-level positioning was clearly a function of the accuracy of the spirit-level, and the new Fischer instrument issued in a new era of advances in the vertical networks. Historically, these networks began at the coast, and advanced inland along routes chosen for the strategic and transportation significance of the route. In Tittmann's era, the most developed and densest vertical networks advanced along the Mississippi River and its tributaries, with smaller networks advancing uphill from Chesapeake Bay and its major tributaries, and adjacent to the major canals, like the Erie and Delaware canals, and along the important trunk railroad lines, especially the main line of the Pennsylvania River.[5] In each case, a specific spirit-line leveling survey marched inland and uphill from specific coastal points. A major research objective was to determine if sea level was the same for the Atlantic and Gulf coasts. There was much speculation that ocean circulation patterns and geography "piled up" water in the Gulf of Mexico, such that sea level there would be higher than sea level along the Atlantic coast. Four surveys run in 1893 and 1894 disclosed that the Gulf of Mexico sea level was a mean of 0.2585 meters higher than sea level on the Atlantic, but it wasn't clear that the accuracy of the leveling warranted a definite conclusion.[6] Adolph Lindenkohl, now working in his 4th decade with the Survey, attempted to determine differences in specific gravity (density) of surface sea water on the separate coasts in order to answer the question. His data was inconclusive for determining sea level, but hugely important for the subject of global ocean circulation and patterns of salinity and temperature.[7] These matters of determining mean sea level for specific seas and their relation to other seas, and the leveling networks running up from the ocean, would continue to be major research frontiers for the Survey and later for NOAA.

The second major instrument associated with Fischer was the great Tide Prediction Machine No. 2, the successor to Ferrell's Tide Prediction Machine No. 1. The second machine began with design work by R.A. Harris, and then Harris was joined by Fischer in the effort (later on, they disputed their relative contributions to the device). The Machine was, simply put, one of the most sophisticated analog calculators ever made. The input to the machine was historic tide data for at least a 19 year tidal cycle, which was then encompassed in a 39-term spherical harmonics expansion. The sun-moon-earth geometry for any arbitrary date for that place could then be entered, and the device cranked (literally) to produce the curve of the tides for that specific date and place. The Machine was used in both world wars, and continued in service until the middle 1960s, when digital computers finally made the machine obsolete[8].

A third technology developed for hydrographic surveying in this period represented a major advance for the Survey and the safety of navigation of any mariners using Survey charts. It also marked the debut of one of the most remarkable scientists in the Survey in the 20th century—Nicolas H. Heck (1882-1953). Heck was born in

[5] Hayford, 1898-99.
[6] Ibid., p. 397
[7] Lindenkohl, 1895.
[8] Schureman (1958).

Pennsylvania, graduated from Lehigh University, and then joined the Survey, where he remained for the next 40 years. Heck was a great enabler, a designer and improver of instruments and technologies. His contributions to the Survey spanned hydrography, terrestrial magnetism and seismology (he spent 20 years as head of that division) and the larger earth sciences, but they began with the perfection of wire-drag.

Hydrographic surveying when Heck began was changed little from the days of Hassler. Horizontal positioning of a Survey boat was determined by triangulation of visual observations of signals at known locations on land or in the water. Vertical lead line soundings at that position gave the depth. But between two different points, there was no data at all about the depth to the bottom, or the possibility of snags or protrusions or other dangers to mariners in between the surveyed points. In the 19th century French hydrographers had worked on techniques to sweep a mast or other straight object weighed down to a certain depth, in order to catch the mast on any potential obstruction. In the US, Army hydrographers in the Lakes Survey tried their own variant on this, called wire-sweep. When Nicolas Heck entered the Survey, he took on the task of adapting the technique to the constraints of the Survey, and making it work efficiently. The basic concept of a wire-drag is: a wire maintained at a determined depth by a combination of floats and weights is pulled or dragged through the wire between two work boats. Should any part of the wire encounter a significant obstruction or hit the bottom, then parts of the system float to the surface or otherwise indicated clearly and quickly that something has been encountered. A third boat (or more) then goes to the site of the obstruction to mark its position and depth. If the area is dragged without encountering an obstruction, then data has been obtained about the relative freedom of obstruction (at that depth) of the area, and this can be mapped as such. Heck developed the technique until it worked reliably, then he fine-tuned it in a series of successive improvements, addressed to the different constraints of three different classes of work—"first, to determine whether an apparently open sea is free from obstruction; second, to find the least water in a shoal area; third, to develop the maximum safe depth in a channel".[9] The idea was relatively straightforward, but its execution required a seemingly infinite series of tiny design improvements, for submerged floats that would surface when they encountered just the right tension on a line, etc. By patiently analyzing progress or the lack, and making a myriad of tiny improvements, Heck eventually developed the wire-drag technique to the point where the wire drag arrays could be as long as three miles wide as dragged through the water. Wire-drag was successful enough that the system, essentially the same as in 1904-07 when Heck developed it, was used by the Survey, and then by ESSA and then NOAA, until the final years of the 20th century.

Finally, during the latter years of Tittmann's tenure as head of the Survey, some applications of ocean acoustics began. Reginald Fessenden and the Submarine Signal Company were the pioneers in the uses of sound in the ocean for signalling, and then later for sound and sound echoes to indicate distance through the water. The Survey had long associations with the Lighthouse Service, and through its responsibilities for navigation and the avoidance of dangers, the Survey began to experiment, via equipment of the Submarine Signal Co., with acoustics. These efforts redoubled after the loss of the

[9] Heck (1914, p.3)

Titanic in 1912. Fessenden designed an acoustic broadcast and receiving apparatus designed to echo horizontally off icebergs at the surface—but the system also noted echoes off the bottom, which could yield the ocean depth[10]. Only beginning experimentation with this revolutionary technique for hydrography occurred during Tittmann's tenure. However, with the literal explosion in ocean acoustic research by all sides in World War One, and the energy and drive of Tittmann's successor, the Survey was about to enter an entirely new world of acoustic surveying and mapping that continues to the present as the very foundation for most NOAA operations at sea.

Steaming from Manila: The Unique Case of the Philippines Coast and Geodetic Survey

As a result of the Spanish-American War, and also the great expansion of shipping in areas like the seas adjacent to the Yukon Territory and the newly opened Panama Canal Zone, the Survey acquired responsibilities for charting vast areas of new territories in both tropical and near polar waters. Of all the new areas to be charted, the case of the Philippines was in a class of its own.

The Coast and Geodetic Survey's new responsibilities for charting the Philippine Islands were enormous; the archipelago contained thousands of islands, and they were located on the other side of the Pacific Ocean from the United States. This effectively "opened up" the entire north Pacific Ocean to Survey ships and crews, going and coming from the west coast, Alaska, Hawai'i, and the other American island possessions, and the Philippines. As the relatively overworked and underpaid Survey staff members were commonly rotated through tours of duty in many disparate sites, they acquired experience in many different environments, which would become particularly critical decades later during World War II.

The legal and political context of the Philippines was complex. The Philippines had been a colony of Spain, now captured by the United States. A local revolutionary struggle for independence appealed to the United States to grant independence. The United States agree to do so—within 50 years. The revolutionaries then turned against the United States, mounting what the Americans termed an insurrection. This put the United States in the unusual situation of fighting to suppress a revolution in a colony that the US had pledged to grant their independence eventually. The first US Survey personnel arrived during the insurrection, and their immediate tasks were to assist military vessels fighting the insurrection. However, this meant that deep-draft boats were sent to unknown harbors hitherto used only by fishermen, which quickly led to a realization that the primary function of the Survey should be its traditional strengths in geodetic surveying and hydrographic charting. The Survey compiled the full archives of British and Spanish maps and charts, but it was recognized immediately that these were not accurate enough to suffice[11]. The Survey was brought in to develop a geodetic network and chart the insular waters and harbors, but it would do so working on behalf of

[10] Bates (1982)
[11] The Survey reprinted a revised Spanish language atlas in 1900 as C & GS Special Publication No. 3, unique in the history of the special publications. (US Coast and Geodetic Survey, 1900)

a new enterprise in the Philippine government, the Philippines Coast and Geodetic Survey, headquartered in Manila. As interior regions of many of the islands were inaccessible because of the rebellion—and also the challenges of Philippine geomorphology and tropical ecosystems—the Survey started by charting significant ports an harbors, then spreading out from them along island coasts. Eventually the major rebellion ended, and more "normal" working conditions and objectives could develop[12].

The challenges of the Philippines Survey were unique in American experience, as the country's islands ranged in size from almost the largest on earth to tiny atolls, occupied by large populations of people speaking many languages, although these populations were heavily concentrated on the west coasts along the China Sea, while the east side of the Philippines archipelago was much less settled, less developed, and much more remote. E.R. Frisby, a Survey senior hydrographer, wrote a memoir about the early history of the Survey in the Philippines. His descriptions of field work in the tropics are vivid:

"One raised in the temperate zone, educated in the high average social culture of America and not inured to the bodily hardships of tropical exploration, little conceives the first shock of contact with aboriginal life. Reconnaissance was often on all fours behind a gang of knifemen slashing a tunnel through matter underbrush; at other times, it was in stifling fields of giant grass so dense and tall as to exclude all views except that of the blasting overhead sun; and again, it was a problem of waist-deep slimy swamps. Physical effort in the warm and humid air bathed the body in perspiration; and contaminated water demanded that the torments of thirst be met with self-denial or with an unbearable load of canteens.

"Station clearing in dense hardwood forests turned the teeth of cutting tools and elicited amusement when severed trees refused to fall. Days of cutting were followed by days of disentangling the lacework of vines tangled in the tree tops.

"Camp life was a struggle against the personal discomforts caused by insects, skin infections and diseases, primitive lack of sanitation, and the prevalence of intestinal disorders and fevers. There was a pervading sense of helplessness in dealing with native inhabitants and in securing efficient work from native employees. Irritations were multiplied by the failures of language, the inertia of the people, and their inability to comprehend either the haste of the foreigner or the intricacies of the occidental methods. A sense of isolation and loneliness completed the undoing of all but the strongest spirits. It was natural that reports of these conditions, exaggerated by distance and repetition, should cause apprehension in the United States, with the result that numerous resignations occurred in the early days of the Survey as an alternative to three years of Philippine service.

"Fortunately, however, there are individuals of the pioneer type who delight in discomfort and revel in the curiosity and humor of strange and novel situations. Such men flocked to the original organization of the Philippine government—officers of the

[12] Putnam, 1907.

army and constabulary, engineers, teachers and provincial officials—and the similar elements in the Coast Survey enthusiastically carried its work through the early crucial and formative stages and pointed the way to its successful continuation."[13]

The Philippine Survey evolved a unique structure and work methodology appropriate to its novel context. The capable George Rockwell Putnam, who was later the Director of Lighthouses for the United States, was the founding director of the Philippine Survey, serving from 1901-06. All work was organized through and came back to the headquarters in Manila. Since the Philippines was so geographically distant from the United States, virtually all Survey data reduction and analysis, and chart construction and printing, was performed in Manila, not back in Washington, as was the case with the Coast Survey proper.

The tasks in surveying the new tropical areas were quite similar to those necessary for Alaska and the original surveys of the west coast. In the northeast Pacific areas, the human populations were sparse, and geodetic networks had to be begun from scratch. The Philippines had large populations of very diverse peoples, but geodetically the archipelago was as much a pioneer coast as California had been under George Davidson in the 19th century. Previous British and Spanish charting and positioning were inadequate to the demands of commerce and military needs, so once again the work started from scratch. The Coast Survey dispatched the hydrographic survey ship the Pathfinder, then the largest Coast Survey ship, from duties in Alaska to the Philippines. Although the *Pathfinder* had been especially designed for service in the cold waters off Alaska, it served for four decades in the tropical waters of the Philippines. After the ship was scuttled in Manila Bay in 1941, its original name was revived for a new survey ship, the legendary *Pathfinder* of World War Two[14].

The Philippine Survey paid a heavy price for its initial military-related work charting important harbors and island passageways without benefit of a central datum. The geodetic foundation for the Philippines Survey involved establishing "39 fundamental positions which served to fix all original separate surveys during the period they remained detached. These positions were well distributed over the west coast and central portions of the archipelago, but were sadly deficient along the east coast where lack of telegraphic facilities made longitude determinations impossible".[15] Thereafter, local topographic and hydrographic surveys were tied in to the 39 fundamental positions. This meant that, in effect, there were actually many local, disparate datums. Charts made using projections from the positions did not match. As Frisby noted, at one point there were 51 charts of parts of Luzon and its surrounding waters, based on 19 different positions. The work to develop a single Philippine datum converged on a geodetic network based on the island of Luzon (where Manila is situated) which could be expanded throughout the archipelago. By 1906 the Luzon Datum had crossed the waters to adjacent islands, where 19 astronomical stations were brought into geodetic connection. This early approximation, the Vigan Datum, was tightened and corrected over a period of many years, an arduous process. As Frisby noted, "details of the

[13] Frisby, 1921, pp. 10-11.
[14] See Cloud (2006).
[15] Frisby, ibid, p. 7.

computations extending over several years are so voluminous and involved as to require separate presentation”.[16]

Thus the Philippines Coast and Geodetic Survey developed, separate from the U.S. Coast and Geodetic Survey but also complexly inter-twined. The exchanges of personnel between assignments in Alaska, Hawai’i and the other island possessions, and the US west coast did result in a Survey that plied the northern Pacific Ocean continually, producing data that would eventually be fundamental to the conceptual upheavals of plate tectonics.

The Long Road from Cheltenham: The Division of Terrestrial Magnetism under Tittmann

There are three elements of terrestrial magnetism at any point on earth (the absolute magnetic intensity, and the horizontal (declination) and vertical (dip) components of the local magnetic field) and the only constant of the three is their continual variation, in response to changes in the earth’s mass distribution and the planet’s interaction with the magnetic fields of the Sun. Therefore, resolving the local magnetic field, at any given time, for any given point, requires the use of three sets of instruments designed to measure one of the three elements. These instruments must be calibrated to standards, but these standards are set using other instruments, which vary with the local fields. Hence Pritchett set operations in motion to develop a national network for magnetic observations and instruments, using the observatory at Cheltenham, Maryland as the national standard, with permanent observatories as well in Sitka, Alaska and Ewa, on Oahu, in Hawai’i, along with other observatories established for short periods in specific regions. It fell to Tittmann to realize the national observatory system, and to coordinate the growing and increasingly sophisticated practices of the Survey’s Division of Terrestrial Magnetism with the new, internationally oriented Department of International Research in Terrestrial Magnetism of the Carnegie Institution of Washington, established in 1904. Louis A. Bauer was the head of the Division; he was also the founding director of the Department, a role he held until 1931.

There was an entirely cooperative relationship between the Division, in the Survey, and the Department, in the Carnegie Institution, because they were meant to play complementary roles. The instrumentation of terrestrial magnetism from the Survey side was constrained by the territorial responsibilities of the Survey, which had greatly expanded but were still confined to the land and seas of American possessions and territories. But Bauer wanted to acquire and assimilate magnetic data from around the globe, precisely outside those areas that would be the responsibility of the Survey. These goals were compatible. It also helped that, in 1906, shortly after the founding of the Department (hence DTM), former Survey Superintendent Pritchett was elected as a

[16] Ibid., p. 25.

Carnegie Trustee, and he soon secured a post on the three-member Finance Committee, much to the benefit of Bauer and his initiatives.[17]

The initial collaboration between DTM and the Survey involved development and standardization of instruments at Cheltenham and the other observatories. Later, in 1905, the DTM's first somewhat non-magnetic ship the *Galilee* (a converted brigantine from which much iron was removed and replaced with non-magnetic metals) was sailed under the command of the Survey's Captain J.T. Hayes from San Francisco to San Diego, then to Hawai'i and back to the mainland. On route the instruments were tested and procedures for their use formalized. At the end of this trip the Survey leaders decamped, and DTM personnel—which included former Survey personnel who shifted to DTM—continued alone for two other cruises. In 1908, the completely non-magnetic ship *Carnegie* was contracted, and completed and launched the following year. J. T. Ault became its sailing master and captain, a role he maintained to the very tragic end, dying in the fiery explosion of the vessel in 1929.

With Bauer's transfer from the Survey to DTM, Nicolas Heck, already mentioned for his role in developing and perfecting wire-drag, transferred to the Division of Terrestrial Magnetism, becoming its head for the next three decades. The magnetic observatories all contained seismometers as a part of the instrument array, so that local disturbances of the magnetic instruments attributable to earth tremors could be identified and compensated for. Providentially, then, the Survey's magnetic observatories, although not designed for seismological work as such, proved extremely important when the great San Francisco earthquake struck California in April, 1906.[18] The earthquake was named for the city of San Francisco because the damage there was enormous and apparent, but in fact a major slippage along hundreds of miles of the San Andreas Fault has occurred. In response, the Survey reoccupied primary, secondary, and tertiary points between Monterey in the south and Fort Ross on the north to create a new modified triangulation network, in order to determine the relative motion of stations due to the earthquake, the first application of the technique in the US[19].

The earthquake dramatically highlighted the necessity for major expansions in seismological networks and development of new techniques. The point was certainly not lost on Heck; eventually under his leadership the Division would be renamed the Division of Terrestrial Magnetism and Seismology, with primary responsibility for seismological research in the federal government. That expansion would require time, and the transition to the tenure of the next Superintendent of the Survey.

The Rise and further Rise of Isostasy: The Division of Geodesy under Tittmann

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[17] See Louis Brown, 2004, p. 3 This is the definitive history of DTM and quite useful for the story of Survey interactions with DTM until the end of WW II, at which time the Department of Terrestrial Magnetism abandoned the study of terrestrial magnetism, although it kept the name in its title.
[18] The earthquake was sensed and recorded on seismographs at C & GS magnetic observatories at Cheltenham, Maryland, Vieques, Puerto Rico, Ewa, Oahu, Hawai'i, and Sitka, Alaska. See Reid (1910).
[19] See Hayford and Baldwin (1907).

During the tenure of Tittmann, the Survey consolidated and expanded upon research activities developed through the 19th century to become recognized as one of the premier scientific agencies of the world. How its prominence eroded in subsequent decades and after subsequent wars is reserved for other chapters; here the emphasis is on this period as a geodetic flower unfolding.

In a sense the story is one of continual expansion in space and objective, as geodetic surveys turned into triangulation networks, then into transcontinental arcs, then national and then continental datums, then finally a model of the Figure of the Earth itself, culminating in the Hayford Spheroid. In another sense the story is one of the increasingly internationalized scope of the geodetic sciences, as instrument designs were standardized and promulgated to gather increasingly large and spatially diffuse data sets which were shared and collectively analyzed by national-level geodetic agencies and by international associations whose memberships came from the national bureaus .

This shift to increasingly international scope is exemplified in the history of the United States Datum. In the late 19th century, the original coastal geodetic networks were tied together by the great 39th parallel arc triangulation project, the last great enterprise of Charles Schott. Other arc surveys were developed, especially the Atlantic coast diagonal arc from Nova Scotia to the Texas-Mexico border, and the arc of the 98th meridian. As has been noted, arc surveys define not a line along a meridian or parallel of latitude, but rather a zone of triangles running along the line and determined in large part by the nature of the local topography. Very close to the intersections of the networks of the 39th parallel arc survey and the 98th meridian arc survey the Survey established a geodetic monument on a large private ranch in Kansas. That station, Meades Ranch (39° 13' 26.686" North, 98° 32' 30.506" West) was to become prominent in the entire history of geodesy and cartography in North America for most of the 20th century.

Under Tittmann, in 1901 the Survey proposed a national datum be established for the United States. A datum is a specific geodetic network schema associated with a specific reference ellipsoid model of the Figure of the Earth. “Datum” is the singular of “data”; Meades Ranch was the point where the American reference frame system would be pinned to the ground, as it were. Meades Ranch was chosen because it was very close to the geographic center of the lower 48 states, and because the local and regional terrain were as flat as could be found, minimizing the possibility of deflection of the vertical in plumb bobs at the site, which will be examined in much greater detail shortly. In effect, a plumb bob at Meades Ranch was defined, legally, as pointing directly to the center of the earth, as that center was defined by the Clarke Ellipsoid of 1866. That being defined, then the goodness of fit of the rest of the geodetic network radiating out from Kansas would be most accurate for the great mass of the American portion of the continent, with error pushed to the national margins.

At the same time, though, Tittman and the Survey sought to extend the network and its accuracy of positioning beyond the political boundaries of the lower 48 states by appealing to Canada and Mexico to join the United States in one unified continental datum. This effort was particularly driven by the efforts to extend the 98th Meridian arc from Arctic Canada on the north to the southwest coast of Mexico on the south, and by the US-Canadian effort, to determine the 141st meridian as the boundary between part of Alaska and Canada. These collaborations led to the declaration by all three countries, in 1913, of the North American Datum, the first great international datum. The survey work to complete the arcs, and the necessary reduction and calculations of the data took more than another decade, so that eventually when the initial resolution was finished, the result was the North American Datum of 1927, which was the continental datum for over half a century, finally replaced, in the era of satellites, by the North American datum of 1983 and the World Geodetic System of 1984, both of which were based on a point of origin at the center of mass of the earth, and oriented along the polar axis.

Thus the work of the Division of Geodesy under Tittmann reached standards as high or higher than anywhere else in the world, and attracted scientists of the highest calibre, particularly John Hayford and William Bowie. But this geodetic progress also suffused the Survey's activities in other divisions as well. As Bowie later noted: "any survey of the land in which the shape and size of the earth are taken into consideration can be called geodetic; thus the hydrographic surveys along the coast made for a sailing chart are really geodetic surveys and, similarly, a topographic survey of a large area may be considered to be a geodetic survey".[20]

Thus, as the Division of Geodesy expanded its scope of activities and its ambitions, these suffused the activities of the rest of the Survey. But the Survey and its leaders also impacted scientists and disciplines far beyond the traditional fields of geophysics, as Survey scientists, especially Division chief John Hayford and his associate William Bowie, theorized about and then tested, through re-analysis of classic Survey geodetic data, a set of concepts that arose in the second half of the 19th century, with far-reaching implications for practitioners in the 20th century. Their research brought the Survey to the very center of the struggle to propose, test, and evaluate the theory of *isostasy*, which proposed to account for the equilibrium of the continents and oceans in vertical movement. The concept of isostatic equilibrium became a driving force in geophysics for many critical decades, not withstanding the fact that the concept did little to resolve the larger battles about supposed horizontal movements of continents. These combined struggles to detect and understand horizontal and vertical movements together later on, in the middle 20th century, gave rise to plate tectonics. Looking back a long century from that, the significance of isostasy seems diminished. But, to its credit, the theory of isostasy was never succeeded by a rival theory, but instead by a body of data that largely corroborated the theory.

Isostasy will be described more fully later; what is important for the moment is why it was necessary and important. The word "isostasy" was coined by the geologist C.E. Dutton in 1889. Its meaning, derived from Greek, is "equal pressure" or "equal standing", and it refers to an evolving concept that the materials visible at the surface of the earth are supported by thicker, more fluid materials below them in some sort of globally regular manner. Isostasy arose as a conceptual solution to very tangible problems with the observation systems and results from high-order geodetic surveys.

[20] Bowie "A Survey of Research Problems in Geophysics" 1920, p. 546.

Assuming isostasy and modelling for it in specific ways allowed corrections to observations to be made that decreased errors and tightened the fit of geodetic networks to the real world, which is why the concept/theory arose and was applied. But isostasy, once committed to, had implications that suffused one's entire conceptions of the earth and how it worked. These matters worked out over many decades and involved the entire community of the earth sciences. But since isostatic corrections arose to address very specific problems in geodetic survey data, it is best to begin with a description of the array of geodetic survey techniques and instruments as they were pursued in this critical era of the Tittmann years.

Survey networks began as triangulation networks running along the different American coasts, wherever these were located as the nation and its empire expanded. Then larger and longer networks, called arcs (because they constituted arcs on the earth's ellipsoidal crust) tied together the networks. Starting after the Civil War in the early 1870s, the Survey's great arc of the 39th parallel was built across the continent to tie the Atlantic and Pacific networks together. The arc was a network of geodetic triangles, which is to say that its points were determined and positioned by measuring vertical and horizontal angles that took the Figure of the earth into account. At the same time, at various (but not all) of the network points, measurements of local relative gravity were obtained using an instrument developed by former Superintendent Mendenhall of the Coast and Geodetic Survey, a set of reversing pendulums carried in a near air-tight case to minimize the effects of atmospheric drag on the pendulums. At the same time, a small number of critical observation stations distributed across the length of the arc survey were designated Laplace stations, in honor of the great Marquis de La Place, the French polymath who, in his masterpiece *Mecanique Celeste* had extended and corrected the schema of physics of Isaac Newton and the other pioneers of celestial mechanics[21]. A Laplace station is a site where rigorous astronomical observations are made over enough time and with sufficient reduction of the data, to determine the astronomically determined position of the observation station. This is then compared to the geodetically determined position of the station, based on the positions of a myriad of points in the network.

There are three bodies of potential error, which is to say disagreement, between the astronomic and geodetic positions. Specific errors in the geodetic network of points on the ground may result in a geodetic position differing from the "real" position determined astronomically. However, the astronomically-determined position is based on the notion that a plumb-bob at that point points to the very center of the earth. This can be in wrong, for (at least) two reasons, each of them distinct. First, on any volume except a perfectly formed sphere, a plumb bob perpendicular to the local level may not point to the geometrical center of the Figure of the earth because of the shape or elongation of the planet—to the extent that the earth is not spherical, there will be disparity between the direction the plumb bob points and the earth's center of mass.

[21] La Place published Mecanique Celeste (Celestial Mechanics) in 5 volumes, 1799-1825. The book was notorious for its sketchy presentation of equations and their derivation (LaPlace, 1799-1825). Over decades Nathaniel Bowditch, the author of the American Practical Navigator, prepared a translation and commentary on the work. His version, published over the years 1825-1839, is one of the classic works of American science (Bowditch, 1825-39).

Second, the plumb bob may be perpendicular to local gravity, but local gravity is affected by differential balances of local masses, like mountain ranges and sea shores, which cause the plumb bob to point away from the reference vertical. Both of these influences will result in a disparity between the positions of the same spot, as calculated astronomically and geodetically.

A Laplace station is one set up to determine and then compare astronomic and geodetic positions and then deal very systematically with the differences in positioning revealed by them. These Laplace stations are scattered strategically around the full network, so that the errors determined through rigorous analysis of a few such stations may in turn be applied to most or all other stations in the network. The deflections of the vertical at a number of Laplace stations can be used for astro-geodetic orientation. A Laplace station is defined as a triangulation or traverse station at which a geodetic (Laplace) azimuth is derived from an astronomic azimuth by use of the Laplace equation. The Laplace equation expresses the relationship between astronomic azimuth, geodetic azimuth and the astronomic longitude and geodetic longitude. Although it is not in the definition, the astronomic latitude is normally observed at each Laplace station. In an orientation of this type, a correction is made at the origin (initial point) which in effect reduces the sum of the squares of the astro-geodetic deflections at all the Laplace stations to a minimum[22].

Hence, as the 39th parallel arc survey proceeded, at certain critical points, astro-geodetic positionings were obtained, along with values for relative gravitational attraction at these points. Certain classes of corrections of the positionings were computed during or immediately after the arc survey. However, the entire matter was revisited, first by Hayford, and then by Hayford and Bowie, in order to correct for errors in the positionings at the Laplace points and across the network, based on characterizations of both the top and the bottom of the land surface segment on which the points stood. Corrections at the top involved local gravity and the slope of the local geoid (an equipotential surface of gravitational attraction, of which the classic and most common is sea level; hence, the geoid under elevated continental lands would be the conceptual surface of sea level should the sea be extended into the continent via great ditches or the like)[23]. Corrections at the bottom of the column of planetary crust segment involved the complex concept of isostasy.

Isostasy was and is a brace of theories that were designed to explain the mechanisms by which continents stand higher than ocean basins, and to what extent these phenomena are in equilibrium. Their further extensions led to the great debates of the 20th century about the possible movements of continents which in turn led to speculation and debate about the very nature of the earth's crust and its organization and dynamics. Interestingly, though, all this began with the effort to resolve and explain errors in another geodetic survey in the middle of the 19th century.

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[22] See the modern classic *Geodesy for the Layman* for further explanation of these basic geodetic terms.
[23] Geodesy for the Layman, ibid.

The Great Trigonometric Survey of India included a geodetic network arc that marched from the Indian Ocean north to Mount Everest, named for the Survey's original director. Survey geodesists assumed that the great mass of the Himalayas would deflect the plumb bob towards the mountains, so they estimated the masses and degree of deflection they expected. The deflection was significantly less than their estimate. Counter-intuitively, at the arc's southern end, by the Indian Ocean the plumb bob was found to be deflected towards the ocean, which had not been expected. What explanation could account for the disparate deflections at either end? Two of the greatest earth scientists of the century, J.H. Pratt, then the Archdeacon of Calcutta, and the British astronomer G.B. Airy, developed opposing yet related theories that the deflections of the vertical were caused by different densities of planetary materials around the point where the plumb bob was hung, and that these blocks of earthly crust of different density essentially floated in equilibrium on a deeper fluid layer. The Pratt and Airy models differed on how and where equilibrium occurred, with the Pratt model proposing blocks of varying density floating at a uniform height, while the Airy model proposed blocks of uniform density floating at varying depths. The main point is that they opened the topic of the structure of the earth's crust and the concept of equilibrium, and the processes of vertical movement in the crust, a debate that has continued to the present era[24].

Now we can deal more specifically with the Airy and Pratt models for the compensation of continents and islands. In Airy's conception, land masses rest hydrostatically on highly plastic materials below, with roots projecting into the lower material; hence the greater the projection above the surface, the greater the unseen root below supporting it. In Pratt's conception, the land masses project above the average elevation because they are on material of less density beneath them, and so the higher the surface materials project, the less dense are they and the roots beneath them. These disparately dense materials are supported, ultimately, by material at depth in a transitional state from solid to fluid. In the Pratt model, the masses of material of varying density are supported at a uniform level at great depth, called the level of compensation. Therefore, less dense materials would extend higher above the uniform level of compensation, while denser materials would extend to a lower point. Common to both Airy and Pratt is the notion of equilibrium—one way or the other, masses of materials of different density are supported above a plastic media at great depth, and apart from relatively transient disturbances these materials remain in equilibrium, relative to vertical motion (as opposed to horizontal motion, which became the source of bitter debate in subsequent decades).[25]

Geodetic surveys in India had yielded data about local gravity indirectly, through the plumb bob's deflection of the vertical. In the 1870s, pendulum instruments to measure local gravity (but not necessarily its orientation) were developed. The Coast Survey's polymath Charles Sanders Peirce developed the initial gravity program within the Coast Survey, in the classic style going all the way back to Ferdinand Hassler. Peirce traveled to Europe to secure instruments and materials, then calibrated his pendulum apparatus against the gravity standard at Potsdam, near Berlin, which was the world

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[24] The primary documents in this are Airy (1855) and Pratt (1855, 1859).
[25] See Bowie (1927) for a useful presentation of the history of the concepts of isostasy.

standard. Upon his return, he organized gravity measurements as important constituents of Survey geodetic work. In less than a half-decade, his analysis of gravity data yielded deductions about the Figure of the Earth.[26] Around 1885, Von Sterneck invented an apparatus consisting of a short pendulum swung in a case in a partial vacuum, and the absence of friction through air resistance allowed the apparatus to be used to detect difference sin gravity between two stations with a high degree of precision. Around 1890, Thomas C. Mendenhall, while working as the Superintendent of the Survey, developed an improved version of the compensated pendulums apparatus that remained the major gravity instrument for at least the next 30 years.[27]

Precise geodetic surveys overland in India had first revealed disparities in gravity that pointed to disparities in density of the materials at the earth's surface that were correlated in some way with conditions at great depth, although direct evidence from the depths was impossible to obtain. The next major phase in geodetic discovery on these matters involved surveys on coasts and islands, which is to say, the nexus of continental masses and oceanic crust. The Coast and Geodetic Survey here came into its own as a player, which is to say as a generator of data and purveyor of theory. Much of the work in surveying was organized by George Rockwell Putnam, who later was director of the US Lighthouse Board, and Erasmus Darwin Preston, who pioneered gravity surveys on islands in the Pacific Ocean, and then later the Atlantic Ocean. These Pacific islands included new territorial possessions of the United States, and also the Kingdom of Hawai'i, where the Survey initiated cooperative projects with the Government Survey of Hawai'i almost a decade before the annexation of the Kingdom to the United States.[28]

The isostatic debate may be seen as an element of an increasingly internationalized and cooperative process linking national institutions and individuals into global scientific organizations. In 1886, the geodetic association originally founded by the German state of Prussia, which eventually expanded to include other European states, thoroughly internationalized as the International Geodetic Association. From that point on, the annual conferences of the IGA became major venues for presentation of new data and analysis by Survey scientists, as well as sites for discussion of the latest theories and newest controversies in geophysics. In was in this context that Dutton, in 1889, coined the term "isostasy" to refer to this great nexus of data and contention.

With the Spanish-American War, the US acquired Puerto Rico, and soon the Coast and Geodetic Survey acquired responsibilities for surveying the island and its context. The astronomical latitudes of San Juan, on the north, and Ponce, on the south, were determined. The north-south component of the distance between them was about 30 miles. The distance between them computed by their astronomic positions was almost a mile compared to the distance computed by triangulation between them. The disparity was caused by the deflection of the vertical in plumb bobs positioned at the two sites, on either side of the great mountainous land mass of the island, next to depths of the Atlantic

[26] See Peirce (1876) and (1881).
[27] See Mendenhall (1891) and Bowie (1920).
[28] See Putnam (1894) and Preston (1883-1893).

and Caribbean, respectively, on the north and south[29]. Apart of the disparity was the lesser density of sea water than island rock, and there were indications that the submerged rock masses beneath the seas were denser than island rocks. Clearly the matter of the differences in density of the masses at the surface of the earth, and their complex relationship to the yielding materials at depth, would have to be analyzed to the point of a solution if the Survey was to progress.

Around 1904, then, Tittmann authorized Hayford, in his capacity of Chief of the Computing Division of the Survey, to begin a project to re-visit the data from the 39th parallel arc and other Survey networks, as an "investigation of the figure of the earth and of the reality of the condition called isostasy... based entirely upon observed deflections of the vertical in the United States".[30] The geodetic reference system was the new United States Datum with origin at Meades Ranch, Kansas, using the 1866 Clarke Ellipsoid. By comparing the astronomic and geodetic positionings of major point in the arc, and assembling the astrogeodetic disparities in position, the deflection of the vertical could be characterized for each major point.

The process involved three major stages. First, the astronomically derived position of any given point was based on the alignment of stars at certain times, but that alignment was based on the vertical as defined by the orientation of a plumb bob at that point. If the geodetic position of that same point, based on the triangulation network, was significantly different, it was evidence that the plumb bob at that point was not pointing to the earth's center. That difference in orientation was the deflection of the vertical at that point. Second, Hayford devised a system of partitioning the land mass around the point in question, with radiating sectors and concentric rings. The local topography was partitioned into the "boxes' defined by the segments—a mountain in a segment would be an excess of mass, a valley would be a deficiency of mass, etc. The sum of these segments, calculated out to a radial distance big enough to capture most of the topographical deflection bearing on that point (the interpolation distance out varied depending on local and regional topography) would give, at the end, an estimate of the local topographic deflection of the vertical, which could then be compared to the astrogeodetic deflection of the vertical. Third, and most important, given the fact that the astrogeodetic deflections tended to be systematically smaller than they should have been, based on the topographical deflections calculated, the principal of isostasy was invoked. "Isostasy must be considered. The logical conclusion from the study from the study of the geoid contours for the United States, taken in connection with the fact already noted that the computed topographic deflections are much larger than the observed deflections of the vertical, is that some influence must be in operation which produces an incomplete counterbalancing of the deflections produced by the topography, leaving much smaller deflections in the same direction. There is abundant evidence in the literature of geodesy indicating that this relation of observed deflections of the vertical to the topography is not peculiar to the Unites States; that, in fact, it exists everywhere". [31]

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[29] Bowie, 1920, p. 547.
[30] Hayford, 1909, p. 10
[31] Hayford, 1909, p. 65.

Evidence may have existed everywhere, but the perception of that evidence and insistence on its significance was and is another matter. Thus, we must recognize the entrance of William Bowie to the stage of the full exertion of his considerable powers. John Hayford had been made chief of the division of computing in 1898 by Superintendent Pritchett. He served as chief under Tittmann until 1909, when he left the Survey to become head of the College of Engineering at Northwestern University. He was replaced as chief of the computing division and inspector of geodetic work by William Bowie, who had entered the Survey in 1895, after university studies at Trinity College. Bowie became a giant in American science in the 20th century, and he rose to these heights with isostasy.

Hayford left the Survey for a more secure and academically recognized position, and possibly also because it was clear that Bowie's time to rise had come. They continued to work closely in any case, and in 1912 they jointly published the treatise that secured their reputations and marked the triumph of isostasy.[32] The work was an extension of Hayford's topographic deflection work, only applied to the other end of the topography, as it were. It will be recalled that the concept or theory of isostasy was devised to address the fact that different portions of the earth stood high or low, and the relative stability of their positions in geological time indicated a good degree of equilibrium in their states. That equilibrium implied an overall balance in the system, i.e., that lighter, less dense materials floated higher on top of deeper materials and lower, more dense materials floated lower. Since the differences in densities of portions of crust at or near the surface could not account for the deflections of the vertical actually observed, that implied that the disparities in density continued down deep below the surface. The Pratt model of isostasy proposed that all these crustal blocks, of varying density, floated at about the same depth everywhere, the uniform level of compensation. Bowie and Hayford's next major step was to estimate the depth of the uniform level of compensation for the North American data, and to so by bringing to bear data on the intensity of gravity, as measured at certain stations along the Survey arcs, using the Mendenhall pendulums. As they stated: "logically the next step to be taken was therefore to introduce such a definite recognition of isostasy into gravity computations. Moreover, it appeared that if this step was taken it would furnish a proof of the existence of isostasy independent of the proof furnished by observed deflections of the vertical, and would therefore be of great value in supplementing the deflection investigations and in testing the conclusions drawn form them. In other words, the effects of isostasy upon the direction of gravity at various stations on the earth's surface having been studied, it then appeared to be almost equally important to investigate the effects of isostasy upon the intensity of gravity".[33]

The Hayford-Bowie project involved correlating a geometrical reference system for the earth, which became the Hayford Spheroid, which in turn became the International Reference Ellipsoid, the internationally recognized reference ellipsoid until the postwar era of satellites, with the actual North American triangulation networks of the Survey and their thousands of points, the several hundred points for which both

[32] Hayford and Bowie, 1912.
[33] Ibid, p. 5.

astrogeodetic and topographical deflections of the vertical, and finally the 88 stations for which gravity intensity was obtained[34]. Various systems to estimate density of crustal blocks were used, along with various types of corrections to gravity intensity anomalies (free-air, Bouguer, etc.). Finally, different estimates for the effects of levels of compensation at different depths were applied (imagining these different levels of compensation to be onion layers at different depths under North America). They had to make major assumptions about average density of crustal materials as depths for which there was not, nor ever could be, any direct measurement. But, at the end of the day, they found that, assuming certain densities, and assuming a level of compensation around 113 kilometers below the surface, they could account for most of the differences in both the deflections of the vertical and the gravitational anomalies measured at the major stations.

It is with difficulty that we, now, can appreciate the nature of their achievement and also its profound impact on the earth sciences of the era. Essentially, the theory of isostasy arose in response to the complete absence of sufficient data about the earth at depth necessary to explain the patterns of data obtained at the surface. Isostasy involved the assumption about various aspects about how the earth system worked. Hayford and Bowie proposed that, making that assumption, and calculating values based on the assumption, the theory of isostasy could explain the coherent and systematic patterning of otherwise anomalous data from two independent (but related) phenomena—deflection of the vertical, and gravity anomalies. Given this, they could then approximate the portion of the geoid running under the continent of North America, and they could project from that continental portion an estimation of the figure of the earth. As it happened, the shape of North America is anomalous, and this introduced substantial error into their estimation of both the size and the shape of the figure of the earth. The error in size was soon recognized through the results ofvery long arc surveys on other continents, but it would take half a century and the advent of satellites to disclose the error in the shape of the earth. And as it happened, the apparent triumph of isostasy was a major element of larger and exceedingly complex battles about horizontal movement and equilibrium, in addition to vertical movement and equilibrium, which would be played out in terms of continental drift and then plate tectonics. In that context, the arguments of many players, most especially Bowie, would be swept away in later decades. Nevertheless, in that moment, in the final years of the long tenure of Otto Tittman as Superintendent of the Coast and Geodetic Survey, it was as though the Survey had occupied a very high peak, and that point on that peak was a very important point, brought into a very important network, in a world in isostatic equilibrium, at the very least.

But that world was in no other form of equilibrium, and would soon be swept into world war, world depression, and major changes in the roles and significance of the Coast and Geodetic Survey. The Survey would change and expand and tackle whole new projects and responsibilities, under the direction of a very different man. Otto Tittmann was a magnificent exemplar of the Survey, but his era was quickly succeeded by that of his successor, the most important director of the Survey in the 20th century, the one

[34] There were actually 89 stations, but two of them, at Seattle, were so close to each other the data from one station only was used. See footnote, Ibid, p. 113.

person in the history of the Survey most directly comparable to Alexander Dallas Bache. The era of E. Lester Jones was about to begin.

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The Survey Jones Made:
E. Lester Jones and the Postwar Triumph of the Coast and Geodetic Survey

Caption: The headquarters staff of the US Coast and Geodetic Survey assembled outside headquarters on New Jersey Ave., on March 6, 1925. E. Lester Jones, dressed in a dark suit, is the twelfth person from the left in the front row.

Ernest Lester Jones (1876-1929) became the 11th Superintendent of the Coast and Geodetic Survey in 1915, and served as Superintendent, and then Director, until he died in 1929. He led the Survey for 14 years, apart from a leave of absence for military service in World War I; he died from the long-term effects of the poison gas exposure he suffered while serving as Colonel Jones in the Division of Military Aeronautics on the Western Front. Jones did not rise though the ranks like many Survey leaders, nor was he a practicing scientist or engineer when selected to replace the retiring Otto Tittmann. Nevertheless, E. Lester Jones was the Alexander Dallas Bache of the 20th century—only Ferdinand Hassler and Bache played larger roles in the history of the Survey and its successor NOAA than did Jones. He positioned the Survey in larger historical context, and organized a Centennial Celebration for the Survey in 1916 that represented and reflected the Survey's status at the apex of American governmental science, a height it has never occupied again. He worked tirelessly to extend the Survey and its mandated responsibilities, and to fund and develop new technologies to fulfill those new responsibilities. He worked as well to support the personnel of the Survey and raise their salaries and working conditions. In particular, he orchestrated the creation of the Uniformed Corps of the Survey, the ancestor of NOAA Corps, in order to expedite Survey personnel entry into service in World War I. Significantly, postwar he worked though Congress to establish parity between similar ranks of Survey Corps and military officers' salaries and benefits, which continues to the present day. This salary parity by itself has probably had more impact on personnel retention and organizational and scientific continuity in the Survey and later NOAA than any other single action taken by Survey and NOAA leadership in the 20th century.

Jones' background will be described later; for the moment, it should be noted that he first intersected with the Survey around 1913 when he was appointed Deputy Commissioner of the Bureau of Fisheries, which was, like the Survey, in the Department of Commerce, newly separated from Labor in what had been the Department of Commerce and Labor. The Bureau of Fisheries had established the Alaska Fishery and Fur Seal Service which was embroiled in scandal over the poor management of the seal populations of the Pribilof Islands. Jones was directed to investigate the matter[1]. His activities brought him in close contact with Survey personnel working on the Alaska Survey. Shortly thereafter he was asked to succeed Otto Tittmann upon his retirement as Superintendent. Jones' work in the Pribilof Islands and the Survey were of a piece; Jones' major role was to establish boundaries and to set things right. He never advocated for novel ideas and technologies, but rather, he singled out problems that needed to be fixed—it just happened that only new ideas and technologies would do. He was hence not a revolutionary or major innovator in his time directing the Survey—yet he wrought more changes in the Survey in his tenure than any other leader with the possible exception of A.D. Bache.

Jones was unlike any Survey leader before or since, and his quiet and efficient methods of leadership meant he cruised through the water like a sleek frigate that leaves little wake. He left the Survey with budgets and responsibilities far higher than they were when he entered, yet his managerial talents were such there were few scandals in his tenure. Despite the fact that many of the years of his tenure postwar he was in declining health, and Acting Director Faris was really the leader of the Survey in terms of day to day operations, Jones steered the Survey through the first stages of a global depression that would eventually cause great changes to the Survey and its activities; but these were held in abeyance during Jones' tenure. Perhaps the best "memorial" to Jones and his service in the Survey was the celebration that Survey staff organized in 1925 to celebrate the 10th anniversary of Jones' reign in the Survey. As with the Survey Centennial Jones created, there had never been any function like this for any previous leader of the Survey, not even Bache. The nature of the feast, the participation of so many Survey personnel, and the toasts addressed to Jones make clear how Jones was regarded by the men and women who worked under him. And even the "silly" names of the food items on the dinner menu convey the breadth of Survey functions and activities that Jones had expanded and successfully funded. Behind the menu lies the story of the Coast and Geodetic Survey as it was revitalized and expanded by the greatest Survey leader of the 20th century.

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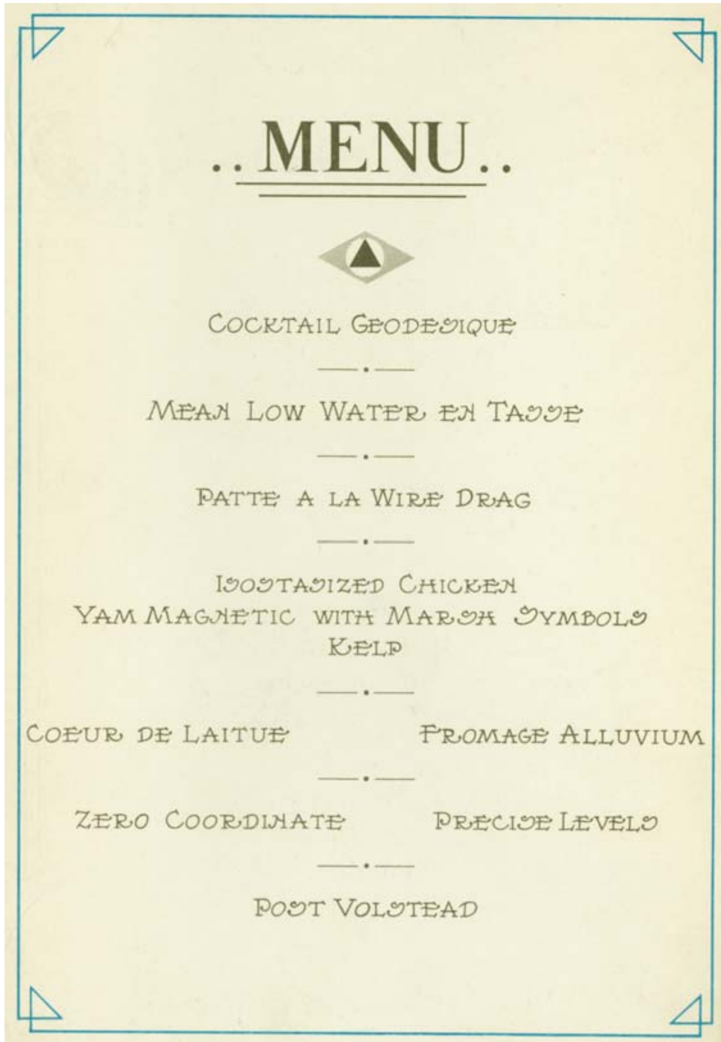
[1] See Jones, 1915.



The menu items refer, to the initiated, to landmarks of scientific and technical progress in the Survey during Jones' tenure, distributed across the divisions and offices of the Survey. The references are interesting both for what they include, and for what they do not. Turning first to what they reference directly:

- Patte a la Wire Drag refers to the Division of Hydrography and Topography and their elaboration of the techniques for wire-dragging in hydrographic surveys, a technique originally developed in the late 19th century in Europe and in the U.S. in the Army's Lake Survey. The Survey's techniques for wire-dragging were developed under the direction of Nicholas Heck in the administration of Otto Tittmann, but particularly expanded in surveying work under Jones.

- Cocktail Geodesique and Isostasized Chicken are references, largely esoteric, to the work of the Geodesy Division, which culminated in the creation of the North American Datums of 1923, 1927, and 1929 (to be explained later) and the global adoption in 1924 of the Survey's Hayford Reference Spheroid as the International

Reference Ellipsoid as the basis for the Figure of the Earth, and finally, the relative triumph of the concepts of isostatic equilibrium and compensation associated particularly with William Bowie. Isostasy refers to a theory and concept of geophysical equilibrium. As Bowie defined it: "The continents will be floated, so to speak, because they are composed of relatively light material; and, similarly, the floor of the ocean will, on this supposed earth, be depressed because it is composed of unusually dense material. This particular condition of the approximate equilibrium has been given the name 'isostasy'".[2] These were in turn situated in major developments in the emerging sciences of geophysics, in which many Survey personnel played prominent roles both inside the Survey and outside it, particularly through their roles in the leadership of the new American Geophysical Union which was founded in 1919, 2 years after Bowie's seminal publication on isostasy.

- Yam Magnetic with Marsh Symbols refers to the work of the Division of Terrestrial Magnetism, which under Jones was in 1925 was in the process of becoming the Division of Terrestrial Magnetism and Seismology with primary responsibility within the federal government for research and data acquisition in seismology. The Marsh Symbols and the Fromage Alluvium both refer, in a very vague way, to the renewed emphasis in the Survey on analyzing and mapping geologic and geomorphological conditions, particularly with reference to coastal change.

- Mean Low Water en Tasse and Precise Levels are references that link the activities of the Divisions of Geodesy, Hydrography and Topography, and the Charting Division. Mean Low Water and Mean Sea Level had been concepts and derived data throughout the history of the Survey back to the days of Hassler. But it was particularly Jones who advocated for the extension of sea-level datums inland by extending precise leveling surveys throughout the United States. As he did in so many other contexts, Jones identified and accentuated a problem which, given sufficient money and personnel, the Survey could and would solve for the betterment of all. Jones wanted the Survey's precise sea-level datums to be extended nationally, to all states, and to most or all municipalities in order to integrate disparate engineering and scientific activities to a common vertical datum.

- Post Volstead is a reference to the Volstead Act, passed in 1919, the federal law banning possession of alcohol pursuant to the 18th Amendment in the US Constitution. Apparently, it was widely ignored in the District of Columbia (and elsewhere) and presumably the reference "Post Volstead" meant that, for the purposes of the celebration, the act had been at least temporarily repealed.

Left unreferenced in the menu for the dinner celebrating Jones' ten years tenure in the Survey are a number of developments of enormous significance to the history of the Survey, although some of these came about in the four remaining years of Jones' life and service in the Survey. These include:

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[2] Bowie, 1917, p. 7.

• The participation of the Survey and Survey personnel, including Jones, in World War I. Jones had been a protégé of Woodrow Wilson at Princeton University which was a factor in his selection as Superintendent of the Survey in 1915. Once the decision had been made to enter the war, Jones directed the Survey into military service on a scale not seen since Bache during the Civil War. Jones orchestrated the passage of laws in Congress that established the Uniformed Corps of the Coast and Geodetic Survey, the ancestor of modern NOAA Corps, the seventh uniformed service in the US government. Under the new laws, members of the Survey field corps, consisting of assistants, sub-assistants, and aids (but not enlisted men and lower level staff members) passed into military service at requisite ranks and later were transferred back into the Survey. Similarly, Survey ships passed into military service until they were eventually de-commissioned and returned to the Survey after the war. During their war service, Survey personnel did a combination of "traditional" survey activities, only transferred to the battle front, and new exercises in the development of special instruments and techniques, especially in ocean acoustics, with far-reaching consequences for all subsequent work of the Survey and its successors.

• Jones also orchestrated the return of Survey personnel and ships to the Survey after the war ended. Survey officers in the new Uniformed Corps had become military officers of comparable rank, but much higher salaries. Many declined to return to the postwar Survey at the traditional salaries, provoking a crisis in the Survey. Jones settled matters by securing Congressional authorization for parity between Survey and military officers of comparable rank which led to increases in Survey salaries never before experienced in Survey history. The Survey's ability to retain competent staff increased with consequences that continue to the present era.

• Jones led what can only be described as a cartographic explosion in the history of the Survey. Jones embraced the airplane, both as a new platform for aerial photography, which would change charting and mapping, and also as the source of a whole new class of Survey chart users. The Survey had pioneered nautical charts; Jones would take those into the sky as aero-nautical charts. He advocated for new facilities and equipment including the purchase of the first offset lithography presses from the Harris Company, a cartographic production relationship that continues to the present day in NOAA and the FAA, the inheritor of the Survey's aeronautical chart production function.

• During the war Survey personnel had participated in a wide variety of activities involving aerial acoustics and hydro-acoustics. Postwar, Jones directed the entry of the Survey into major development of hydro-acoustic techniques for determining water depths and horizontal positioning of Survey craft. The latter exercise involved the development, elaboration, and perfection of Radio Acoustic Ranging (RAR), one of the most important contributions of the Survey to the earth sciences in the 20th century. Using RAR, the Survey extended hydrographic surveying beyond the limits set by the curvature of the earth along the coast, revealing bathymetric features that helped transform our knowledge of the earth's history. And, as a part of RAR work, the Survey scientists made the serendipitous discovery of the deep sound channel of the ocean, one of the most important discoveries in oceanography in the century.

E. Lester Jones and Alaska and Government Service

Ernest Lester Jones was born in East Orange, New Jersey, on April 14, 1876. He attended local schools and then in 1894 went to Princeton University. In 1897 he married Virginia Brent Fox. He and his wife then went to Europe where Jones studied for a year at the University of Heidelberg and perhaps elsewhere in Germany, although it is not entirely clear when he studied. The following year he returned to Princeton and graduated with a B.A. degree. His most detailed posthumous biography says that, following Princeton, "Mr. Jones was engaged in research, secretarial work, and business for a number of years"[3]. For nine of these years he was associated with the business of his father who ran a printing company. From 1907 to 1913, he owned and operated a large stock farm in Culpeper, Virginia. In preparation for this role, he studied veterinary medicine in Massachusetts and developed his stock farm as a model of modern scientific management. He specialized in breeding and rearing draft horses, but also maintained a herd of shorthorn cattle and a herd of jersey milk cows[4]. Then, in 1913, President Woodrow Wilson, who had known him at Princeton University, appointed him to a position in the federal government that was far removed from the Piedmont of Virginia.

When, in 1867, the United States purchased Russian America, now known as Alaska, it acquired Russian territorial claims and land-use management practices along with the territory. The first major oceanic territorial claim that extended far beyond "cannon-shot range" was the Russian Imperial Decree, the Ukase of 1821, which claimed rights to 100 Italian miles of the ocean waters off Alaska in the Bering Sea and around various islands, such as the Pribilofs. The intent of the claim was to protect and preserve fur seal populations from over-hunting. In 1878 the US government decreed a complete ban on fur seal hunting on the islands; although, this failed too, in large part because hunting operations shifted to pelagic hunting which meant shooting seals in the water. Predation continued and increased; and seal populations plummeted. This led to stronger restrictions, and eventually a complete 5-year moratorium on harvesting fur seals on and around the Pribilof Islands and other breeding grounds. The ban was administered by the US Navy which had jurisdiction over the territory.

The hunting and fishing restrictions imposed by Washington were part of a larger political movement to change the status and government of Alaska as a US territory. In 1884, the First Organic Act relinquished control by the Navy to a territorial administration in which a total of thirteen officials were made responsible for a population of 32,000 people of which only 430 were white settlers.[5] Alaska remained marginal to larger American interests, except for issues concerning fishing and sealing, until the Klondike gold rush in Alaska and adjacent Canada beginning in 1897-98. The influx of 30,000 new settlers, the complex commercial re-organization of the entire Pacific northwest coast in response to the gold rush, and other matters compelled a new re-organization of the territory. In a revised act of 1900, substantial reforms in

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[3] Faris, 1929.
[4] Brown, 1915.
[5] See Gislason, 2006.

administration were introduced, but complete control over Alaskan fish and game animals remained in the hands of the federal government through the Department of Commerce. However, in 1907 these changes were imperiled by the entry of the Alaska Syndicate formed by the fortunes of J.P. Morgan and the Guggenheim family. Amongst other resources they monopolized were the majority of the salmon canning factories which resulted in their being dubbed the Fish Trust.

In 1910, the US Congress passed a law banning the killing of many or most species of "fur-bearing" animals in the Territory of Alaska, enforced by special agents of the Department of Commerce. However, there were no laws prohibiting hunting of the animals as such, nor possession of live animals, nor possession of the furs of killed animals. This created a situation in which strict legal enforcement of the hunting ban essentially required agents to catch hunters as they were in the act of killing animals, an all but impossible task. Enforcement was haphazard, officials were corrupt, the local populations disobedient and contemptuous. It was a recipe for disaster.

Matters were only compounded in 1912 with the federal passage of a Second Organic Act for Alaska, which established Alaska as an official territory of the nation but maintained complete federal power to regulate the territory's fish, game, and fur resources, which was a legal stance not applied to any previous US territory. As a result, the territorial government began in substantial opposition to federal enforcement efforts as a matter of territorial rights, overlaid on the problems and conflicts of resource depletion and economic and social impacts on the local population.

President Wilson and his new Secretary of Commerce Redfield began by dismissing George M. Bowers as Commissioner of Fisheries. Bowers had been appointed to the post in 1908 and was in many respects an able administrator, but he had no scientific training or experience, and in any case the Bureau's affairs in Alaska were engulfed in scandal. It appears that Wilson and Redfield initially attempted to appoint E. Lester Jones as Commissioner, but this was assailed by committees from the American Society of Naturalists and the American Society of Zoologists, who preferred instead Dr. Hugh M. Smith, a career scientist in the Bureau of Fisheries. The response of Wilson and the Department of Commerce in 1913 was to appoint Smith as Commissioner, but also E. Lester Jones as deputy commissioner of the US Bureau of Fisheries. It was his first experience in government service; he would spend the rest of his life at it.[6]

The assignment was difficult from the start. The problems in Alaska were long-standing and complex, and the problems back in Washington were considerable. Wilson and Redfield had appointed Smith as head of the Bureau instead of Jones, but one critic complained that "that position [deputy commissioner] in many respects, even more important to science than that of the commissionership itself, and which should have been filled only on the recommendation of the Commissioner, was at once filled by the appointment of Mr. Jones."[7] Jones spent considerable time over two years in

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[6] See Ashmun Brown, 1915; Scientific Monthly editorial, 1916; Macmahon, 1926.
[7] Evermann, 1916.

reconnaissance trips to many areas of Alaska on the mainland, the Aleutians, and other areas where contention reigned. At the end of 1914, he published a hard-hitting, incisive, and profusely illustrated report on his investigations. The report's general summary was entirely indicative of Jones:

> "In the foregoing report it has been my aim to bring out forcibly the main issues and needs in connection with the fisheries and fur-bearing animals of Alaska, including affairs pertaining to the Pribilof Islands. Attention has also been called briefly to a few highly important needs of the Territory, some of which are but indirectly related to the primary subjects of my investigation. I have endeavored to view all matters from the standpoint of a practical business man, seeking only to suggest simple and direct ways of correcting any existing evils or practices observed, and at the same time to indicate proper needs and ways and means for building up and expanding Alaska's interests as circumstances may permit.
>
> "The fact must be thoroughly understood and emphasized, however, that if the laws made by Congress relative to the protection and upbuilding of these resources are to be enforced it is absolutely essential that adequate appropriations be made." [8]

Jones was essentially correct in enough of his allegations that major and positive changes in the administration of Alaskan fishing and fur-bearing animals ensued. And it was noted in the Wilson administration that Jones could couple decisive criticism and analysis with a calm and managerially competent plan for improvement, which generally required extracting more appropriations from the Congress to effect the necessary changes. The Wilson administration could use Jones elsewhere in such a capacity.

Otto Tittmann had been declining in his direction of the Coast and Geodetic Survey, and the Survey was saddled with major problems of equipment and budgets. After discreet investigations, Secretary of Commerce Redfield sent a memorandum to President Wilson in 1915 noting: "I have consulted Mr. Charles D. Walcott, director of the Smithsonian Institution, on the subject of the Titttmann resignation and the Jones appointment, and he thinks it is the right policy to pursue".[9] It is notable that Jones' appointment to be chief of the Coast and Geodetic Survey, a role he filled until the day he died, was not sought by him; his first knowledge of the matter was when he received and read the letter of appointment.[10]

Thus, in 1915, Ernest Lester Jones was named to succeed Otto Tittmann as the 11th Superintendent of the Coast and Geodetic Survey. Apart from Superintendent Thorn (1885-89) who was brought in to clean house in the Survey after Gilded Age scandals, and Superintendent Duffield (1894-97) a spectacularly unfortunate choice as leader, Jones was the only head of the Survey during its entire existence who did not have a

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[8] Jones, 1914, p. 153.
[9] Quoted in Macmahon, 1926, p. 774-775.
[10] Corey, 1924, p. 26.

foundation in geodesy or cartography or any other branch of the broad earth sciences. Jones soon acquired considerable knowledge of all phases of the activities of the Survey, but his most important skills were those of knowing and managing people. His conflict with Wickersham notwithstanding, Jones had great facility for noting the crux of problems and grasping solutions. His general sense of the Survey, which was now to become his life's work, was that it was a vital but marginalized agency staffed with personnel of extraordinary talent and abilities, who were paid too little and worked too hard, without sufficient access to the instruments and materials that would make their work much more productive and satisfying. Jones resolved to change that during his tenure. He did not have, nor make, a mandate to change anything in particular in the work of the Survey; instead, he would end up changing everything.

The First Phase of the Jones' Era

When Jones entered the Survey, he encountered an organizational system substantially unchanged from the era of Henry S. Pritchett (1897-1900). The Survey was organized into divisions, of which the largest were Hydrography and Topography, under Herbert C. Graves as chief, along with the smaller divisions of Geodesy, under William Bowie, and Terrestrial Magnetism, under Andrew Braid. In addition, there were two small divisions that serviced the entire Survey — Accounts, under John M. Griffin, and the Office, under Philip A. Welker. The Office division had major sub-divisions called sections, particularly that of Instruments, under the celebrated instrument designer Ernst G. Fischer, and the Library and Archives section, under Robert M. Brown. The first major change Jones made was in the ways maps and charts were produced, which is understandable given his experience in commercial printing working for his father. Before Jones, each of the three major divisions, Hydrography and Topography, Geodesy, and Magnetism, had its own charting operation, and these shared the cramped quarters of the printing shops. Jones put the entire printing operation its own division, called the Division of Charts, under Dallas Bache Wainwright, the last direct descendant of Benjamin Franklin to work for the Survey, who reported directly to him.

To compensate for his lack of experience in the functioning of the Survey, Jones changed and enlarged the position of Assistant Superintendent, a role introduced by Henry S. Pritchett. Jones selected for the position Robert Lee Faris, previously the assistant chief of the Hydrography and Topography division, before that chief inspector of magnetics. Prior to his assignment in magnetics, he was a skilled participant in virtually all activities of the Survey, including primary surveys in the Yukon River delta as well as captaining various Survey ships. The match was a good one, and Faris continued as the Assistant Superintendent and later Assistant Director of the Survey for the next 18 years of his life, dying in office in 1932.

E. Lester Jones walking from the Capitol to Survey headquarters

Jones was a complete outsider to the functions of the Survey, but a quick learner, and as an outsider he saw problems freshly. As Faris put it in a memoir of Jones after his death:

> "It was a part of his philosophy of human affairs that the best work can only be done when men have the best tools and appliances for doing it, and so it was among his basic endeavors while Director of the Coast and Geodetic Survey that the Bureau's engineers be supplied with adequate ships and modern instruments and equipment."[11]

The Survey's deficiencies revolved fundamentally around the fact that the Survey's responsibilities exceeded its capabilities, the facilities available to it were old and inadequate, its ships were old and increasingly dysfunctional, and that, possibly more important than anything else, its personnel were poorly paid, particularly so in relation to their skills and acquired knowledge in comparison to the salaries those same abilities could garner elsewhere. There was also little if anything paid to them upon retirement,

[11] Faris, 1929, p. 2.

which impelled many skilled veterans of the Survey to leave in their prime for other jobs in hopes of acquiring pensions elsewhere. Whatever else, Jones was never subtle. He immediately applied himself to discovering who, in Congress, controlled funding and support for the Survey and began to craft what he called an Urgent Deficiency Bill to address the problems. He also ordered a complete reorganization of the Superintendent's Annual Report to the Congress, the most major change in the reports since Bache had initiated them in 1852. Henceforth, starting with the 1915 edition, the very first section of the report became THE NEEDS OF THE BUREAU, which laid out the problems as he saw them, beginning with "New Building" and finishing with "Retirement". The tenor of the argument may be gauged by his introduction:

> "Part 1 explains the needs of the Bureau by text and illustrations, and is an appeal for greater recognition of its essential requirements. With the increased work in recent years there has been no corresponding increase in the force and equipment, which is a pertinent cause for the backwardness of much of the work".[12]

Jones campaigned for a new building to replace or augment the warren of spaces occupied by the Survey at its headquarters on New Jersey Avenue, a block from the Capitol, to which the Survey had moved in 1874. The core of the complex was a former hotel and a former mansion, and in all there had accreted five different buildings that did not match up—Jones even included a composite elevation sketch in the report demonstrating that none of the floor levels of the buildings matched, and that "the buildings are joined together by fractional stairways, bridges, and narrow passageways"[13]. He described the poor conditions of the ships, the deficiencies of much equipment, and the rather alarming matter that the entire chart archives of the Survey, dating back to Hassler, were housed in a non-fire-proof structure such that records "that cost millions of dollars and could not be replaced short of the expenditure of other millions of dollars are constantly in danger". [14]

And so the Jones' administration began, off and running. Congress responded, the money increased, salaries grew, ships were commissioned, and eventually the Survey even got a new building—but Jones and the Survey would find themselves in a period "constantly in danger" before that happened.

The Centennial of the US Coast and Geodetic Survey

The plan for the Survey of the Coast began with President Jefferson and Ferdinand Hassler in 1807. Jones became Superintendent of the Survey in 1915 and soon announced that the Centennial of the Coast and Geodetic Survey would be celebrated in 1916, which was the actual centennial of the first field work initiated by Hassler . It would appear that the main reason the centennial wasn't celebrated in 1907 was that Jones wasn't yet in charge of the Survey. Jones was brought on board to revive a

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[12] Annual Report, 1915, p. 5.
[13] Ibid, Illustration 2.
[14] Ibid. p.6

somewhat moribund bureau, but the Survey's legacy as the oldest scientific agency in the government and its relationships to other federal agencies and enterprises, along with Jones' adroit abilities at organization, insured that the Survey's centennial was marked with ceremonies and activities on a scale never seen before, and, alas, never seen since, notwithstanding the many activities of NOAA's 200th Anniversary in 2007.

Central Hall of the New National Museum, April 5, 1916

There were three major elements to the centennial celebration which was held on April 5 and 6, 1916. First, the Smithsonian Institution, which had been associated with the Survey in a myriad of ways in its history, agreed to dedicate the main exhibition space of the New National Museum (now the National Museum of Natural History) to a series of displays about the history of the Survey. The exhibits featured old geodetic and cartographic instruments and tools, in some cases paired with their modern equivalents, and many examples of historic and contemporary maps, charts, and other graphics. The exhibits were opened to the public from morning until late evening to allow people who worked days to attend. In addition, all Survey personnel who worked in or near Washington, D.C., were given a day off, half on each day, in order to allow them to attend the exhibition.[15]

The second component of the centennial was a symposium on the history of the Survey and its relations to other federal agencies which was held in the auditorium of the

[15] Centennial Report, 1916.

new National Museum on the afternoon and evening of April 5th, and the afternoon of April 6th. After opening remarks by Jones, the directors or chiefs of the following federal agencies gave addresses on the relationships between their bureaus and the Coast and Geodetic Survey: the Department of Commerce, the Bureau of Fisheries, the National Bureau of Standards, the US Navy Hydrographic Office, the US Geological Survey, the US Army Corps of Engineers, and the Lighthouse Service. In addition, the Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (Louis Bauer, formerly head of the Division of Terrestrial Magnetism in the Survey), a prominent member of the House of Representatives, three Professors from Columbia and Northwestern Universities, and former Superintendent Tittmann, now president of the National Geographic Society, also spoke on specific earth science topics related to the work of the Survey. The papers were collated and published by the Survey a few months later.[16]

Finally, on the evening of April 6th, a lavish banquet was held at the New Willard Hotel near the White House, attended by President Woodrow Wilson who was the principal speaker, along with members of the diplomatic corps in Washington, high-ranking officials of the federal government and allied institutions such as the Smithsonian and the National Geographic Society, along with various high-level employees of the Survey. The main gathering was entirely male, although a small viewing balcony in the ballroom was filled with spouses and other women associated with the major banquet members[17].

The Survey goes to War

The Centennial celebration marked a distinct high-water mark in the history of the major federal agency with responsibility for measuring the tides of the national waters. The occasion was celebratory and peaceful, as the Survey had few competitors as the premier scientific agency in the government. That combination of circumstances and consequences would never come again. Western and central Europe and Russia had been engulfed in war since 1914. Woodrow Wilson had campaigned successfully for re-election in 1916 on a platform to keep the United States out of war; a year later, his Administration entered the war "to make the world safe for democracy". The US entry into the war, and the preparations for that entry by the federal government, produced dramatic changes. The Survey and its leadership and the methods by which they led were altered more so than at any other time in Survey history including the Civil War[18]. Survey personnel participated in traditional and very novel applications of their geodetic, hydrographic, and cartographic skills, and made connections within American military agencies and bureaus that would yield a cascade of new instruments and approaches to Survey work in the postwar period. But a system of German and American cooperation in oceanographic and geodetic research that whole generations of Survey personnel had participated in was threatened and weakened. Survey personnel suffered and died in the

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[16] Centennial Celebration, 1916.
[17] Banquet in commemoration, etc. 1916.
[18] As part of positioning the Survey for wartime service, Jones published a summary of the service and experiences of Survey personnel in the Civil War. See Jones (1916).

war and its aftermath, and ultimately, the last casualty of World War I in the Survey was to be the man who led the Survey into war to begin with: E. Lester Jones.

In a sense, the entry of the United States into the war required Jones to address the problems previously faced separately by A.D. Bache and, to a lesser extent, by Henry S. Pritchett. The Survey had always been a civilian agency, yet civilians in a war zone are considered noncombatants, refugees, or spies. If members of the Survey participated in the war in any capacity on the battle front then they would have to enter the military, but on what terms? And how would the disparate skills and experiences of Survey personnel be recognized adequately to allow Survey personnel to be appointed to military ranks appropriate to their abilities? Second, in 1898 under Pritchett the Survey finally took operational control of its own ships, as they were now no longer operated by Navy crews. Yet civilian ships and civilian sailing masters were problematic in a war zone, especially one characterized by the new menace of submarines attacking civilian shipping on all waters of the Atlantic Ocean. And finally, Survey personnel were historically paid low wages for the work they did, and Jones had entered federal service quite vocal about the problems associated with this.

Jones, the Secretary of Commerce, and requisite members of the Wilson administration and the Congress negotiated a plan that would address all three levels of problems with the civilian Survey. An act of Congress established a Commissioned Service of the US Coast and Geodetic Survey[19]. Members of the Survey field corps (assistants, sub-assistants, and aids) could be appointed to requisite rank in the service, the rankings of which were similar to the rankings of the US Army, from second lieutenant to colonel, and the US Navy, from ensign to captain. The new service was a hierarchy of officers that could be entered only at the bottom, after "passing a satisfactory mental and physical examination conducted in accordance with regulations prescribed by the Secretary of Commerce". However, once Survey civilian personnel were admitted into the Commissioned Service, they could be transferred to military service at a military rank commensurate with their Survey commissioned service rank (meaning that, for example, a Survey Commander could become a Navy Commander or an Army Lieutenant Colonel). In addition, provisions were made that Survey ships could be transferred to military service and would be considered military vessels, until which time as they were de-commissioned from military service. With these changes, the Survey—or at least its officers—was ready to go to war[20].

The United States declared war on Germany and its allies on April 6, 1917, some three years into the struggle. On May 22, 1917, the signing of a manpower bill began the commissioned service corps of the Survey. The war ended with the Armistice signed November 11, 1918. Hence, Survey personnel and all other American forces had less

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[19] 40 U.S. Stat. L., 84, 88, May 22, 1917.

[20] The Survey Commissioned Service, like its successors ESSA Corps and NOAA Corps, was an elite service—it contained only officers. There were no provisions for non-officers in the Survey Commissioned Service, and hence no mechanism for lower level employees of the Coast and Geodetic Survey to pass directly into military service, or to pass back from military service into the Commissioned Service of the Survey.

than two years' time at war. With some exceptions, Survey personnel went into the war to perform a certain role or fight in a certain area, and their experiences were limited to that. Five major areas and activities characterize Survey personnel in the war, all of which had significant impact on the direction of the Survey after the war.

- Ship convoy duty in the Atlantic or elsewhere

- Artillery orienteering, artillery spotting, and sound and flash ranging on the battlefront in Europe, and the development of military grids related to geodetic networks;

- Research and development work with underwater acoustics and allied matters for anti-submarine warfare and other aspects of war in the oceans;

- Research and development of instruments, especially radio and magnetic equipment, computing, and other allied research, primarily conducted "stateside" in association with Army and Navy labs;

- Battlefield cartography, aerial observation, and the applications of aerial observation and photography to mapping.

The larger story of what Survey personnel did during the war is literally outside this story—when they went into military service they vanished from Survey records, and if they survived and returned then only general information and anecdotal evidence of the war came back into Survey files. But their experiences at the front, and the new technologies they encountered, had major impact on the Survey and its operations postwar. These matters can be summarized by considering the war in three very different domains: the war on land, dominated by the story of the long bloody line of the Western Front; the war at sea, primarily in the Atlantic; and the new war in the air, glorious and terrifying, encompassing aeroplanes and aerial photography and also poison gas, used as a terrestrial warfare tactic diffused through the atmosphere, primarily through gas artillery shells.

The major American experience in what was for decades called the Great War occurred in western Europe along the Western Front. The war began in 1914; by the time the Americans in the Allied Expeditionary Force (AEF) arrived in 1917 (as opposed to Americans individuals who volunteered earlier in other services) the front was largely static, and the battle field was a vast series of thousands of miles of trench complexes running in a great zone, with the fabled No Man's Land between the forces. The major military initiatives involved artillery barrages fired from cannons with ranges that exceeded the line of sight. In response, the armies on both sides developed techniques for "sound and flash" ranging to determine the positions of enemy artillery. The "flash" was the light from cannon muzzle blasts as seen at night. The "sound" was the acoustic blast of the cannons as it reverberated through the air. It was in this regard that Coast and Geodetic Survey personnel now in military service saw significant action in the war.

As members of field artillery spotter battalions, associated with Army military intelligence units, they participated in the use of multiple acoustic arrays and visual observatories, all located at well-defined positions. The general method was the same for both light and sound; from multiple known positions, the directions to the sources of light and sound could be determined, and where these intersected must be the position from which the blast occurred.[21] Sound ranging in particular was significant for Survey personnel. It put them in the forefront, literally, of the application of acoustics to position-finding; and it introduced them to the use of sets of hyperbolic curves. For acoustic ranging, two or more sets of linear arrays of microphones were deployed; their positions and alignments defined as precisely as possible. The sound of a cannon blast would reach one end of the array before it reached the other end. That time difference meant the cannon was located along a certain line that was a hyperbolic curve. If the same blast was received by a second microphone array, then the cannon was also located along a second hyperbolic curve. The cannon must be located at the point where the two curves intersected. As we will see, variations on this acoustic technique would come back to the Survey postwar in very different applications.

There was more flying through the air over No Man's Land than the artillery shells. The war was also the first time airplanes were used in combat. They bombed positions, and they were also used to photograph and observe positions and battlefield conditions. In was in this domain that E. Lester Jones participated, a rather unique one for Survey personnel. Jones had orchestrated the legal changes necessary for civilians in the Survey to enter military service. Then he did so himself, starting in the local National Guard unit in Washington, DC. He took a leave of absence from the Survey, leaving Robert Faris in his familiar role of Acting Superintendent, and went to Europe. Here is what little is known about what happened to him:

> "On October 5, 1918, he was promoted to Colonel, Air Services, Division of Military Aeronautics, and on October 8 he sailed for France. Upon arrival he was assigned to special and highly confidential duty with various units at battle zones and later under Brigadier General William Mitchell, Chief of First Army, Air Services, and served on the Meuse-Argonne Offensive, Defensive Sector, and also served in Italy".[22]

It is unknown to the present day what he was doing on "special and highly confidential duty," but sometime during that service he was exposed to poison gas and badly wounded. However, he remained in Europe on or near the front until the Armistice in November, 1918. He was decorated by the King of Italy as Officer of the Order of S.S. Maurizio and Lazzaro, and Fatigue de Guerre; he was also made an Officer of the French Legion of Honor. And then he returned to the United States and civilian service once more.

Outside of the battlefront in western Europe and the skies overhead, World War I was fought in the Atlantic Ocean. There were some traditional naval engagements, but

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[21] Trueblood, 1919.
[22] Washington Post, April 10, 1929.

the major developments in naval warfare involved the first major use of submarines, particularly to destroy supply ships sailing in the vast convoys between the Americas and Europe. Many and possibly most Survey personnel who entered war service participated in convoy duty and also a variety of efforts to detect and destroy enemy submarines. Again, novel technologies involving acoustics were developed and deployed for this.

The history of ocean acoustics technologies in the American case is closely linked to the story of Reginald Fessenden and the Submarine Signal Company. The company began supplying underwater sound-generating and sound-detecting equipment to ships to prevent groundings and shipwrecks in the early 1900's. Following the Titanic disaster in 1912, Fessenden turned his skills to developing acoustic equipment that could detect icebergs. It did—but he found he could also detect the ocean bottom. This led to rapid development of many acoustic technologies[23]. The applications stemming from these two new discoveries have dominated ocean acoustics ever since. During the war years, much submarine detection work was done by the US Army, as its Coast Artillery units had primary responsibility for protection of the near-shore waters of the nation. Various Survey personnel in military service worked on different aspects of underwater acoustics, acquiring knowledge, and maybe more important, connections, that would be tapped soon after the war. One of those men was Nicholas Heck. The connections he made would prove critical after the war.

Finally, the final contingent of Survey personnel re-assigned to military service during the war participated in basic research and instrument development. These included men assigned to the Naval Observatory in Washington, who worked to develop a new generation of ship compasses and other navigational instruments for the Navy.

The Transition back from the War

World War I ended on the 11th hour of the 11th day in November, 1918. The members of the Survey who participated in the war were exposed to new places, many new technologies, and the devastating impacts of those technologies on people subjected to them. Even before leaving Europe, Colonel Jones became a founding member of the core of veterans who established the American Legion, as an aid to returning veterans and a source of support for what they had faced and what they would endure in the future. He was the first commander of George Washington Pioneer Post No. 1 of the American Legion and was instrumental in writing the by-laws of the Legion.

When Colonel Jones returned to Washington, he mustered out as a civilian once more eager to put the war behind him and to infuse the Survey with the new technologies and capabilities the war had highlighted as useful to its core missions. However, his first challenge was a crisis to some extent of his own devising. The Act that enabled Survey civilians to move directly into military service at their requisite rank as officers also increased their pay to that of military officers at that rank. When they returned, their pay would be cut back to the traditionally low pay rates that had characterized the Survey since the era of Hassler. Many men, including many of the best and most capable of

[23] Blake, 1914.

them, refused to return. As before, Jones identified this as a problem to be described clearly and then eliminated correctly. Pulling every Congressional string he could, he enabled a packet of legislation to address the problem. First, Congress passed a law raising Survey pay scales for officers in the Uniformed Corps to parity with their counterparts at the same rank in the military, a condition that prevails to the present[24]. He also initiated a law that brought more civilian personnel of the Survey under the new rules and standards for Civil Service in the federal government. This excluded himself, as he was a Captain in the Survey's commissioned service. Since the days of Hassler, the Superintendent of the Survey served with life tenure, or at least served with that capability. Under Jones' new rules, all that ended. The new post of Director was established, with a term of four years, with possible renewals by the President. So Jones was the last Superintendent, and the first Director, of the Coast and Geodetic Survey[25].

The Survey returned to action in 1919; Jones served for the next ten years. He was the Bache of the 20th century, and there were great changes and advances in every division of the Survey as summarized at the beginning of this chapter.

Many of these changes are critical enough to be explored in more detail. Three pertain to the three major divisions of the Survey: for the Geodesy Division, the first US Military Grid System, the North American Datum and the International Reference Ellipsoid; for the Division of Topography and Hydrography, Radio-Acoustic- Ranging and the introduction of aerial photography and photogrammetry; and for the Division of Terrestrial Magnetism, the rise of Seismology. In the Division of Charting, there would be two major developments, in printing technology and a new type of chart, that affected the entire functioning of the Survey and all of its products which continues to the present day. Under Jones, the Survey finally acquired offset lithography presses for chart production, and it acquired federal responsibilities for navigation charts for civilian aviation.

The First U.S. Military Grid System

The American military entered World War I several bloody years after the other combatants, and it quickly discovered that the military technologies of the European armies were far advanced by comparison. This led to many efforts to reduce the disparity between American and foreign military capabilities. The first major project that the civilian Survey attempted for the U.S. military in the immediate postwar era came out of the American experiences aiming cannons on the Western Front during the war.

Immediately prior to the war, the French Army developed the 75, a small, highly accurate cannon with a range beyond human visual range; this precluded aiming the cannon by "firing in" and using the visual sight of shell explosions to direct the aiming. In order to take advantage of the longer range, the French developed a series of "military grids" which were specialized maps in conformal projections that gunners could use to

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[24]Joint Service Pay Act of 1920. 41 U.S. Stat. L., 812, 825, June 4, 1920.
[25] 41 U.S. Stat. L., 874, 929, June 5, 1920.

aim the cannon[26]. There was an evolving series of grid systems culminating in the Nord de Guerre (the North of War, reflecting the fact that most of the mapping system was north and east of French territory in Germany and the Low Countries). As members of the American Expeditionary Force, integrated with the British and French militaries, the Americans were exposed to the grid system and its applications.

While the war was still on, the staff of the U.S. Army Corps of Engineers asked specialists at the Coast and Geodetic Survey to assist them by designing a military grid system for the contiguous United States. William Bowie, the Survey's ranking geodesist, and the Survey's major geodetic computer/mathematician Oscar Adams were the leaders of the project. Bowie was commissioned a major in the Army and served in that capacity through the end of the war until February, 1919. Adams organized the formidable computations of the tables for the projection and was assisted by Army personnel of the 472nd Engineers who were assigned to the offices of the Survey for the project.[27]

The original conception of the project was the calculation of a grid system (in French, a quadrillage) for the eastern coast to aid the Army's Coast Artillery to aim and fire on enemy ships offshore. Eventually, the project expanded to develop a system of grids for the entire "lower 48 states", called progressive maps, as they progress to the west across the country. Because of the problems created by the curvature of the earth and the difficulties in mapping curved space in a flat map, the system used a series of meridional zones, 9 degrees of longitude wide, each extending from latitude 28 north (central Florida) to 49 degrees 10 minutes north (just north of the main part of the US/Canadian border), along with specific extensions necessary to cover southern Florida and the southern tip of Texas, the Upper Peninsula of Michigan, and eastern Maine. For each zone, a polyconic projection was established and specific points along the boundaries of each zone were calculated and interpolated.[28]

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[26] "Conformal" maps preserve the same angular relationships between lines on the earth and those on the map, so that, for example, on the map and on the earth, lines of latitude and longitude always cross at right angles.

[27] Preface, Bowie and Adams (1919).

[28] The polyconic projection was invented by the Survey's founder, Ferdinand Hassler. Full description of it is beyond the scope of this history, but it suffices to say that for relatively small areas of the earth, within the ranges of artillery, the projection has minimal distortion of a nature that would affect aiming. See Adams (1919) and Deetz and Adams (1928) for details.

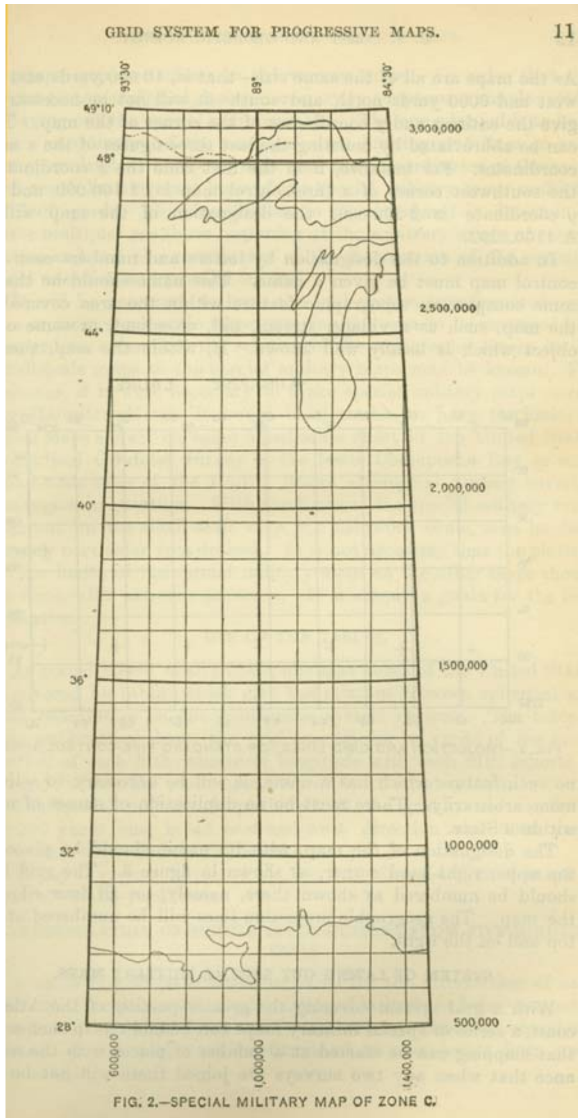


FIG. 2.—SPECIAL MILITARY MAP OF ZONE C.

Zone 6, Special Military Map

It is unclear how much use the military grid system received by the U.S. Army, as it was finished essentially when the war ended. However, it was the first of two military grid systems that the Survey developed for the U.S. military, the other being the World Military Grid that the Survey devised on the eve of the Second World War with computational assistance from the Mathematical Tables Project of the WPA. And the original grid system was also an element of the beginnings of closer collaboration between the mapping agencies of the U.S. government, civilian and military, organized in 1919 into the Board of Surveys and Maps.[29] This new union reflected many developments, but one important driver was the idea, espoused by the Survey, to base all American (and North American) surveys and maps on the same datum, a development

[29] See The Military Engineer (1920)

with enormous consequences for the subsequent history of the United States and the world.

Geodesy, Meades Ranch, Kansas, and the World—and Isostasy

As was noted in the chapters on Superintendents Pritchett and Tittmann, Jones the non-scientist became director of one of the most acclaimed scientific agencies in the world, and probably the division of the Survey with the greatest international stature was that of geodesy. John Hayford's position as chief geodesist was being complemented, rather than threatened, by the rise of William Bowie and their research on isostasy described below. Hayford had, among other matters, developed a reference ellipsoid (named for him) that was, during Jones' tenure, adopted by the International Union of Geodesy and Geophysics (IUGG) in 1924 as a proposed international standard. The details of the ellipsoid are beyond the scope of this history, except for the flattening, which is essentially the fractional departure of the ellipsoid from a round spheroid. In the Hayford case, his flattening was 1/297. Subsequent research has indicated, repeatedly, that his flattening was too great—modern ellipsoids converge around 1/298 as the fractional flattening[30].

In the same era, Hayford, Bowie, et al. also finished a continental datum, the North American Datum (NAD), which was the successor to the United States datum of Pritchett's era. As the Survey had persuaded Mexico and Canada to join in a common datum, the new datum was renamed for the continent. This datum, ultimately NAD 27, was defined by a different reference ellipsoid, the Clarke Ellipsoid of 1866, as tangent to a point on the ground on Meades Ranch, Kansas. The ellipsoid had a flattening of 1/294.98, hence almost 1/295. Why did the Survey, including Hayford and Bowie, adopt datum values different than Hayford's own? The Hayford ellipsoid was a match for the world as a whole, proposed as a common global datum. NAD 27, however, was a datum designed to optimize "fit" to the continent of North America alone.

[30] In the ancient science of geodesy, the Earth is approximated by a conceptual model, called the ellipsoid of revolution. The ellipsoid has an estimated radius for the Equator, called the semi-major axis (a), and an estimated radius for the great circle going through both the North and South Poles, called the semi-minor axis (b). The Earth's flattening (f) is defined as the difference between the semi-major axis (a) and the semi-minor axis (a-b) divided by the semi-major axis (a), hence f = (a-b)/(a).

Geodesist standing at the datum, Meades Ranch, Kansas (undated)

Bowie was at the height of his influence and stature in the field of geophysics during the Jones era. This meant, in effect, that Bowie's assertion of a state of global isostasy based on the Pratt model held sway with many, but not all, influential geodesists in the discipline. See the Tittmann chapter for much more on isostasy, but, succinctly: the Pratt model proposed that continental blocks of material extended to great depths and that they floated in the lower substrate with their bottoms at about the same level, the depth of compensation. The Pratt model was conducive to explaining the possibilities and constraints on vertical movement of continents, especially their edges, but silent on the possibility and mechanisms for horizontal movement which was at the heart of the great debate on continental movements popularly associated with Alfred Wegener[31]. That the Pratt model was espoused by Bowie was not surprising as he opposed the concept of continental drift. The Survey, under his direction, attempted to detect any relative movements between the continents of North America and Eurasia by "tightening" the determination of longitude differences between points on the edges of each continent, using radio time signals. This, then, was the great extension of Survey methods going back to the era of Bache and "the American Method" of telegraphic longitude in the 1850s. At that time, it was believed by participants in the great debate that continents moved, if they moved at all, at something like 50 feet a year which was based on the distance across ocean basins and a general sense of the earth's age that was much shorter than present conceptions. The greatest accuracies obtainable with radio wave longitude (and latitude) determinations were on the order of 10 feet in accuracy. Since these determinations did not reveal movement over time—because actual rates of continental movement are orders of magnitude smaller than 10 feet a year—then Bowie and others concluded that the geodetic evidence argued against drift[32].

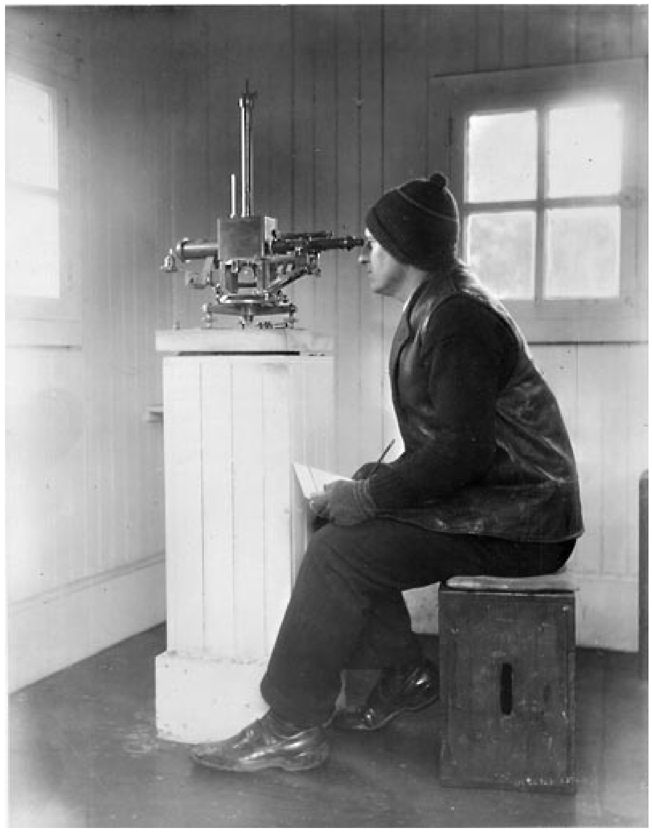
[31] See Oreskes, 1999, for a definitive treatment of these matters.
[32] See especially Bowie, in American Association of Petroleum Geologists 1928,

At the same time, as will be seen ahead in the section on the Survey and the invention of Radio Acoustic Ranging, the Survey was to pioneer vast and accurate hydrographic surveys out to the edge of the continental shelves and down continental slopes, revealing new details and greater resolution of many submarine canyons and other features on the margins of the continents including seamounts and trenches. The canyons were to prove evocative and very difficult of explanation. These accumulating anomalous earth features, not easily interpreted by the standard models of geophysics, would contribute ultimately to major re-evaluations of the processes that had shaped the Earth, most famously in the so-called "paradigm shift" labeled plate tectonics[33]. As a part of that shift, the great majority of geophysicists would eventually abandon Bowie's major theses, although that would be decades in the future after Jones' time.

Terrestrial Magnetism and Seismology

As we have seen, Pritchett established the "modern" division of terrestrial magnetism and a set of national magnetic observatories, some of them permanent standard observatories, and others that were operated for a series of years in a given locale and then were shifted elsewhere once the basic magnetic regime and the rates of secular change in magnetic declination or deviation were established. These observatories, from the beginning, included seismological equipment as a component of the "variation of the needle" could well be earth tremors experienced by the instruments, rather than magnetic storms or other temporary disturbances in the earth's magnetic field. The Survey's seismological instruments at magnetic observatories registered the great San Andreas or San Francisco earthquake of 1906, which became a source of data for intensive analysis of the earthquake itself. Further, the Survey re-surveyed triangulation points in the California geodetic network post-earthquake to detect and measure earth movements geodetically. These side applications of the seismological instruments and the use of the very geodetic network itself as, in effect, an earthquake detector, plunged the Survey into whole new realms of the earth sciences.

[33] The term was introduced by Thomas Kuhn (1962) along with several dozen disparate definitions or uses of the term! The standard history of the initial phases of Wegener's receptions is Oreskes (1999).



Survey observer with magnetometer, Sitka Observatory, 1929

Jones once again saw an opportunity to advance and expand the work of the Survey. In his postwar Director's annual reports, the opening sections on "What the Survey Needs" began to include much more material on the dire necessity to the Survey to acquire responsibility, funding and instruments appropriate to the seismological hazards of the tectonically active parts of the United States, especially in the western states. These hazards included the societal impact of earthquakes, in general, but also the specific damage to structures and facilities associated with earthquakes. He advocated for the Survey to receive the wherewithal it needed to address matters appropriately[34].

Jones' entreaties worked. In 1925, the Coast and Geodetic Survey acquired, from the Weather Bureau in the Department of Agriculture, the primary responsibility for seismology in the federal government. Under the Department of Agriculture, most of the seismological work was observational only with little analysis of the data. This changed completely under Jones. The Division of Terrestrial Magnetism was renamed Terrestrial Magnetism and Seismology, and the Survey, and later ESSA and then NOAA, maintained the lead in various aspects of seismological research for almost the next half century. Jones picked Nicholas Heck, first introduced in the Tittmann chapter as the chief developer within the Survey of wire drag for hydrographic surveying, to be the head of the combined division. His research on the seismic activity of ocean basins would

[34] Jones, 1925.

eventually, by the time of the Patton directorship, yield geophysical evidence that several decades later substantially undermined Bowie's primary assertions about isostasy and the mechanisms of continental movement.

The Changing Practices of Topography and Hydrography

Probably the greatest immediate impact of Jones on the activities of the Survey occurred in the Division of Hydrography and Topography. As always, he proceeded by identifying terrible problems and unmet needs, such that major expansions in charting of American waters were vitally necessary, particularly on the Pacific Coast and most especially in Alaskan waters.[35] He also carefully explained the processes of mapping and the nature and symbols of nautical charts, one suspects for a Congressional audience more than anything else.[36] As usual, it worked. Based on the connections he and the Survey had made by their war service, he arranged for the Survey to acquire four ships from the Navy which were re-furbished for hydrographic and oceanographic work. The largest ships were renamed the *Pioneer*, the *Guide*, and the *Discoverer*, and a converted motor yacht, donated to the Navy by the Lydon family for the war, which was named the *Lydonia*.

E. Lester Jones and his wife Virginia aboard the *Lydonia*, 1926

Surveying from the Air

Jones pioneered the application of aerial photography and photogrammetry to topography in the Survey. In this, he continued as the A.D. Bache of the 20th century. By this is meant that, more than introducing a new technology, he integrated that technology thoroughly in the working structure of the organization. Over a half century

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[35] See Jones (1916, 1917, 1918, 1923, 1927)
[36] And Jones (1922)

earlier than Jones, Bache had prepared the way for photography, in numerous applications, to be introduced into the Coast Survey. As Bache noted near the culmination of the enterprise, on the eve of the Civil War: "But above and before all other reasons, photography was to be introduced as a regular part of office detail, and great changes were necessarily consequent. I determined therefore to have a thorough revision of the whole system".[37] Photography under Bache began in the offices of the Survey, and thoroughly transformed the technologies and services of the office.

By the late 19th century, photography went to the field, in part for personal and official documentation of field work, notable and unusual events, and so on. In the 1890s, photography in the field was used analytically, beginning with techniques adopted from British surveyors with whom the Coast and Geodetic Survey worked collaboratively in the re-survey of different parts of the border between Alaska and the western provinces and territory of Canada. Here, stereo-pairs of photographs were used to characterize and map the topography of rugged mountains and glacial valleys[38].

Under Jones, photography went into the air. A part of Jones' "important and highly confidential" work on the western front in World War I had involved the application of aerial photography to daily assessments of the battlefield. Within a year of the return of Jones and the other Survey officers and men who had served overseas, Jones had developed a program for aerial photography experimentation between the Survey and the military Air Services of the Army and Navy, as they possessed the planes and cameras. Echoing Bache, Jones noted:

> "The surveying done by the Bureau differs to a greater or less degree from surveying carried on by other organizations in this country, and this has necessitated the development of special methods and equipment to suit our special needs...A study is made of all inventions, discoveries, and improvements that give promise of usefulness in surveying. Thus it was that the development of aerial photography was a subject of interest to members of the Coast and Geodetic Survey before the World War, an interest that was intensified by the rapid strides made by aeronautics during the war. As soon as possible following the Armistice arrangements were made with the Air Services of the Army and Navy to carry on cooperative experiments in aerial mapping..."[39]

The initial applications of aerial photography were made in environments that were basically flat as topographic relief imposed distortions in the photography that were problematic. The first trial project was photographing the shore of Atlantic City, New Jersey, in June and July of 1919. Initially, mosaics of photographs were assembled from which rectified and re-scaled maps were created. Following these, there were field inspections using the photographs paired with establishing or re-occupying suitable

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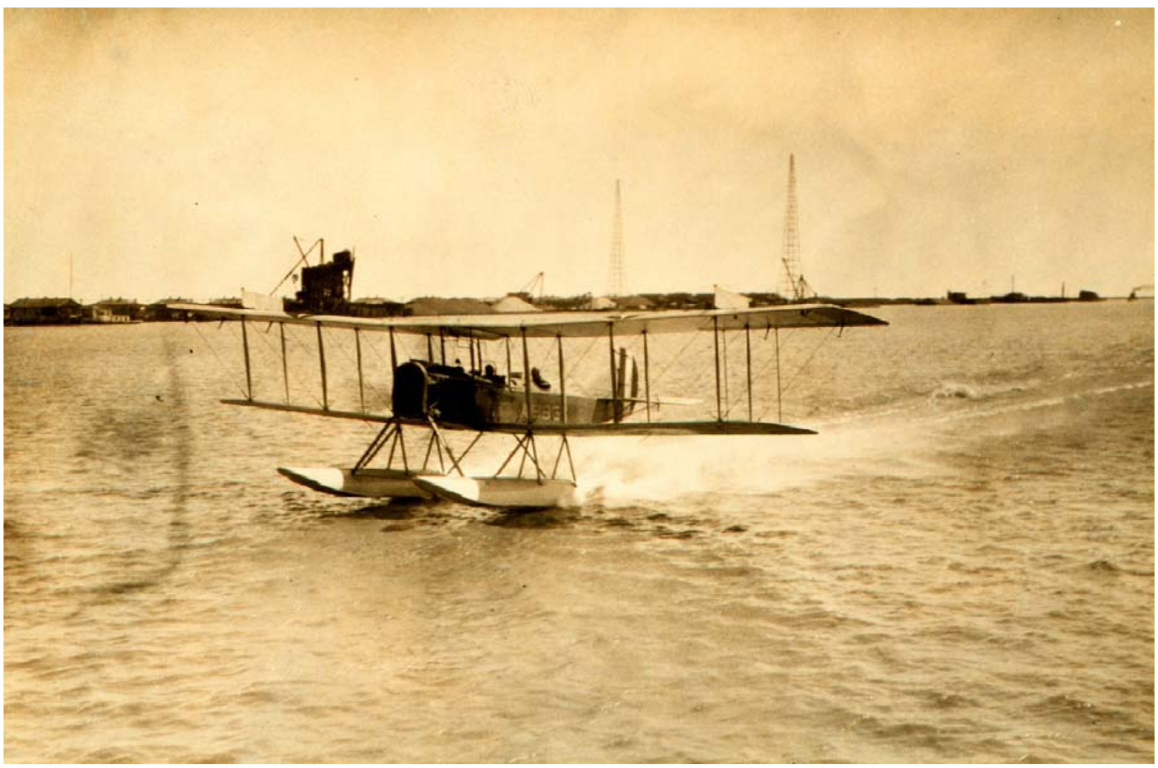
[37] Bache, 1860, pp. 18-19.
[38] See Flemer (1893, 1897).
[39] Jones, 1922, p. 461.

control points. Then, the final accurate compilation of the data was made, the revised map plates were finished, and the maps printed.[40]

The next experiment was aerial photography of underwater features, taken by the Navy Air Service in the clear and shallow waters off Key West, Florida, in July, 1919. This application developed directly from war experiences, in which submarines not seen from surface ships were successfully photographed from airplanes. In Florida waters, the objective was to test whether aerial photography could be used to replace wire drag to detect and map underwater coral formations, but the results were disappointing.

In 1920, the Survey scaled up in two much larger applications of aerial photography: with assistance from the Army Air Service, the entire coast of New Jersey was photographed, as well as the Mississippi River delta in Louisiana. The latter application was quite successful, as photography from above had capabilities beyond anything that could be accomplished down in the waters and willows of the swamps and bayous. "The aerial survey discovered scores of lakes unknown before. The advantages of the aerial method over the ground method in this type of survey are very evident even to the casual observer"[41].



Navy Air Service Float Plane with Survey camera system, Mississippi River delta, 1921

[40] Ibid, pp. 479-480.
[41] Ibid, p. 482.

Early in the applications of aerial photography, the Survey anticipated they needed no planes as they would acquire all the photography they needed through the military air corps. This later changed, and in the era of Patton and beyond, the Survey ended up devising its own unique multi-lens camera systems. But from the beginning, aerial photography affected the throughput of Survey work as thoroughly as photography did in Bache's day. T-sheets rapidly turned into rectified and rescaled maps devised from aerial photography with much less field work than in the pre-airplane era. As Jones noted, this meant that there was much better delineation of difficult to map natural features, like lakes in a marsh. At the same time, there was an erosion of cultural features on the T-sheets, particularly place names, because the field crews spent much less time traveling on the ground.

Sound in the Water and Positioning

As we have seen, while Fessenden tried to reflect sound horizontally off icebergs, he also discovered that sound in the water could reflect off the bottom and could thereby reveal ocean depths. These discoveries took place immediately before the Great War, and so ocean acoustics developed quickly as an arena of warfare technology. These developments had a deep impact on members of the Survey, in all their disparate participations in the war effort. For some, ocean acoustics became a matter of survival, as they navigated ship convoys through submarine-threatened waters. For the Survey scientists who stayed stateside, ocean acoustics became a major focus of research they participated in as part of Army and Navy research projects and laboratories. The Navy's preoccupation with ocean acoustics is understandable, but less so that of the Army. In that era, the Navy projected power outside the United States' waters, while the Army Coast Artillery staffed coastal forts fortified with enormous gun batteries that were essentially land-based battleships which would be primary defenses against attack or invasion from the sea. As a result, both the Army and the Navy and the Survey were occupied with establishing positions, distances, and depths in coastal waters, particularly through the use of these new and novel capabilities in ocean acoustics.

Many innovations in hydrographic surveying were made in this era, but the most important of these was the story of the Survey and its allied agencies and other cooperating scientists, and the invention of Radio Acoustic Ranging (RAR).

The Invention and Early Development of Radio Acoustic Ranging

Hydrography is based on establishing a water depth associated with a specific horizontal position on the surface of the water directly above the water depth. The basic technologies and systems to do this were formalized for the Survey by Ferdinand Hassler and his assistants, and had really not changed very much in the century that followed. Horizontal positioning was established by the geometrical establishment of a three-point fix, utilizing sextants to observe towers, flags, or other signals located on the shore or on fixed buoys and other sites that were positioned into the land-based geodetic network or locally established datum. The limits on the system's capabilities were line of sight constraints, including obstructions, weather effects such as fog and rain, and ultimately the curvature of the earth. Establishing depths depended on lowering a weighted line to the bottom on a line or wire of known length, and was constrained by the myriad inaccuracies that increased with increasing depth, water currents, etc.

The Survey decided to explore the new developments in ocean acoustics as applied to hydrography. As noted, the two principal elements of hydrography were quite different although they are accomplished simultaneously: horizontal positioning, and vertical water depth. The earliest applications of ocean acoustics, pre-war, were attempts to establish horizontal positioning of ships as aids to navigation, using underwater bells mounted on or adjacent to lighthouses and buoys marking dangers. The pioneer enterprise in this was the Submarine Signal Corporation, now a part of Raytheon Corporation. Submarine Signal proposed "to surround the coast with a wall of sound so that no ship can get into dangerous waters without warning, to make collisions between ships possible only through negligence."[42] As mentioned earlier, Reginald Fessenden joined the company and introduced a cascade of new acoustic technologies and applications, many of which were used in the Great War, particularly for anti-submarine warfare.

Among the many Survey scientists who served in various capacities in the war was Nicholas Heck, introduced earlier for his work developing and perfecting wire-drag for hydrography in shallow waters and waters with unseen hazards. During the war, he served in the US Navy in American waters and off the British coast, working with British and American research groups on methods to detect submerged submarines. There were many aspects to the research, but a major part was trying to determine the complex question of velocity of sound in seawater[43]. Sound velocity changes with temperature, and also salinity and pressure, and possibly other matters. How the ocean is structured, relative to these variables is at the very heart of oceanography, and so it came to be that Survey research under Heck, devoted to very specific and well-structured traditional hydrographic activities of the Survey, brought the Survey scientists into the forefront of basic discoveries in oceanography.

What became Radio-Acoustic-Ranging (RAR) started out from work on a very limited and specific objective. Heck, a pioneer in many types of geophysics applications in the Survey, wanted to obtain an acoustic vertical depth finder, called the Sonic Range Finder, originally developed by the Navy for the task of measuring depths acoustically instead of by line or wire. Heck had attended the annual meeting of the American Association for the Advancement of Science (AAAS) in Boston in 1922, where he heard a presentation by War Department physicist E. B. Stephenson on the subject of "Variation of the Velocity of Sound in Sea Water with Temperature".[44] Heck wrote to Stephenson stating that the Survey proposed to use the Navy's "sonic range finder" for measuring water depth, but that "so far as can be learned the Navy has not yet made tests to determine the variation in the velocity of sound in sea water. As our vessels are especially equipped to take deep water soundings by direct measurement and to

[42] Blake, R. F. (1914).
[43] Proceedings, GSA (1954) and The Buzzard (1954).
[44] Heck to Stephenson (Jan. 4, 1923) in Correspondence between N.H. Heck and Stephenson.

determine temperature at various depths, it is believed that we will be able to contribute a great deal to the problem of getting absolute measurements by this method. The outstanding problem is the variation in the velocity of sound in sea water".[45]

Several weeks later, Stephenson replied from his post at the Subaqueous Sound Ranging Section of the US Army Coast Artillery Corps at Fort Wright, New York, on Long Island Sound. He provided Heck information about his own research into the velocity of sound in sea water, but he also made another offer, one with far-reaching implications for the Survey and the very history of oceanography. Heck wanted acoustics technology to establish vertical depth, but Stephenson had another idea: "I am very glad to note you propose to use the Sonic Range Finder… There is a possible application of our apparatus and method to your work…namely, the accurate location of the position of your ship at any time and any place within 50 miles of our stations…*To determine the position of your ship it would merely be necessary to drop a small bomb over board*…"[46](Emphasis added)

Stephenson proposed using a new system the Army had been working on, appropriate for determining on shore at a coastal artillery battery the position of a vessel in the water by using hydrophones placed offshore in known locations, based on the differences in time between the reception of the sound of an explosion (the small bomb) set off next to a vessel as received by the various hydrophones. The time delay would yield, just as in the case with artillery sound ranging, families of hyperbolic curves. With data from three or more hydrophones, it would be possible to estimate graphically the position of the vessel when the bomb was exploded. The vessel in the water could be an ally ship deliberately exploding the bomb, or it could be an enemy ship or submarine spotted and targeted by an aircraft. In all cases the data came to shore facilities at which the vessel's position was derived.

Heck replied two days later. "In the third paragraph of your letter of January 15th, you mention very interesting results in the determination of the accurate location of a ship. We are even more deeply interested in this problem than in the use of the sonic range finder, for the reason that we find it difficult to maintain the desired standard of accuracy. This is especially true in the location of off-shore ends of sounding lines. Our vessels are also obligated to stop work during a fog. I am especially interested in knowing whether the method being developed at Fort Wright has possibilities for use on the Pacific Coast; whether the apparatus could be temporarily installed at an isolated station; whether it is entirely or only in part a military secret, and if the latter, whether substitutions could be made to adopt it for the use of this Bureau"[47].

Both Heck and Stephenson went up their chains of command to request permission to proceed, and to pull in such other specialists as would be needed to adopt and test the Army's new idea. A formal request to the Army was sent by the Survey

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[45] Heck (ibid)
[46] Stephenson (Jan.15, 1923) in Correspondence between N.H. Heck and Stephenson.

[47] Heck to Stephenson (Jan, 17, 1923) in Correspondence between N.H. Heck and Stephenson.

Assistant R.L. Faris, in his periodic capacity as Acting Director of the Survey (due to the episodic disabilities brought on by Director Jones' war injuries). As was characteristic of modern scientific developments, a complex array of specialists and institutions were eventually enlisted for the enterprise. The principal leaders and scientists were Heck and Stephenson, Colonel R. S. Abernethy, the commander of the Sub-Aqueous Sound Ranging Section of the Coast Artillery Corps, the physicist Dr. E.A. Eckhardt of the US Bureau of Standards, who was an authority on radio technology, and the Survey Corps member Jerry H. Service, who organized the Survey's research under Heck's general guidance[48].

A full description of how Radio-Acoustic-Ranging was developed is beyond the scope of this history, but it suffices to say two things: the Survey "turned around" the Army's concept of the system completely, and they developed a plan to work systematically on all elements of the technology at once, allowing incremental progress to be made constantly, so what became known as RAR evolved considerably over time. The Survey "turned around" the Army concept, because for hydrographic surveys, they wanted the data to accumulate and be assimilated *on the ship in the water*, not on shore. This meant, among other matters, that the hydrophone systems on the edge of the shore or mounted under buoys had to be connected to semi-automatic or automatic radio signaling systems, which could signal back in near-real time when the sound of the explosion of the bomb was received at the hydrophone. Further, given that, at 0 degrees Centigrade, the velocity of sound in seawater is approximately 1454 meters/second, and the Survey wanted horizontal positional accuracies of around +/- 10 meters, the system would require distinguishing radio signal timings in centiseconds if not milliseconds, far beyond human capabilities. Therefore, a major degree of system automation and electronics development was demanded in order to accumulate and process the data on the boat. That also meant the bombs would be exploded close to the ship. This was one part of the system that was definitely designated for human management. Later in 1923, Heck wrote to Director Jones, specifically lauding Colonel Abernethy because "[h]e has placed a non-commissioned officer of long experience aboard to direct the bomb firing work, an assistance that was of great importance because of the lack of familiarity of most of our personnel with this kind of work, and the danger of doing such work without such skilled advice".[49]

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[48] In 1945, Captain Heck organized his original correspondence to and from these men during 1923-24 and had it incorporated in the Survey's Library and Archives Collection, and it is supposed that this reflects Heck's judgment of the principal players in the development of Radio-Acoustic-Ranging. There were many other specialists, many more being listed in the Survey's Special Publication No. 107.

[49] Heck to Jones (Oct. 23, 1923 in Correspondence between N.H. Heck and Col. Abernethy.

Timing the Fuse before throwing the RAR bomb

Fully developed RAR was a system in which the hydrographic survey ship established its horizontal position by exploding a bomb off the vessel, while simultaneously recording the time of the explosion with a chronograph. Sound traveled through the water to the hydrophones, and automatic equipment radioed back to the ship at the instant the sound was detected. The time between the explosion and the detection at the hydrophone could yield the distance the sound traveled in the water. Specialized chart frames and protractors were then used to plot the hydrophone locations and then the ship's position.

Initial development work was made at the Army's "laboratory" in the shallow waters of Long Island Sound, using the Army's network of shore and island based receiving stations. But from the beginning, the Survey hoped to adapt the system to use in the very different, much deeper waters of the Pacific coast. There, starting in 1924, the Survey ship *Guide*, under the command of Commander R. F. Luce, made considerable improvements in the system. Within a year or two, off the Oregon coast, the *Guide* was able to accurately determine its position well over 150 nautical miles offshore, an unparalleled feat in human navigation and geodesy. The Survey, and its partners, had developed the first precise positioning system in human history that was completely uncoupled from any type of visual observation.

The key to RAR's working was, of course, that complicated matter of the nature of the velocity of sound in sea water. Experience in the field quickly demonstrated that the path of sound in sea water was complex. As Heck noted years after the initial system was developed: “There was one great surprise in the results. All of those who discussed the project in its early stages questioned whether radio acoustic work would be successful on the northwest Pacific Coast of the United States on account of heavy surf noise interfering with the signals and the difficulties of installing shore stations and cables, while it was taken for granted that no difficulty would be encountered on the Atlantic Coast. The exact opposite proved the case and it is only recently in the course of the Georges Bank work that use under Atlantic Coast conditions has proven practicable”.[50]

Resolving those counter-intuitive field results in Atlantic and Pacific waters required much further research, past the end of Jones’ directorship of the Survey. Hence, how the problems were solved will be disclosed in the Patton chapter. Suffice to say that, in resolving the velocity and sound path of sound in sea water, the Survey stumbled upon, and correctly theorized one of the greatest discoveries of 20th century oceanography—the deep sound channel of the ocean.

E. Lester Jones and Offset Lithography

Jones was a capable and intelligent man, but not a scientist. He managed scientists ably instead. He did have great experience in printing and publishing, based on his years working for his father’s printing press operations. As noted, one of his first actions when he became Superintendent of the Bureau in 1915 was to keep the three major scientific divisions devised by Superintendent Pritchett: Geodesy, Topography and Hydrography, and Terrestrial Magnetism, but combine the three separate charting and mapping sub-divisions into one integral Printing Division which answered directly to Jones. Then, over a period of years, he introduced an entirely new system for map production in the Survey, using presses built by one American company. His innovations were successful enough that the same system—and the same presses from the same company—are still used by NOAA for chart production in the 21st century.

On the eve of Jones’ tenure in the Survey, there were two methods of printing maps and charts in use. The first method was direct engraving, using an intaglio press purchased new in 1851 and still in use in 1915. (That press was the first and only intaglio press the Survey ever possessed—it is presently on display in the NOAA Science Center, in Building SSMC-4, in Silver Spring, Maryland). The press utilized copper electrotype plates and, towards the time Jones entered the Survey, aluminum plates as well. The Survey also possessed several lithographic transfer presses, which were used to transfer print chart designs photo-mechanically to the lithographic plate.

The Superintendent’s Report for 1914 describes the status of printing technologies as they were on the eve of Jones’ entry, and a hint at the future.

“In the engraving section, besides the new charts on scales of 1:400,000 and 1:200,000 which are being engraved, the 1:80,000 charts of the coast of Maine will be

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[50] Heck (1932).

engraved. The greater number of ledges and details along this coast are best represented by the sharper prints from an engraved copper plate.

"In order to make an advance both in quality of prints and in rapidity of printing, new offset presses are needed in the printing section.

"The 'direct process,' by which a photoprint is made on a sensitized aluminum plate from the chart drawing, replacing the glass negatives and prints on transfer paper, promises to be the sole method employed in the future. To carry on this method conveniently, a pneumatic printing frame should be provided, and to be independent of the sun an additional open arc electric lamp will be required".[51]

As soon as Jones entered the Survey, he re-ordered the annual report, beginning the volume with a section called "Needs of the Survey". What follows is his section on "Better Facilities for Printing Charts" from the 1915 report, in its entirety. In this section, Jones laid out the rationale for re-organizing the method of printing nautical charts to offset lithography, the method in use to the present day, 90 years later.

"By far the larger part of the results of our surveys reaches the navigator and the engineer in the form of charts. Every effort should be made to have this final product to be of an excellence commensurate with the large amounts of time and money spent in collecting and arranging the material the chart shows in a condensed form. The final stage in producing the chart is its printing, and the best press adapted to the work should be employed in order to maintain this branch of the work to the highest standard, and a sufficient number should be provided to render it possible to meet urgent demands properly.

"Each copy of a chart is run through the press from two to five times, the average being three times. First, for the black plate; second, the buoy plate, by which the buoys are colored; third, the tint plate, by which the land areas are distinctly defined from the water areas; and on certain charts blue and yellow tints are also used.

"It is most important for the distinctness of the charts that the colors on the different plates should register or fit exactly in their assigned places. How close this register must be will be understood when it is stated that the outline of the symbol which represents a buoy is only one-twentieth of an inch in width. Within this outline the red color must fit.

"Faulty register is produced by the expansion or contraction of the chart paper during the intervals between the printings of the three plates.

"To obviate this lack of register and to assure the same conditions for the three runs, the second and third runs should follow the first as closely as possible, all three being completed in one day. With a single press this rapid sequence in printing is

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[51] Tittmann, O. H., 1914.Annual Report of the Superintendent, US Coast & Geodetic Survey, to the Secretary of Commerce, for the Fiscal Year ending June 30, 1914. p. 120.

impracticable, due to the amount of unproductive work it involves. This consists in the necessary cleaning up of the press after the run of the black plate to prepare it for the red buoy color, and a second clean-up after the run of the buoy plate to prepare the press for the run of the tint color. Each of these clean-ups consumes at least an hour's time of additional unproductive work from this source alone.

"It therefore becomes necessary to run a number of different charts through the press for one color before it is changed for another color.

"Our press is the flat-bed type, which is being rapidly replaced by the rotary offset press in all large commercial lithographic establishments. The Hydrographic Office, United States Navy, has two of the latest type one-color offset presses which have proved highly satisfactory.

"A two-color offset press has now been perfected which can be run with the same force as a single-color press. By means of this type of press the two most important impressions, the black base and the buoy color, could be done at one printing.

"The offset press presents three distinct advantages for our chart work. First, sharper prints; second, the rapid drying character of the ink used permits the printing of the various colors in rapid succession; third, a reduction in the cost of paper, by omitting the high-surface finish of the paper required by the present process.

"It is therefore recommended that Congress be asked for one of these modern two-color offset presses".[52]

The lack of modern presses was only one of a myriad of problems the Survey faced in the printing of charts in Jones' estimation. The other major problems were the sub-standard salaries the Survey paid to its skilled workers, and the appallingly poor physical facilities of the press operation. The Survey's headquarters, then still on New Jersey Avenue near the Capitol, were built into a former mansion and former hotel next door which had been converted to the work of the Survey. In addition to descriptions of the poor facilities, Jones' 1917 report contained six full page photographs of the Survey's poor facilities.

In the end, it was the mobilization of the Survey for service in the First World War that provided the funds Jones insisted must be invested for optimum work by the Survey. The Survey's field scientists and officers were mobilized into service in the war, or in research stateside on war-related instruments and technologies. The charting operation of the Survey redoubled domestic chart production for the aid of mariners in submarine-infested waters, and also took on major responsibilities for production or re-production of military maps and charts for the AEF. Jones directed the mobilization, but also adroitly secured sufficient funding to change the printing plant completely.

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[52] Jones, E.L., 1915. Annual Report of the Superintendent, US Coast & Geodetic Survey, to the Secretary of Commerce, for the Fiscal Year ending June 30, 1915. p. 19-20.

Immediately after post-war mobilization, when Colonel Jones returned to civilian status as head of the Survey, his first post-war Annual Report recounts his success.

"…The emergency requirements of the war threw a great burden upon the Coast & Geodetic Survey. Demands were made on us for charts in unprecedented numbers by the Navy Department and the Shipping Board. .. On my presentation of these facts to you [Secretary of Commerce], you in turn brought them to the attention of the President, and under date of March 8 and June 17, 1918, he authorized allotment of… $105,000 for providing needed facilities for the work of preparing charts, military maps, and other special work for the Army and Navy by the erection of a suitable building for the purpose. On September 18, 1918, an additional allotment of $29,250 was made for the purpose of equipping the building. ..

"Another great improvement was the installation of a Harris offset automatic printing press, with a capacity of printing charts 34 by 48 inches at the rate of 3,500 per hour. This press, too, was purchased through an allotment of $14,000 made for the purpose by the President from the funds placed at his disposal by Congress for national security and defense during the war with Germany and Austria. At the time the allotment was made, the Bureau was largely engaged in the printing of navigational charts absolutely necessary for the use of the Army and Navy, and realizing the resulting disaster in case of a breakdown of one of our other presses the purchase of this other additional press was authorized".[53]

The Harris press installed in 1919, under the rationale of war-time emergency funding, was the first of a long series of Harris presses that continued to print Survey charts, then ESSA charts, and finally NOAA charts, to the present day.

The Transition from Nautical Charts to Aero-Nautical Charts

> "Therefore, while we are regretful that the Coast and Geodetic Survey is no longer in the Navy, we are looking forward to an achievement by this branch of the service which will add even more reputation to it than all its achievements of the past, because we are on the threshold of a period when the battles of the world will not be fought on the land or sea alone, but in the air, and I look to you gentlemen to chart the air as you have charted the ocean, so that when the airy navies grapple in the central blue, they will be able to miss the pockets and hit the enemy!"[54]

The postwar world was full of airplanes flown by pilots who needed maps. E. Lester Jones, while on leave from the Survey as Colonel Jones on the western front in World War One, had advocated the use of aerial photography for map-making and had also advocated the production of maps for aviators. Immediately post-war, aviation maps were produced exclusively by the Army and Navy until the Civil Aviation Act of 1926

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[53] Jones, E.L., 1919. Annual Report of the Superintendent, US Coast & Geodetic Survey, to the Secretary of Commerce, for the Fiscal Year ending June 30, 1919. p.23. Extraneous sections removed for clarity.
[54] Secretary of the Navy Daniels, 1917, in Buzzard, 1947.

began the modern era of civilian flying. Under the Act, the Coast and Geodetic Survey was given responsibility for civilian aviation maps. For a century, the Survey had created nautical charts, so it now produced aero-nautical charts. The Survey's charts were widely sought after as being superior to all others, and the Survey's name for them—aeronautical charts—was adopted around the world[55].

The cartography associated with aviation evolved rapidly, with a high degree of collaboration in design and testing of the maps by aviators themselves[56]. By the 1920s, U.S. military aviation maps were primarily "strip maps", long narrow maps printed on thick paper, and often used in a scrolling apparatus that would allow small sections of the map to be revealed at a time which helped in the very cramped quarters of the cockpit. These strip maps were oriented along the major flight direction line between known destinations, whatever that direction was. When the Survey received responsibility for maps for civil aviation (the military retained responsibility for maps for their own pilots) it began producing strip maps, the first of which was for the flight line between Kansas City, Kansas, and Moline, Illinois. The strip maps were produced from 1926 until 1937, but by the middle 1930s they were being phased out.

Airway Map 137 A, the Columbia River Gorge, 1931

As airline routes and airplanes proliferated, many maps were necessary to display routes to and from a given airport. It was decided to adopt an entirely different system, using rectangular charts that would "tile" to fill the United States. A pilot then would carry the relevant maps covering the probable areas to be traveled over. The Survey created a new system of charts called "sectionals" as each chart covered a single section of the system. Because compass directions were so critical to airplane navigation, instead of using the Survey's non-conformal polyconic projection, the Survey used a system of maps based on the Lambert conformal projection which was the same projection system used by the French for their Norde de Guerre which was the inspiration for the Survey's Military Grid System. The development and use of the sectionals will be described in the Patton chapter, for, with the advent of the Survey's strip maps, the Jones' era came to a close.

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55 Ristik (1960) p. 62.
56 See Ehrenberg, 2006.

E. Lester Jones, RIP

On April 9, 1929, after a last illness of several months, Jones died in Washington, DC. His obituary in the next day's Washington Post was titled "War Gas Victim". His exposure to poison gas on the battlefield in Europe, during his execution of "special and confidential duty among various military units" in 1918, impaired him to some degree or other the rest of his life. It also made him sympathetic to the travails and plight of other war veterans, although, as has been seen, this patrician administrator entered the Survey before the war with the primary goal of raising the status, salaries, and amenities of the men and women under him. Jones was a co-founder of the American Legion, and was the director of the first post of the Legion, in Washington. He had also been a trustee of the National Geographic Society, and had acquired the honors and responsibilities of a true leader, many of which were listed and lauded in the many memorials issued after his death.

But these paled in comparison to what he had thought his finest achievement, which became personified in the battle that his successor, Raymond Patton, and Jones' widow Virginia Jones had to wage after his death. Jones was buried in Arlington National Cemetery as Colonel Jones, based on his service in World War One. Patton and Mrs. Jones fought long and hard, and eventually successfully, to have Jones' gravestone changed to include, right below his name, the title that had been the most important to him in his life:

Director, U.S. Coast and Geodetic Survey

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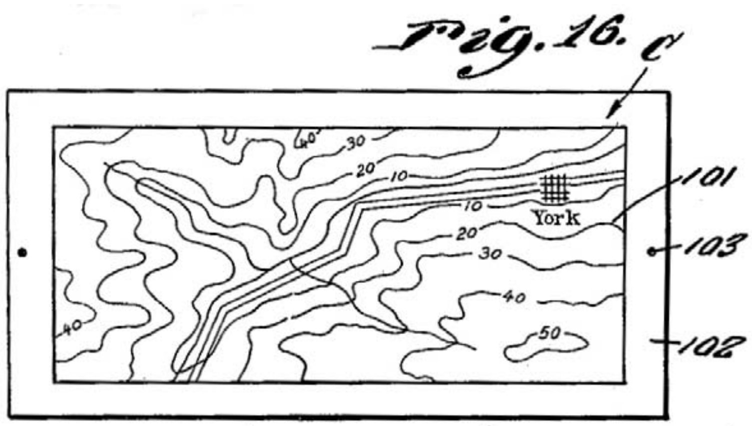
Extending Relief to the Nation:
Director Raymond Stanton Patton
(1929-1937)



Schematic from the Braund Reliefograph Patent , 1935

E. Lester Jones had been the very last Superintendent of the Survey, and also its first Director. The name change was a small part of the great reorganization and revitalization effected under Jones, but was significant, none the less. Superintendents served until they died, were incapacitated, or removed for scandal. Directors were to be appointed by the President for terms of four years, with renewals possible but not guaranteed. Jones served until his death, on April 9, 1929. Twenty days later, President Herbert Hoover commissioned Captain Raymond Stanton Patton, a member of the Survey Commissioned Corps and at the time the Chief of the Charts Division, to be the twelfth leader of the Coast and Geodetic Survey. Like Jones before him, he would serve until he died in 1937.

Like many men who served at sea during a major part of their lives, Patton was born and raised far from the ocean in Ohio. He lived in Ohio from his birth in 1882 until after graduating from Western Reserve University (now Case Western University) in 1904. He then joined the Field Corps of the Survey, and, like Superintendent Tittmann before him, would spend the rest of his life working with the Survey. As a member of the Corps of the Survey, he was trained for shipboard service and eventual ship command; and he was also trained in the myriad of activities on ship, on shore, and in the office that constituted Survey work. An examination of his early work assignments, and their locations, conveys the scope of the Survey in his era. Patton began as a Junior Officer on the ship *Hydrographer* working on revisions to the Atlantic Coast Pilots and also on topographic surveys in Virginia. In 1906 he was posted to duty on the *Gedney* in Alaska. In 1907, he began a three- year tour of duty in the Philippines as a part of the Survey's efforts in the Philippine Survey. Patton arrived when the Philippine independence forces were still battling with the US military forces. Living and working conditions were very difficult, far beyond the difficulties Survey personnel encountered in stateside work. Patton was noted for his friendly efficiency and good humor under stress, qualities that would later serve him well as he guided the Survey through the depths of the Great Depression and tremendous challenges in American life.

Upon his return to the United States in 1910, he worked in various capacities on the Atlantic and Gulf coasts, on approaches to the Panama Canal, and Alaska again. He found time in 1912 to marry Virginia Mitchell of Seattle, Washington, presumably in-between ships. After an additional command of the ship *Explorer* in Alaska, in 1915 he was posted to Washington to oversee revisions to the Coast Pilot series. At that point, E. Lester Jones entered as the 11th Superintendent. And then the war came, and Patton was transferred to the Navy as a lieutenant and later was promoted to lieutenant commander. Patton returned to the Survey after the war as Captain Patton. Jones and Patton returned to the Survey at a critical moment. Jones reorganized much of the Survey, especially map production and its relation to other branches of the Survey. He elevated cartographic production to the status of an independent division reporting directly to him. Jones appointed Raymond Patton the first Chief of the Printing Division. Patton coordinated not just new kinds of charts and maps, but entirely new cartographic production systems which would become the foundation for the extraordinary cartographic explosion of the Survey and its staff during the Second World War.

By the time of Director Jones' last and fatal illness, Captain Patton had worked in every area under jurisdiction of the Survey, in every Survey division, and with every major type of publication and map series the Survey produced. As Alexander Dallas Bache built the Survey on Ferdinand Hassler's foundation in the 19th century, so also did Raymond S. Patton build on the foundation that Jones had made in the 20th century.

By the time of Patton's directorship, the scientific divisions of the Survey were a third of a century old. Survey personnel moved between divisions, but for the most part, before Patton's era, "what happened in hydrography stayed in hydrography"; the nature of the work and research results within a division had little impact on other work. This was to change markedly in Patton's era. In keeping with the ordering of these chapters, the Survey history will be described division by division, but the inter-connections between these will become increasingly important and complex. As a key example, new research on earthquake distribution patterns in the Division of Terrestrial Magnetism and Seismology would intersect with an explosion of technologies developed in Hydrography and Topography, with vastly expanded ranges and detailing of hydrographic mapping off American coastlines in the Pacific and Atlantic Oceans. The convergence of these two arenas of earth research would return to undermine, literally, the concept of continental stability based on isostatic equilibrium espoused by William Bowie in the Division of Geodesy, and would provide critical data for an idea about the structure and history of our planet's continents and oceans that would eventually move the earth literally and conceptually.

Division of Terrestrial Magnetism and Seismology

The Survey's work in terrestrial magnetism can be traced back to A.D Bache himself. Nearly a century later, the Survey's emphasis had shifted away from primary research in the subject largely because there were other institutions that had assumed that role, particularly the Department of Terrestrial Magnetism of the Carnegie Institution of Washington which was founded by personnel from the Survey. However, the Survey maintained the network of national standard observatories which began with the Cheltenham, Maryland station that celebrated its third of a century anniversary during Patton's era[1].

The Survey concentrated on increasing the density of observations for the locally observed magnetic elements for two very different applications. First, in keeping with the drive to standardization of datums and reference systems of both federal and state agencies pioneered by Jones after World War I, the 48 states developed or improved and extended state-level reference systems, the state plane coordinate systems[2]. Surveyors in the local state planes needed local values for magnetic declination to better correct their surveys and also to better re-construct or estimate historic magnetic declinations experienced by surveyors in the past. To provide this information, magnetic observing parties were dispatched across the 48 states to acquire the data sets needed within the individual states. The state systems also required sophisticated cartographic transformations between the state plane systems and the Survey's North American Datum of 1927 (NAD 27), so the Survey issued and re-issued many special publications to assist state agencies and civil surveyors in this.[3]

Second, the Survey needed local magnetic declination data broadly across the US and its territories for its expanding series of aeronautical charts. Under Jones the Survey began its own civilian versions of military strip maps, which charted the routes between specific airports. Early in Patton's era, the profusion of strip maps necessary to fly to, Chicago, for example, from increasing numbers of other airports led to the decision to abandon strip maps for maps that covered all American airspace. These were and are the sectional charts, which will be described further under the Division of Charting. Aeronautical charts note true and magnetic north azimuths on each chart, and as the plan

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[1] Heck, 1934.

[2] Essentially, the area of a state or discrete sections of it were treated as a plane instead of a portion of the curved earth, and an x-y coordinate grid was established for that plane. This was then correlated with appropriate coordinates in latitude/longitude of the Survey's North American Datum of 1927 (NAD 27). If the size and/or shape of the state made this unworkable for civil surveying accuracies, then the state was divided into a set of smaller and differently oriented planes, and then the x-y coordinates within each plane were coordinated with NAD 27. As well, counties and even cities developed their own coordinate systems, all correlated with NAD 27.

[3] See especially Deetz and Adams, 1934. [URL to Special Publications by function]

of the sectional charts was to cover the area of the 48 states, then the Survey required magnetic declination values for the entire country.

Finally, the Survey re-extended work far north of the "lower 48". In 1882-83, Survey personnel had participated in the first International Polar Year, occupying stations at Point Barrow, Alaska. There they had built a geomagnetic observatory. Fifty years later, for the second International Polar Year the Survey returned to Point Barrow to re-occupy the non-ferrous observatory for new observations of terrestrial magnetism and to construct an integrated geophysical observatory at Fairbanks in collaboration with the University of Alaska and the Division of Terrestrial Magnetism of the Carnegie Institution of Washington, all under a grant from the Rockefeller Foundation. That laboratory became the nucleus of a great set of laboratories and projects in Fairbanks to the present day[4].

Seismology

Seismology was linked to terrestrial magnetism since Bache's era because a part of the "variation of the needle" could be attributed to earth tremors. The Survey had received primary responsibility for seismology in the federal government in 1925. Jones initiated the new program by making Nicholas Heck the head of the division. Hence, the man most responsible for initiating Radio Acoustic Ranging was now charged with developing the key technologies for seismology. There were two basic types of instrumentations and applications that Heck and the division concentrated on. First, the Survey needed to coordinate data networks from a myriad of seismographs, including state, federal, university and religious networks (primarily Jesuit) in order to locate the epicenters and intensities of earthquakes. The distribution of contemporary earthquakes tended to be closely correlated with past earthquakes which led Heck to direct that significant historical research on the earthquake history of the United States[5] be undertaken. The combination of the patterning of historic earthquakes, which were mainly located on the land because these were the ones perceived by humans, and the contemporary earthquakes located through world seismic network data located primarily under the oceans, revealed patterns of earthquakes that did not support the nested assumptions of the model of continental isostatic adjustment and un-moving continents of which William Bowie was one of the strongest proponents. Under that model, earthquakes should be concentrated on continental margins where the processes of erosion and sedimentation would concentrate changes to the isostatic equilibrium of the continents. Earthquakes, under this model, were the results of shifting masses re-establishing equilibrium. But Heck's data showed clearly that earthquakes were concentrated not only in the vicinity of the great oceanic trenches which only paralleled some continental margins, but also on "the great ridges or rises in the Pacific, Indian, and Atlantic Oceans," the areas farthest removed from the zones of sedimentation and erosion.[6] Eventually, Bowie's horizontally stationary continents were to be undermined

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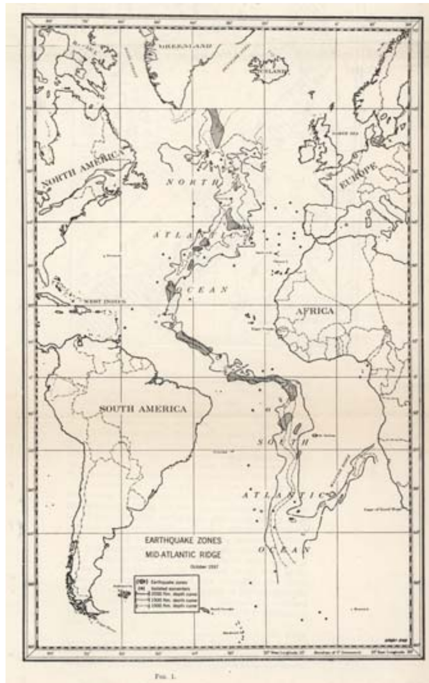
[4] Eickelberg, 1932.
[5] See especially Bowie, 1924 and 1928; Heck, 1928; and Wood, et al, 1934.
[6] Heck, 1938, p. 97.

by Heck's seismology. The next synthesis that would converge, beyond the lifetimes of both Bowie and Heck, was the theory of plate tectonics as the driver of continental drift.[7]



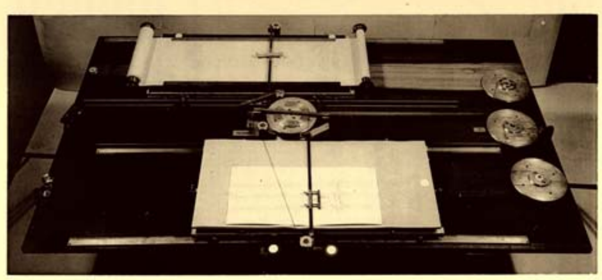
Earthquake Zone of the Mid-Atlantic Ridge
From Heck, 1938

Heck could theorize, but he also had superb skills in marshalling scientists and technicians to develop new technologies for new needs. Seismographs are best suited for measuring the intensity and timing of earthquakes whose epicenters are located at some distance away from the instrument. A local earthquake causes them to swing wildly. The Survey needed instruments that could measure the patterns of locally experienced earthquakes with minimal distortion and error in the data. Eventually, Heck and his staff developed a cluster of instruments to do this. The key device was the accelerograph, which used three separate instruments to detect horizontal motions of the earthquake in horizontal (x,y) and vertical (z) directions. The data from all three instruments would then be recorded simultaneously on a revolving paper drum, similar to a regular seismograph. From this data the pattern of acceleration of the movements in each direction was derived.

[7] The standard history of all this is now Oreskes, 1999.

Accelerograph, U. S. Coast and Geodetic Survey type.

The Survey then developed a mechanical device, similar to the pantographs the Survey had used since the era of Ferdinand Hassler. In this case, the expander device allowed a mechanical transformation from the acceleration curves to a double integration, leading to a graphic that was an integrated curve that showed the resultant horizontal motion of the earthquake in time as perceived at the site[8]. Very busy and hard to interpret data was thereby condensed to elegant curves.



APPARATUS FOR EXPANDING ACCELERATION CURVES PREPARATORY TO DOUBLE INTEGRATION

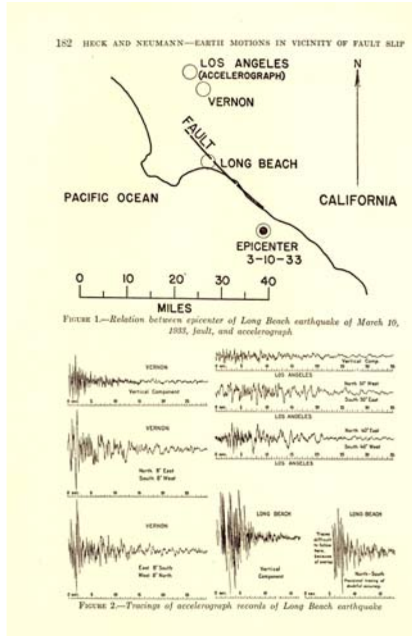
The Survey Apparatus to Expand the Acceleration Curves
From Heck and Neumann, 1942

The Survey's new instruments were deployed around the country, concentrating on areas with a significant history of earthquakes and/or a terrain that made earthquakes especially destructive. In particular, a set of three instrument clusters were established in southern California and placed in buildings in downtown Los Angeles, the nearby industrial city of Vernon, and the seaport town of Long Beach.

On March 10, 1933, at 5:54 pm, the earth and the Coast and Geodetic Survey converged. A powerful earthquake, estimated at magnitude 6.4 and intensity VIII, shook a major area of southern California. The movement occurred on what is now called the Newport-Inglewood fault zone, and the epicenter was situated about a mile offshore from

[8] See Heck and Neumann, 1942 for a detailed explanation of the instrument and these graphics.

Newport Beach. Next to Newport Beach is Long Beach. The instrument was located only 8 miles from the epicenter.



Positions of the Fault, the Epicenter of the Earthquake, and the Positions of the three C & GS Accelerographs, and their Data, 1933

The Survey's accelerograph worked well and survived the destruction of the earthquake. The data from the instrument was the most accurate earthquake motion data ever recorded from very near the epicenter of a major earthquake.

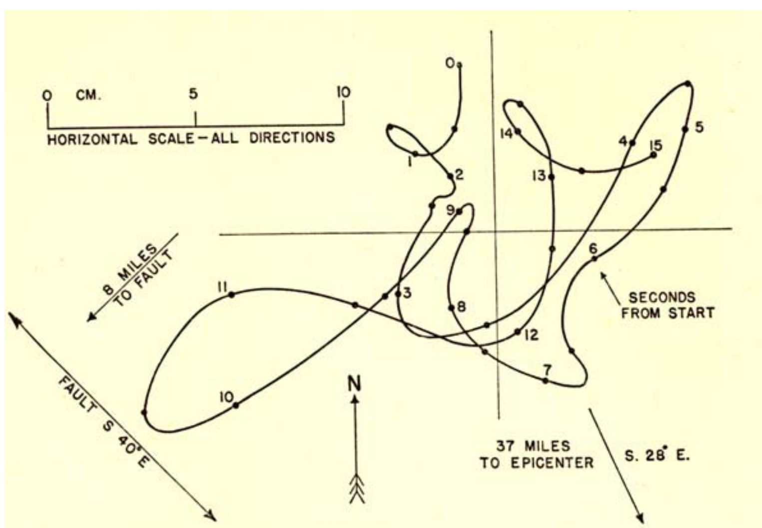


FIGURE 8.—*Resultant horizontal motion at Los Angeles during first 15 seconds of Long Beach earthquake*

The integrated horizontal motion of the earthquake in the first 15 seconds as recorded in Long Beach

The Long Beach earthquake, like all very powerful earthquakes, was a great tragedy for those who experienced and suffered it. But it was also a major source of validation for the Survey and its Division of Seismology, only eight years old at that moment. And, the Long Beach earthquake demonstrated that it was possible to design and deploy seismic instruments that could function where data was most critical - the places where the earthquakes occur. As a direct result of this, the Survey started a collaboration with the California Institute of Technology (Caltech), the state of California, and other partners by helping develop a series of laboratories and experimental stations for designing and applying a new generation of instruments for studying how buildings moved and failed in earthquakes and how building structures could be changed to better survive earthquakes. As the Inspector of the San Francisco Field Office noted, "The property loss from the Long Beach earthquake was conservatively estimated at $41,000,000, and the most valuable data obtained for engineers came from $1200 worth of instruments installed by the Coast Survey in that area".[9] These investigations, implemented through seismic design elements of building codes, have saved an untold number of lives in the decades since[10].

The Division of Geodesy

The Division of Geodesy was the foundation of the Survey, and it was an agency directed to highly organized and meticulous fieldwork; but it was also the mathematical and computation heart of all the other enterprises of the Survey. In 1927 the Division had completed the North American Datum of 1927 (NAD 27) which was an effort that began over half a century earlier with the planning and execution of the transcontinental arc of the 39th parallel.

The major work of the Division during Patton's era was, essentially, tying more and more of the land masses of the US and its territories under Survey responsibility via NAD 27 through extension of first, second, and third order horizontal networks as well as greatly extending the vertical network. In 1927, the Sea Level Datum of 1927 was established which clarified and corrected the disparities between sea levels as determined by tide stations on both coasts. This new datum was then transferred across the country by leveling crews working inland from the coasts and by systematic corrections to earlier heights based on the previous sea levels. Leveling parties continued to use railroad corridors whenever possible; serendipitously this era was the high point of railroad development in the United States. As will be described later, during the Roosevelt Administration's response to the Depression, the field crews and office personnel necessary to support this vast undertaking were expanded to the point that the Survey had the highest number of personnel working for it in its history.

The expansion of the horizontal network of NAD 27 was facilitated in this era through the evolved versions of the Bilby tower, designed by Jasper Bilby, who had risen to the position of chief signalman of the Survey. These towers, some of which were over

[9] Inspector, 1934, p. 127.
[10] See especially Wood, et al, 1934, and Anonymous, 1936, and McComb, 1936.

150 feet high, provided inter-visibility between distant survey points. Bilby towers are a system of two steel towers, one built inside the other but completely independent and not touching each other. Crews climbed up and down and worked on the outer tower, while the survey instruments were located on the inner tower, unaffected by vibration and movement on the outside tower. The towers were built out of prefabricated and standardized lengths of angle iron, which were adapted from materials designed for oil derricks and windmills. The system was based on complete standardization of parts, and experienced crews could put up and take down the towers in a few hours.

The oldest known photograph of a Bilby Tower being erected, 1928

Finally, there was, in Patton's era, one particular horizontal network observation site that was unique in the experience of the Survey. As part of the expanded federal workforce under FDR, there was a renovation of the Washington Monument. This required sheathing the Monument in scaffolding. The Survey requested permission to occupy the summit with theodolites in order to clarify and correct observations extending back to the earliest Survey work in the District of Columbia. In 1999, during the second renovation of the Monument, the National Geodetic Survey occupied the Monument's apex once more, this time the NGS used Global Positioning System equipment.

Survey geodesists at the apex of the Washington Monument, 1934

As mentioned under the section on Terrestrial Magnetism, much of the work of extending and infilling the geodetic networks was related to establishment of state plane coordinate zones in the 48 states, which correlated state-level Cartesian coordinate systems (x,y) to the geographic coordinate systems of longitude and latitude of NAD 27. The state-level zones could be divided further into local control systems, as for example covering a single city or county within the state. The work to establish the local control surveys was a particular focus of the FDR years because local control projects could hire people locally, who worked in their own cities or counties, in contrast to the triangulation and leveling crews which traveled across the country like Gypsy caravans[11].

The final major scientific project of the Division of Geodesy during the Patton era was acquiring local gravity data. The Division chief, William Bowie, was the great American patriarch of the concept of isostasy, and continental isostatic equilibrium. A discussion of this very complex debate is beyond the scope of this history—Oreskes (1999) is to be consulted there—but suffice to say that the most critical areas of scientific interest to Bowie and people in his camp—but not Heck—were the broad zones at the edges of continents and oceans. The major activities of the Survey regarding this in Patton's era was cooperative participation with national and international scientific projects to acquire gravity data using a unique and revolutionary instrument, a pendulum-based gravimeter designed by Felix Andries Vening Meinesz (1887-1966) a Dutch scientist. Vening Meinesz' gravimeter was used at sea mounted inside a submarine on numerous expeditions. In the 1930's, Survey personnel worked with various submarine expeditions in the waters between Florida, the Bahamas, and the Caribbean. The accumulated data, ironically, eventually "undermined" Bowie's concepts of local isostatic equilibrium[12].

Division of Tides and Currents

[11] See Hemple 1934 for the origins of the local control survey projects.
[12] See Hoskinson, 1938 for the Survey's work in the Vening Meinesz gravity surveys.

Tides and Currents was a small but critical office within the Survey, pursuing observations and research that tied in to every other division. They operated about 20 permanent tide stations distributed at carefully selected points along the coastlines under Survey jurisdiction. Data from the tide stations were used to check and correlate with tide prediction data produced by the Survey tide prediction machine No. 2, at headquarters in Washington. The tide station data were also used to control hydrographic surveys, determine initial points for precise leveling work, determine datum planes for charting and defining title to lands bordering tidal waters, and hence of great economic and political significance, and finally to extend the historical record of tidal observations given what seemed to be the inexorable rise in sea level underway. Further, in keeping with Director Patton's own focus on shore preservation, there was a major emphasis on the application of tidal data to issues in coastal stability. Patton's foresight was reflected in the following, "The coast is not a stable feature of our earth. There is indubitable evidence that the land and sea have changed in relative elevation at various times in the past. Whether such changes are going on now is not only an interesting scientific question, but one of more than academic importance to our seaboard cities. The primary means of answering this question is through the continuous tide observations being made at the Survey's primary tide stations".[13]

Finally, it should be mentioned that Tides and Currents played a role in environmental science education. The Survey scientist Henry Marmer wrote the Survey treatise on tidal datum planes which were local sea levels established by long-term datasets from specific local tide stations. But he also wrote several popular books, including *The Tides*, originally published in 1926, and *The Sea*, published in 1930, each of which went through many editions as they became standard and frequently used references on the subject.[14]

Division of Hydrography and Topography

The seashore is the most dynamic environment on earth occupied and used by humans, and so members of the Coast Survey were preoccupied from the very beginning of the Survey with noting and mapping shoreline and coastal changes which then evolved into devising models and explanations of coastal dynamics. Coast Survey repeat mappings of coastal changes have been the basic data source for much or most coastal change research in the United States.

Patton recognized this when he wrote, "Members of the United States [Coast and Geodetic] Surveys, Bache, Mitchell, ... Whiting, Marindin, Davidson, and others, have worked out many of the details of coastal forms and their changes, and a large number of observations recorded upon maps and charts have been the basis of much of the work of this paper".[15]

[13] Patton, 1932, p.5.
[14] See Marmer 1926, 1927, 1930.
[15] Gulliver, 1899, p. 153

The annual reports of the Superintendent of the Coast Survey, later the Coast and Geodetic Survey, contain dozens of detailed reports and analyses of coastal, harbor, and inlet processes and changes, a constant preoccupation of Survey scientists since the beginning of the Survey[16].

A convergence of natural events, coastal development, new research initiatives organized by the US government for World War I, and Raymond Patton's intelligence and insight led to him, and the Survey, playing a starring role in the initiation, if not the execution, of major federal involvement in coastal management in the US. The place in question was the long shore of New Jersey. Changes in transportation and the rise of a broad middle class in the late 19th century brought many thousands of people from New York City and other crowded urban areas to "summer" on the New Jersey shore. Temporary camps and summer hotels were developed into year-round settlements located as close to the shore as possible. But the New Jersey shore is almost constantly retreating, as the shore has little source of deposition from inland, and storms and waves erode the coastal margins. This mattered less when the major settlements along the shore were fishing villages situated in bays and harbors for maximum protection of the inhabitants and their boats. But summer people wanted to stay as close to the beach as possible, exposing them and their settlements to the dynamic processes of the waves. In addition, a direct hurricane strike and a number of near misses as well as "northeaster" storms swept over the New Jersey shore in the early 20th century, every time creating more destruction because there was continually more to destroy.

Then the US entered the Great War. In 1917, the National Research Council was formed to coordinate scientific research and technology development for the war effort. A little more than a year later, the war was over, but the National Research Council (NRC) continued as a source of coordinated federal research. Meanwhile, the processes of development and erosion and storm loss first noted in New Jersey led the leadership of that state to create the State Board of Commerce and Navigation, charged with studying the problems and developing solutions. The State Board appealed to the NRC to bring in federal involvement. Into that mix came Raymond Patton and his coastal surveying experience, ranging from Alaska to the Philippines and all coasts of the contiguous 48 states. Patton became the founding chairman of the NRC Committee on Shoreline Investigations of the Atlantic and Gulf Coasts.[17] The initial collaboration was between the New Jersey Board and the NRC Committee, but much of the rest of the Atlantic and Gulf coasts was also "New Jerseyifying"[18]. The problems were national, so the enterprise to address it must also be national. Patton became a founding member and officer of the American Shore and Beach Preservation Association, established in 1926[19].

The basic problems, as the Association found them, were that beach areas were increasingly important and valuable, that beach erosion and other problems were increasing and increasingly difficult and costly, and that the major responses to these

[16] Notable examples are: Whiting, 1850 and 1886; Mitchell, 1869 and 1871,and many more.
[17] American Shore and Beach Preservation Association, 1928.
[18] Pilkey and Dixon, 1996, p. 7.
[19] The Association's history described in Patton, 1930.

matters were individualized by homeowners, towns, and states. In addition, the Association noted that, particularly on the Atlantic and Gulf coasts, riparian laws and their jurisdictional zones were very complex, ancient and not well understood by hardly anyone, not uniform and at times in conflict from state to state, and also in conflict in various ways with federal responsibilities for navigation. The Association proposed to address these problems by serving as a source of experts for various committees to research a variety of geophysical and social aspects of the problems, and to induce all coastal states to develop effective state level agencies to address matters based on the model of the collaboration between the NRC and the New Jersey Board[20]. "Heretofore little has been accomplished because these matters were everybody's business and therefore nobody's. We propose to make them somebody's business; somebody whose bread and butter depends on getting results".[21]

As matters evolved, however, another player entered the arena, along with an enormous amount of bread and butter. The Army Corps of Engineers had been given primary responsibility for coastal and inland navigation at the beginning of the 19th century. Now the Corps entered as a player along the entire length of the coasts, outside the context of navigation. In 1930, Congress authorized the Corps to establish the Beach Erosion Board which in 1936 became the Beach Erosion and Shore Protection Board.[22] The Board would then coordinate matters with state level authorities in each coastal state.

Progressive changes of the names of the organizations tell the story. There was an initial interest in "shore and beach preservation". Preservation has many nuances. When the Army entered, the emphasis was clear: "beach erosion". When the title changed to "beach erosion and shore protection", it signaled that the Army had displaced the original Association. The Army's subsequent history on the coasts, primarily devoted to erecting structures to prevent erosion (or at least displace it down the beach) led to the whole enterprise becoming known as ocean engineering or beach engineering. By contrast, consider the title and implicit model of one of Patton's most important research papers on these matters: "Moriches Inlet: A problem of beach evolution". [23] Patton was an evolutionist! But as matters developed, beach evolution turned into beach engineering, and the history of what followed is almost entirely that of the Corps of Engineers.[24]

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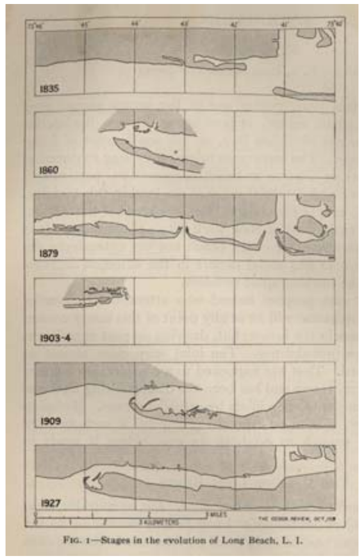
[20] NRC, 1929.
[21] ASABPA, 1928, p.10.
[22] Beach Erosion Board, 1938.
[23] Patton, 193.
[24] See, for example, Wicker, C.F., 1951; Pilkey and Dixon, 1996; Wiegel and Saville, Jr., 1996

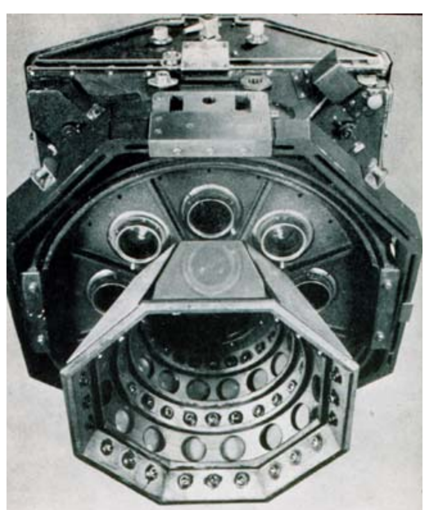


Stages in the Evolution of Long Beach, Long Island 1834-1927

At the beginning of Patton's era, the Survey was producing t-sheets ("t" for topography) and h-sheets ("h" for hydrography) that were produced by equipment and techniques essentially identical to those of Hassler nearly a century earlier. The major differences between the older and newer sheets were the veritable explosion in new innovative technologies that were used to acquire the data mapped on the sheets.

Topography

By Patton's era, topographic surveying was based, almost always, on aerial photography as rectified and positioned by locating control points on the photographs that could be correlated with survey stations and monuments. The theodolites used in establishing the ground correlations were essentially the same as in Bache's era. The photography systems evolved to an apex in Patton's time: the Survey's nine lens camera.



The Nine Lens Camera

The camera, designed by Lt. Oliver Reading of the Survey Corps, was the most advanced photogrammetric camera in the United States at that time. The camera was part of a complex system: the camera matrix, with one large camera in the center, surrounded by eight smaller cameras which photographed terrain off to the side as reflected to these cameras by tilted mirrors; all nine separate images focused by prisms onto one single piece of film, 23 inches on a side. The system then used a special transforming printer, which rectified each of the eight distorted side images, and printed them with the image from the large central camera on one very large paper photograph.[25]

Washington, DC with original negative and transformed print, 1938

The Survey's camera system allowed much larger areas to be photographed quickly and efficiently, which meant more areas could be covered, and also that re-surveys of changes in areas previously surveyed could be made readily. The camera was used, especially, for surveys of enormous areas of Alaska, although that occurred after Patton's era.

Hydrography

There were two new major technologies that transformed hydrographic surveying in the Survey in Patton's era. The first was Herbert Dorsey's fathometer. As was described in the Jones chapter, Coast Survey in and out of the military in World War I worked with underwater acoustics for communications, positioning, hazard avoidance, and submarine detection. After the war, the Survey's first plan for direct application of acoustics was to obtain a Navy-designed acoustic depth finder. That quest led them to the Army Coast Artillery and the National Bureau of Standards, in a collaboration that led to Radio Acoustic Ranging (RAR). RAR used sound transmitted horizontally. That

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[25] Reading, 1935.

still left the quest for a vertically sounding instrument. The Navy's instrument wasn't accurate enough for the standards of hydrographic surveying.

In 1925, through Director Jones' intervention, the Survey had acquired responsibility for federal research in seismology. Jones directed Nicholas Heck out of the Division of Topography and Hydrography to the Division of Terrestrial Magnetism and Seismology. This is possibly closely correlated with the decision of Dr. Herbert Dorsey, a senior physicist and accomplished inventor, to leave his position with the Submarine Signal Corporation working with Reginald Fessenden and come to work at the Survey. He quickly became the chief electrical engineer and chief of the Radiosonic Laboratory. There, he had access to the extensive investigations of the speed of sound in sea water made by Survey scientists in the development of early RAR[26].

Dorsey eventually developed a sounding acoustic instrument that was simple and brilliant. Pulses of sound were emitted directly from the ship. The sound echoed off the bottom would be received with a delay correlated with the double path to and from the bottom. Dorsey figured out how to translate the perceived ocean depth into distances between lit-up parts of the instrument dial, so that crewmen could easily note and record the depth. By changing the frequencies of sound emission using a simple dial, Dorsey's device could sound accurately in waters from quite shallow to quite deep. He had devised a universal sounding machine, which he named the Fathometer[27].

Herbert Dorsey and the Fathometer, circa 1930

[26] See Dorsey, 1932.
[27] See Dorsey, 1935.

The Fathometer was an extraordinary instrument, highly accurate and versatile, and also easy to use. It was so successful that Dorsey's former employer, the Submarine Signal Corp., adopted the name as a general term for echo sounding devices, and the term was in use for decades.

Major progress had been made on the vertical component of hydrographic sounding, but that still left the problem of the horizontal position of the ship. The early work with RAR had been tantalizing, as participants knew they were on the verge of perfecting a revolutionary technology. But, from the beginning, the RAR work on the Atlantic coast, and then on the Pacific, encountered results that were counter-intuitive and difficult to explain. RAR was initially developed and tested in the relatively shallow broad shoals of the Atlantic coast. When the Survey ship *Guide* tested RAR in the Pacific, it was initially thought that the dramatic waves and surf noises of the Pacific would overpower the RAR acoustic signal unless much larger bombs were used. In fact, in the deep Pacific waters, RAR acoustic signals were received at much greater distances than had been the case in the Atlantic. These results were encouraging, but also unsettling, as they indicated how little the Survey, or anyone for that matter, really knew about ocean acoustics.

In 1929, the Survey had been dispatched to survey the Georges Banks, off the coast of New England. The eastern flanks of the vast banks extended nearly two hundred miles offshore from the nearest point of land in New England. In order to position the Survey ships properly, a system of anchored RAR station ships was devised, which then allowed the ships conducting the hydrographic surveys to use the anchored boats as navigation stations and work much farther distances offshore. Unfortunately, this also meant that the anchored boats, often lying under persistent fog cover, were exposed to great danger from collisions with passing ships[28]. Completion of the Georges Bank Survey was accomplished during the field seasons of 1930-32.[29] The completed survey, and the special maps for the fishermen created from the data, to be described later, fulfilled a mandate extending back to the very enabling law that authorized President Jefferson to create a Survey of the Coast: "SEC. 2. **And be it further enacted**, That it shall be lawful for the President of the United States to cause such examinations and observations to be made, with respect to St. George's bank, and any other bank or shoal and the soundings and currents beyond the distance aforesaid to the Gulf Stream, as in his opinion may be especially subservient to the commercial interests of the United States".[30]

The Georges Bank RAR surveys covered vast areas quickly and reasonably accurately, and they also disclosed complex submarine canyons on the outer sides of the banks. But the baffling problems of sound wave paths in the water remained. Given their knowledge of the variation in sound velocity dependent on the variables of temperature, pressure, and salinity, the most probable explanation for the velocities they had measured were that the sound waves traveled to the bottom and traveled across at the bottom, before somehow rising to the surface

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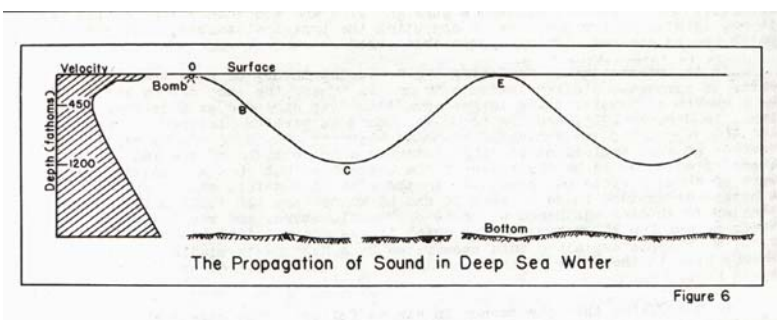
[28] Anonymous, 1932, p. 1.
[29] See Rude, 1932 for explanation of the Georges Bank survey strategy.
[30] Ninth Congress, Act of Feb. 10, 1807, Section 2.

Aaron Shalowitz, who had a long and varied career in the Survey, acted as a theoretician in the enterprise. As he noted, after the 1929 Georges Bank field season was over:

"...I believe it is too early to formulate a definite theory regarding the behavior of the sound wave. It will be time enough to consider these possibilities when we have supplemented our present data with experimental work carried out along certain lines which the investigation has shown is urgently needed.

"For the present, the important thing is that a practical working relation has been established between experimental and theoretical velocities that has enabled us to adopt a definite policy for the work on the Georges Bank. In addition, the study has shown that any assumption that the effective sound wave travels along the surface or close to the surface is wholly untenable. Other than that the investigation should be considered in the nature of a preliminary finding and as laying the foundation for a thorough and comprehensive study, both in the field and in the office, of the whole subject of sound transmission in all its ramifications"[31].

The Survey personnel in this enterprise decided to use, as a natural laboratory for the "thorough and comprehensive study," the deep, stratified basin of Pacific Ocean water between the northern and southern Channel Islands, offshore from Santa Barbara, California. The deep and largely still waters were highly stratified by temperature; meaning that sound would travel fairly uniformly in velocity within each "layer cake" layer of water in the basin. Observers posted with radios on the bounding islands could position the survey ships' horizontal positions easily and accurately, so they would have accurate data about the real distances between the ships, to correlate with the distances derived from RAR distances. They also developed electrically triggered RAR bombs, which could be lowered on cables and detonated at precise depths[32]. Given these, they would attempt to work out, experimentally and theoretically, the velocity paths of the sound in the water.



Recent Acoustic Work by the US C & GS, Paul Smith, 1934

[31] Shalowitz, 1930, p.455.
[32] Smoot, 1935.

What they discovered was that the velocity of sound was at a maximum in the warmer water at the surface, then decreased with decreasing temperature down to a depth of around 450 fathoms (2700 feet), after which, the temperature did not decrease much, but the pressure did, causing sound velocity to increase, eventually to a level equivalent to the velocities in shallow water. Based on this data, and the results of RAR determined ship positions and ranges compared to visual positions and ranges, they then theorized as to how the sound had traveled. This profile of changing velocities would then cause sound waves to refract downward from the surface towards the depths, but turn upwards from the depths back towards the surface, traveling great horizontal distances via refraction around the zone of lowest velocity at 450 fathoms. They had theorized and observed what is now called the deep sound channel of the oceans.[33]

The California research results, assimilated into hydrographic survey practice, led to a literal explosion in survey work in the Pacific and Atlantic Oceans. Following the work in 1934 to fully realize RAR, research shifted to finding a substitute for the dangerous anchored ship-borne RAR installations, as had been used in the Georges Bank survey. Almon Vincent, of the Survey, invented the concept for the radio-sono buoy, which was a buoy-mounted radio repeater that could be anchored off shore and positioned using shore stations. Essentially, the radio-sono buoy automated what had been an installation requiring human supervision. There were difficult technical problems to resolve lasting until about 1936, but eventually advanced RAR, equipped and extended by the radio-sono buoys, was ready[34].

With RAR and the radio-sono buoys, survey ships could position at full speed as much as hundreds of nautical miles offshore, while Dorsey's fathometer could determine depths with great accuracy as they steamed along. This allowed the Survey to map far out on continental slopes and beyond, and also allowed a densified network of soundings that allowed more fine-grained details of submarine geomorphology to be identified. Two experimental nautical charts, one from each ocean, reveal the Survey personnel at the apex of their work in Patton's era.

In 1938, C.K. Green of the Survey published a pair of new nautical charts under production by the Survey, both covering the waters offshore California from San Diego to Santa Rosa Island. Both charts were based on the greatly increased volumes of hydrographic data now available through advanced RAR and the Dorsey fathometer[35]. The first chart, 5101, presented the soundings in the traditional way, and used contouring of depth for the three traditional contours of very shallow water.

[33] The key papers on the Santa Barbara Basin RAR research results are Smith, 1934, and Swainson, 1936.
[34] Borden, MacIlwraith, and Cowie, 1936. pp. 142-149.
[35] Green, 1938.

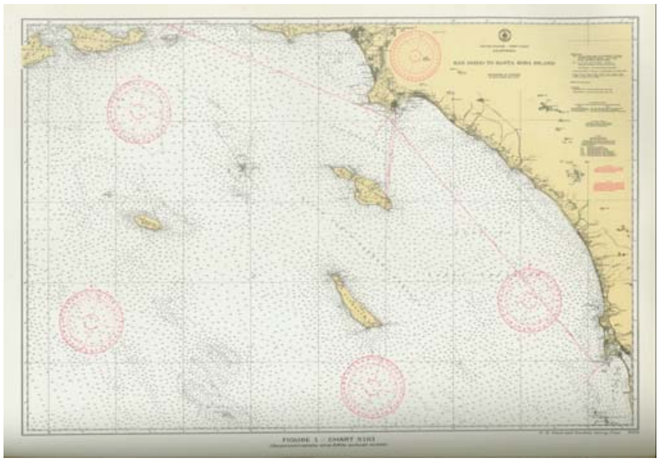


Chart 51010 using traditional hydrographic techniques

The newer chart design utilized exactly the same sounding data, but was contoured with 50- fathom contours through the full range of charted depths.

Chart 5101A contoured bathymetry to the ocean bottom

The submarine topography of the complex ridges and basins is clearly revealed. But what use was complex geomorphology to mariners? As Green, and the chart text makes clear, Chart 5101A was an experimental chart. RAR was a difficult and sophisticated horizontal positioning system based on uniquely specialized equipment mariners would not have access to. But fathometers were becoming common. The Survey proposed that, in far offshore waters, mariners could navigate by changes in bathymetry, roughly positioning themselves by watching the changes in bottom depth compared to the depths on the chart.

Ocean and submarine geomorphology conditions on the Atlantic, as well as new technologies for radio navigation, were very different than on the Pacific. In 1932 and 1934, the Survey published two new experimental charts “for the Fishing Industry” for the vast, fish-filled Georges Banks offshore from Massachusetts. The charts were produced at the suggestion of The Massachusetts Fisheries Association, because “the nautical charts constructed therefrom are lacking in some details desired by the fishermen”[36]. The maps were based on the extensive new hydrographic data acquired in 1929-31 with RAR and radio-sono buoys. As well, there were now radio stations broadcasting signals that could be used by ship-board radio direction finders. The Survey again used depth contours, but in this case, they used color-coded depths, in a schema appropriate for the vast shallow submarine plateaus of Georges Bank. The project was a productive experiment for the Survey, as “for, in reality, what the fishermen actually want is something that combines all the advantages peculiar to both large and small scale charts, and it has been found that complying with their desires is not such a simple matter”.[37]

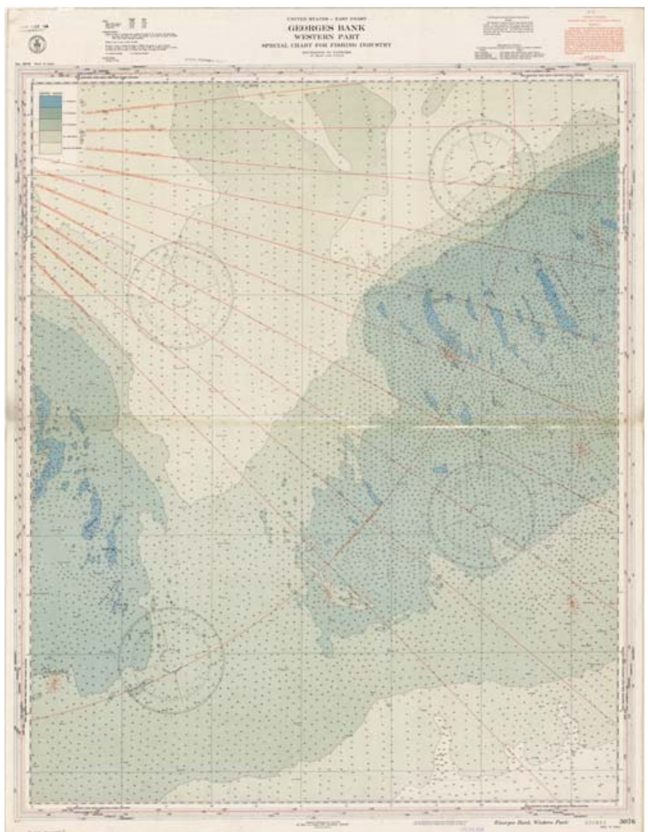


Chart 3076 Special Chart for Fishing Industry, Georges Bank, Western Half

Very prominent in the chart are the incisions of submarine canyons on the margins of the submerged plateau, here delineated in greater detail than ever possible before, because of the combination of RAR and the Dorsey fathomer. Nicholas Heck noted, in annotations to a copy of fine contouring of several of these canyons by Francis

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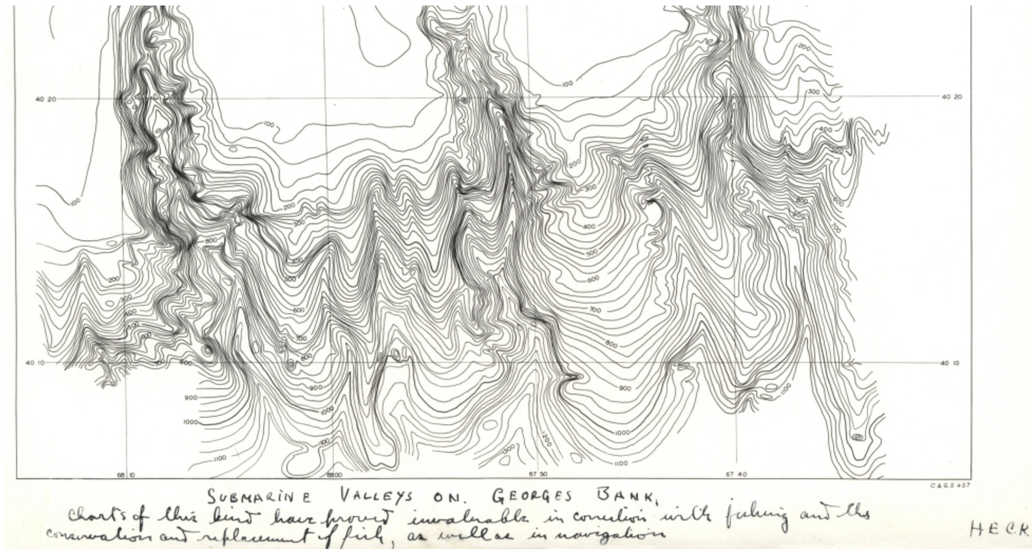
[36] Kirsch, 1932, p. 75.
[37] Krisch, ibid, p. 75.

Shepard, that the increased geomorphological detail might benefit the fisherman in various ways, which was an aim of the project. These charts were also notable for being the first Survey charts ever published with electronic navigation aids—in this case, the configuration of azimuths to various radio direction-finding stations newly established on the New England coast.



Submarine Valleys on Georges Bank
from notes for a paper by Nicholas Heck, 1934

Knowledge of the submarine canyons could benefit fishermen, but they could also benefit earth scientists. As Heck noted: "In geology, not only does the physiographer have a better understanding of what happens to the sediments which constantly leave the land, but the working area of the geologist has been extended to the edge of the continental shelf with accuracy comparable to that obtained on land. The finding of great gorges or submarine valleys has stimulated thought in regard to their possible origin. Accordingly work that was done to aid the needs of the mariner is aiding in revealing the history of the portion of the continent that is at present submerged beneath the sea".[38]

Other scientists, as well, were quick to see the importance of this new data, and where investigations of it might go. ""… the invention of radio-acoustic position-finding and the invention of echo-sounding has made possible the recognition of minutiae of sea-bottom configuration that was entirely impossible only a few years ago."[39] Scientists making use of the new data, particularly the oceanographer Francis Shepard, then passed on the data and its significance to others. "Little by little, however, it was found that such canyons exist also where no connection with a river is possible, and that they are so numerous that most of the continental slopes are notched by several, even by innumerable gullies. A debt of gratitude is particularly owed to the American Shepard for having

[38] Heck, 1935, p. 404.
[39] Vaughn, 1937

directed attention to these most remarkable formations. This investigator arranged that the vast echo-sounding material collected in recent years by the U.S. Coast and Geodetic Survey be put at his disposal….”.[40]

In sum, Patton’s era was one of skilled personnel in a well-managed enterprise, wielding brilliant new technologies, developed both within and without the Survey, which greatly extended Survey data and data products, such as the new experimental charts on both the Atlantic and Pacific coasts, made with new cartographic methods and directed to new purposes. What else was the Survey publishing?

The Division of Charting.

E. Lester Jones had elevated the chart-making operations of the Survey to a separate division, reportable directly to him. Raymond Patton had ascended to be Director from his post as head of the Charting Division. This was an era of great changes and innovations and experiments in cartography and printing, perhaps even greater than the important decade 1850-1860 under Bache.

Perhaps the greatest change in the Division of Printing, and certainly one that enabled so many other changes to take place, was the move of the Division to the new facilities of the Commerce Building in Federal Triangle in 1932. Printing was the very first arm of the Survey to make the move from quarters all over Washington to which the elements of the Survey had been scattered after the ancient warren of buildings on New Jersey Avenue was razed in1928 for the new House Office Building. At Commerce, for the first time in the entire existence of the Survey, almost all the facilities and operations of chart compilation, production, printing, and distribution were together under one roof.

The printing equipment assembled in Commerce ranged from Bache’s original copperplate engraving press, purchased in 1851 and used until well into the Patton era, although sparingly, to lithographic transfer presses to move between engraver charts and lithographs, to new Harris Co. two-color and then five-color offset lithograph presses. The vast proportion of the charts and maps published by the Survey in this era were printed on the Harris offset lithograph presses, just as NOAA charts are to this day.

The printing plates for offset lithography are thin aluminum plates wound around rollers. The images on them are translated photo-mechanically from plate masters which are stable “originals” of the chart. In Bache’s day, the masters were the copper plates themselves which were never used to print directly since the Survey’s development of electrotype plates in the 1850s. In Patton’s era, there were still some copper plates in use as masters, but these would be used only once to pull an impression on a transfer press. That single impression would be used to develop printing plates photographically, which would then be wound on the Harris offset lithograph presses. The major new development in Patton’s time was the creation of stable glass plates which were painted with a dark emulsion which could be scribed mechanically or etched with chemicals to leave lines and dots showing as clear glass against the areas covered by the dark

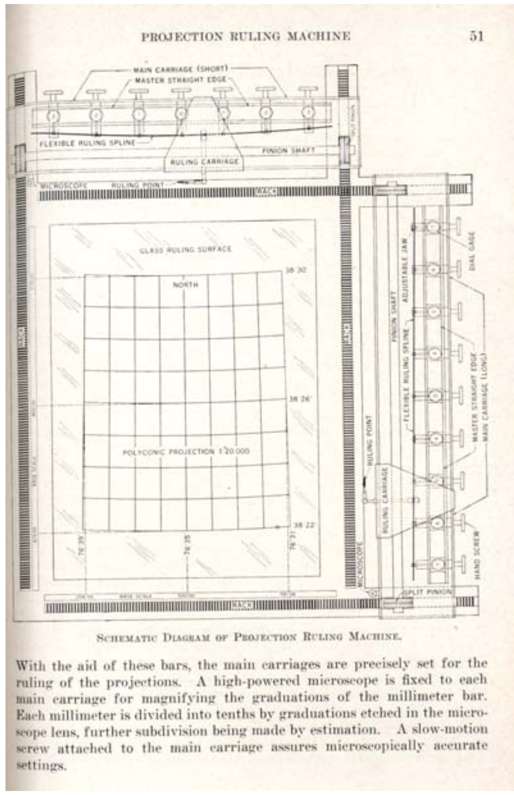
[40] Kuenen, 1939.

emulsion. These glass plates were the new plate masters. When a printing plate was needed, light would be shined through the glass allowing only the clear glass areas to transmit light with the rest of the plate area blocked by the dark emulsion. That pattern of light would be transferred photo-mechanically to the aluminum printing plate; and then off to the presses it would go.

There was one unique machine devised by the Survey to which every map and chart was bound in common. Regardless of the type of chart, its projection, whether it was colored or not, that chart was printed from plates that were designed in a certain projection, with a certain size and map extent, all of which was first calculated and then drawn using the great projection ruling machine.

The Projection Ruling Machine, 1934

Any map, whatever its projection, can be described and bounded by a set of lines, the map's boundaries and graticule, the network of crisscrossing lines (like latitude and longitude), or simply tick marks, which help map users orient and determine their position relative to the map. These lines, except in the simplest cases, are in fact complex curves. Defining and drawing these lines correctly gets to the heart of cartographic production. Survey cartographers devised a system by which the lines and graticules and tick marks of any map in any projection could be scribed accurately and precisely on a stable medium, first a glass plate, and then, eventually, a vinylite plastic sheet. The key to the system was an orthogonal set of two thin steel blades, each of which could be bent into any arbitrary curve with a series of thumbscrews, based on a set of calculations derived from specialized mathematical formulas developed by Survey computers for each projection to be used. Using a scribing pen that followed a path parallel to the curve, any arbitrary line needed could be scribed in the right position on the glass or plastic sheet. Depending on the projection, the steel curves would then be bent to the next curve shape, and the next parallel curve line would be drawn. Gradually, the master frame for the map would emerge. The curves could be fine-tuned to a precision that was, literally, microscopic.[41]



Schematic of the blades and the adjustment system

The projection ruling machine was essentially a universal cartographic resource for the Survey. Projections, geographic positions, and all manner of charting data could be scribed quickly and accurately for many applications, including many outside of chart printing. “Projections are prepared on celluloid for field airphoto reductions, on aluminum-backed drawing paper for cartographic compilations, and on copper plates for chart engravings”.[42]

The Survey published many kinds of maps and charts, but there were four major classes of maps and charts published in this era.

The first class was maps and schematic diagrams for control surveys associated with the horizontal network of NAD27 and graphics associated with precise leveling and the vertical network. The emphasis was on meticulous accuracy, but beyond that, they were not graphically elaborate and were rarely printed in any more colors than black.

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[41] Rose, 1945
[42] Patton, 1935, p. 136

Nautical charts, the traditional cartography of the Survey, could be divided into two large classes. Harbor charts, coastal navigation charts, and charts for inland waterways on the Atlantic coast were developed in the polyconic projection introduced by Hassler in the 19th century. Sailing direction charts, ocean route charts, and specialized charts like the Georges Bank charts for the fishing industry, all of which were much smaller scale charts, were generally developed in the Mercator or Transverse Mercator projections. In some cases, harbor charts and other nautical charts, particularly pertaining to smaller harbors that didn't change very much, were still produced as engraved charts. However, the vast majority of the nautical charts of both kinds were produced by offset lithography. Some were monocolor, but by this time most were chromo-lithographs, with water or areas of specific depth of water in color(s), bright dots to show lighthouse locations, and directed tints to show lighthouse sector of visibility. (Many lights were shielded, so they could be seen only from certain directions around the lighthouse). As well, as was seen with chart 5101A on the Pacific and chart 3076 on the Atlantic, experimental charts allowed more color applied in new ways to be used to provide new or unusual information. In general, there was a close correlation with the arrival of new multi-color Harris offset presses and the use of significantly more color on the charts.

The aeronautical charts developed and changed rapidly in the Patton era. In the beginnings of aeronautical charts under Jones, the Survey inherited a system of airways strip maps developed by the US military. Strip maps extended from one airport to another. As airports developed as hubs, and more maps were needed to describe more routes to and from the hubs, the overlap of strips became inefficient. So, in the late 1920s, the Survey developed a completely different mapping system - the sectionals. These maps looked rectangular, and they tiled to fill the air space of the United States completely. The sectionals were developed on the Lambert conformal conic projection which Survey personnel had first encountered in Europe as the projection used in the map system of the Nord de Guerre, the French military map zone system that all modern military mapping systems are descended from. Similar to a military grid system, the plan for the sectionals was to create a spatial framework and map naming system that would cover all US airspace that was under responsibility of the Survey, and then "populate" the grid by completing maps. The first sectionals were published in 1930, and they were quickly adopted by all pilots.[43]

In Patton's era, the strip maps were phased out and the sectionals came in. To differentiate them clearly from the strip maps, a new name was necessary. By this era, the Survey had been producing nautical charts for almost a century. The Survey dubbed these new maps "aeronautical charts", which soon became their standard name world-wide[44]. The relative novelty of aviation, and the inherent dangers of flying, made a context for aeronautical charts in which there was rapid evaluation and feedback of charts between cartographers and flyers. The maps evolved rapidly, and the many changes in the flying environment, particularly with the introduction of radio direction finding and radio communications, meant that editions of aeronautical charts were updated and

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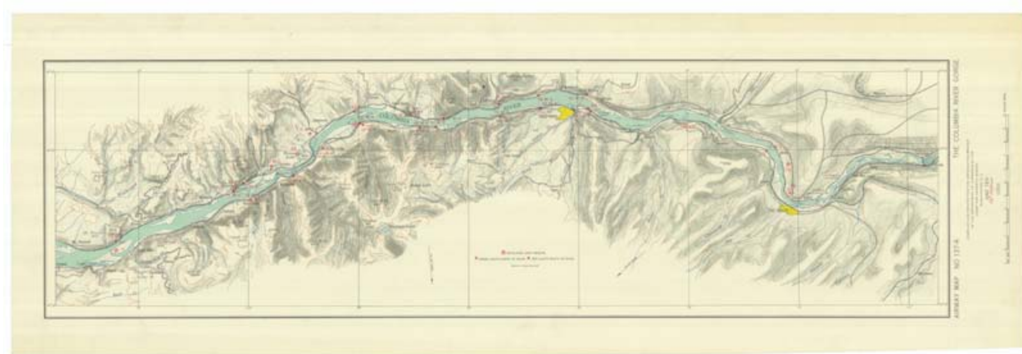
[43] See Ross, 1932.
[44] Ristow, 1960, p. 146.

printed in revised editions in ways unimaginable with nautical charts. As well, given the exigencies of flying in low light or at night, it meant that aeronautical charts carried constraints on colors and visual perception very different from nautical charts. Aeronautical charts started out in multiple colors with many experiments made to optimize chart perception under actual flying conditions. In general, the Survey's aviation cartography was characterized by a tight coupling between map designers and pilots, as innovations were tested, adopted and changed to benefit the pilots better[45]. Many Survey personnel were integral to the aviation charting, but Lt. Paul Smith was particularly prominent in the evolution of the aeronautical charts. The result of all this was that the entire system of aeronautical charts became substantially different from nautical charts, like proverbial apples and oranges.



1932 Airway Map 137A Columbia River Gorge

The final class of maps and charts developed by the Survey in Patton's era were 3-D maps of coastal topography and hydrography produced through the use of John Braund's Reliefograph.

An interest in depicting topographical and hydrographical relief extends through the history of the Survey. Ferdinand Hassler brought with him from Europe a 3-D model of the Swiss Alps around Mont Blanc, and over two hundred years later the model resides in the collections of the American Philosophical Society in Philadelphia. As early as the 1880s, George Davidson had commissioned a 3-D model of topography and bathymetry of western North America and adjacent waters. At about the same time in the Atlantic and Caribbean, Adolf Lindenkohl and others experimented with various methods to display bathymetric depths and profiles. In 1923, the C&GS's Philippine adjunct, the Philippine Coast and Geodetic Survey, had experimented with different plaster and wood 3-D models of the Philippine archipelago showing both topography and hydrography. One of these models had been sent to Washington[46].

John Braund was a Washington-based inventor whose work came to the attention of the Survey. In 1931 Director Patton and Braund signed a contract giving the Coast

[45] Ehrenberg, 2006.
[46] Bureau of Coast and Geodetic Survey, 1923

and Geodetic Survey the rights to make and test one single set of machines that could make 3-D maps by his design while he was in the process of getting his inventions patented[47]. There were two basic assemblies to the process. First, a contoured map was printed on the back side of a thin metal plate. Then, using the Reliefograph, a machinist embossed down the area within the contour area representing the highest relief on the map. The depth embossed was controlled by a device called the altimeter. Then, the second highest contour area would be embossed down. Then the machinist embossed the third, and so on. After all contours were embossed down, the plate was turned over, and what had been valleys were now peaks, corresponding faithfully to the actual heights of the highest relief.

e model—a thin guage aluminum sheet—is formed on the Reliefograph. The "altimeter" is seen on the left.

John Braund"s Reliefograph in Action

The embossed metal plate was then put into the second major assembly of the process. The metal plate was installed, and a very thin metal plate printed with the map on it was placed over the bottom plate. A chamber of hot hydraulic oil was suspended over the top plate, and pressure was exerted on the oil, which warmed and deformed the top metal plate, forming it to fit the 3-D form of the first metal plate below it. Then the hydraulic oil assembly was lifted off, and the top metal plate, now a 3-D printed metal map, was pulled off the press[48]. The Braund 3-D maps were used mainly internally in the Survey in this era but that would soon change, when the war came. As will be described subsequently, after the war a new version of Braund's system was created and patented, using sheets of newly invented thermoplastic instead of metal plates. The second

[47] Braund and Patton, 1931.
[48] Braund, 1936.

generation of Braund's Reliefograph would yield important 3-D maps that played a critical role in visualizing both land topography and submarine geomorphology.[49]

Director Patton Extends and Receives Relief

The activities of the Coast and Geodetic Survey to map the coasts of the United States in Patton's era go back to the original charter of the Survey of the Coast in 1807. But that charter also contained another charge, with a profoundly social orientation, beyond the scope of preparing aids to navigation itself:

SEC. 2. **And be it further enacted**, That it shall be lawful for the President of the United States to cause such examinations and observations to be made, with respect to St. George's bank, and any other bank or shoal and the soundings and currents beyond the distance aforesaid to the Gulf Stream, as in his opinion may be especially subservient to the commercial interests of the United States".[50]

A recurrent theme of Patton's administration is the activities of the Survey in new areas, with new projects, in order to further environmental, social and economic goals of the Nation. These did not begin with Patton, of course—in fact, special projects to analyze harbor sedimentation or establish local control for municipal projects goes back to the days of Hassler and Bache. But these greatly expanded in scope and nature in the 20th century. In Jones' era, there was the special map of the Mississippi Floods of 1927. Under Patton, the subject of beach and shoreline preservation became a major emphasis of the Survey, leading Survey personnel into new kinds of research. The Georges Bank chart "for the fishing industry" is another example of the shift in orientation of the Survey and its activities in direct application to projects with social and economic objectives. It was also the first Survey chart to include radio aids to navigation. And the providential fact that the Survey's Division of Seismology had accelerographs in place and functioning in southern California at the time of the 1933 Long Beach earthquake led directly to a major role in subsequent research in all aspects of earthquakes and seismic engineering in the US.

By far the greatest of these projects undertaken by the Survey in Patton's era was the Survey's response to the Great Depression and the many initiatives of the Roosevelt Administration to re-employ unemployed workers and direct them to socially productive tasks. There were many elements to this, as the crisis developed and, over time, the federal government created and evolved responses to it. But by far the greatest project the Survey was involved in was the Local Control Surveys Project. The project began in 1933, when the Survey was approached by the Federal Emergency Relief Administration, and asked to develop a program for productive work for unemployed persons with enough education and engineering background to be able to perform skilled surveying work quickly after appropriate training.

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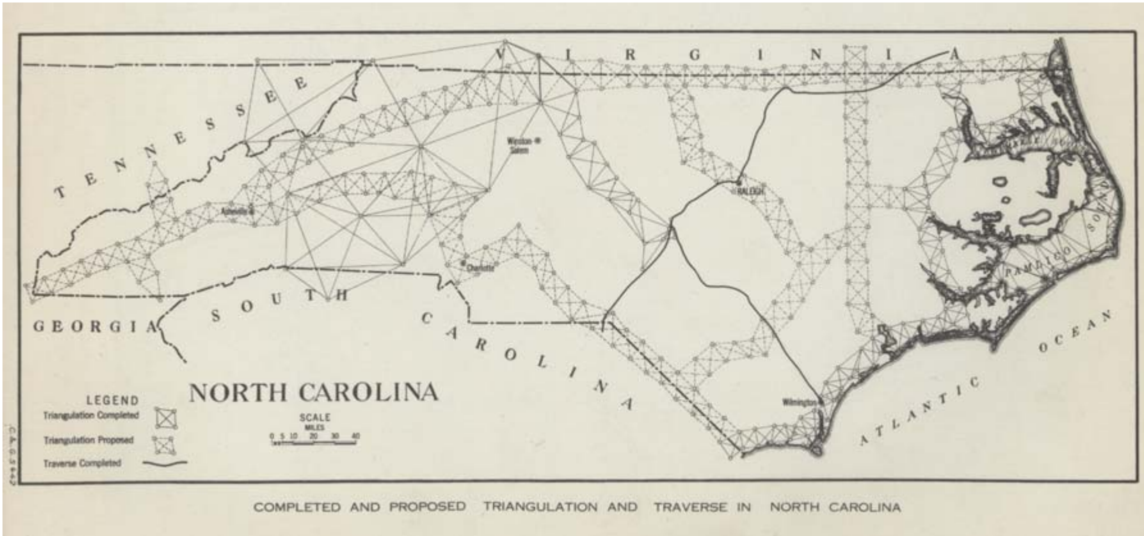
[49] Wilson, 1949: Rosen, 2005.
[50] Act of Feb. 10, 1807, Session II, Ch. 8, 2 Stat. 413-14 (1807)

C & GS Crew and Camp, Mojave Desert

In some ways, the task was a perfect match for work related to projects the Survey had been working on for a long time for completely different purposes. NAD 27 was completed in1927, but was begun over a half century earlier. Shortly after NAD 27 was completed, George Syme, the Senior Highway Engineer of the state of North Carolina, approached the Survey with a proposal for intensified triangulation and leveling by Survey parties in the state, which would then be the "skeleton" upon which a state-organized triangulation network would be developed, with particular reference to developing the system of highways in the state. Syme had, in 1932, been elected to the Executive Committee of the Surveying and Mapping Division of the American Society of Civil Engineers, and the new North Carolina project received national notice. As Syme noted, the funding for the project, which involved substantial funding from the state legislature for both Coast and Geodetic Survey work and work by a new state-level survey, was justified by the legislature from "a strictly highway point, although it was, of course, cognizant of the tremendous profit that would accrue to other state departments, counties, municipalities, corporations, and property owners".[51] Further, Syme noted that the new state triangulation network could serve as a foundation for a much larger enterprise. "Possibly some sort of general mapping agency, armed with the necessary authority but not connected with the Highway Commission will be set up at Raleigh to serve as a clearing house... since the geographic position of each control station will be known, plane coordinates will be used in our future surveying and mapping operations...".[52]

[51] Syme, 1932, p. 26
[52] Ibid., p. 27.



The Actual and Proposed Survey Network for North Carolina, 1932

Here Syme developed the idea, originally presented in 1921 by the Survey's chief geodetic computer Walter Reynolds, for a system that could correlate a plane coordinate system for "the survey of a city, town or county" with geographic positions from the Survey's networks.[53] Syme proposed developing a set of plane coordinate systems at the state level, which could then be used by smaller entities within the state. Thus developed the "modern" system of state plane coordinate systems in which latitudes and longitudes of points throughout a given state could be transformed into plane rectangular coordinates on a grid[54]. In many cases, the size and/or shape of the state would require a set of different zones, each with its own grid system. Further, the plane coordinate systems involved cartographic projections for the specific zones of the state. There were two principal projection systems, the Lambert conformal conic for areas trending east-west, and the transverse Mercator projection system, for zones trending north-south. Appropriately, the state of Florida used both. Survey geodesists and computers worked out how to coordinate geodetic coordinates with state plane coordinates, and then began to apply the system to specific states. North Carolina's pioneer system was completed in 1933. Soon every state had a developing plane coordinate grid system.[55]

The new infusion of unemployed persons with some technical background could then be immediately deployed to projects involving all states that were already underway, but at a lower level of activity. A full description of the activities of the project is beyond the scope of this history—there were stops and starts, and a bewildering number of program name changes (the classic "alphabet soup" of the Roosevelt Administration). But, in sum, despite many challenges, a great extension of local control projects and

[53] Reynolds, 1921, p. 5.
[54] In the 1890s, the state of Massachusetts developed a very different model for plane coordinate systems, which eventually was abandoned, and subsequently Massachusetts adopted the new "North Carolina-type" system.
[55] Smith, 1997, p. 197.

precise leveling surveys and other projects which involved survey crews in the field, and also offices full of computers, stenographers, clerks, and accountants. At its height, the Project employed over 10,000 previously unemployed people, people "among a class not reached by other work relief measures," of whom about 75% had had some college training. For those employed, and for those affected by the quality of the local control surveys, the project was a success. It was also a success for the Survey, "acquainting the engineer with the fact that accurate surveys can be obtained when using ordinary surveying equipment ... if certain precautions are taken".[56]

As the Depression deepened, and as the Roosevelt era took hold, many other divisions of the Survey took part in extending Survey work to skilled and semi-skilled unemployed people. Lt. O.S. Reading, the developer of the nine-lens camera, was dispatched to New York City in 1934 to organize a map compilation project based on rectified aerial photography to be worked by unemployed engineers. Reading saw at once that none of them had any background in cartography or surveying.

> "But I still have a hollow feeling around the diaphragm when I think of those men. Clean-cut, intelligent engineers who had been earning three hundred to a thousand dollars a month before the depression. There were also some youngsters, a couple of years out of college, with Phi Beta Kappa keys, all facing a world that had no use for their services. They did not say so at the time, but I learned from later questions that all had long since given up their telephones, and most had seen their life insurance reserves dwindle away. Some had no other means of support for their families except twenty-five dollars every other week for relief "made work" furnished by the City of New York. Since none of the men were specially qualified, I finally selected those men who needed the work most and could show by designs of bridges, yards, and building plans they had drawn up in previous years, that they were passable draftsmen".[57]

And so the maps were compiled, and the triangulation and leveling networks advanced overland, and the computers calculated endless tables, and the people progressed. Reading spoke for much more than his specific project when he noted: "But the most important lesson of all is that, given the procedure just described, there are thousands of engineers walking the streets looking for work today who could make during the next few years a beautifully complete and accurate large-scale map of this country; a map we are not likely to have for decades to come if this opportunity is wasted"[58].

Midway through his term, Director Patton became ill. He persevered, but eventually was overcome and died in office in 1937. Six years before he died, he had published a paper on his great focus, coastal preservation. It was an analysis of Moriches Inlet and the evolution of Long Beach, on the southern shore of Long Island. In a certain

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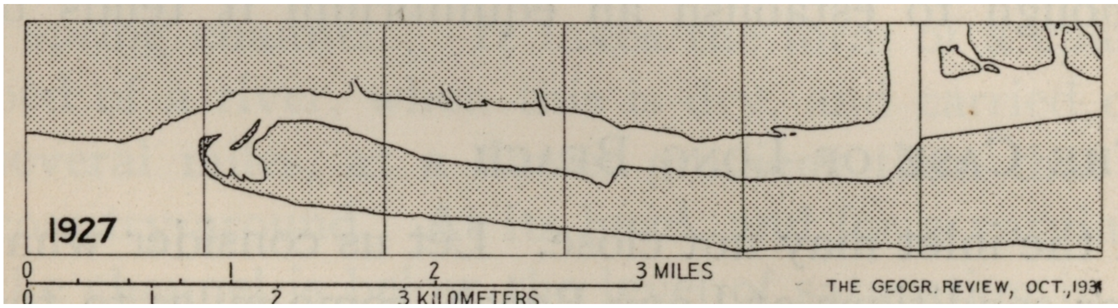
[56] Hemple, 1934, pp. 17-19.
[57] Reading, 1934. p. 118.
[56] Ibid., p. 119.

manner, Patton’s paper condensed the entire history of the Survey. Much of the analysis was based on repeat surveys of the shore prepared by the Survey. The most recent survey was in 1927, using aerial photography and lead-line soundings and wire-drag. The oldest data in his analysis came from the very beginnings of Hassler’s topographic and hydrographic field work for the Survey of the Coast.



Moriches Inlet and Long Beach, 1927, in Patton, 1931

S**urvey of the Coast, topographic sheet T-3, 1835**

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Leo Otis Colbert (1937-1941): The Survey on the Eve of War

"It seems silly to talk about science in general when the world is burning up"[1].

The Coast and Geodetic Survey was a profoundly civilian organization, as NOAA is today. Nevertheless, its two greatest transformations were the total mobilizations of the Survey for war; the Civil War under Bache, and World War II under Colbert. Colbert served as leader of the Survey for 13 years, but he is mainly remembered as the Survey's director during the four years that the United States was at war.

Nevertheless, his service must be framed by the important developments in the Survey that preceded the war. It was a very difficult, yet creative period. The country was still mired in the Great Depression, and the Survey's ranks remained swollen with staff hired through the government's work aid programs, performing work that in many cases was quite different from anything the Survey had done before. Yet at the same time, tensions were rising in Europe, and it was increasingly apparent that conflict on an international scale was coming.

Leo Otis Colbert (1883-1968) had a unique career, but it was also quite similar to the careers of many other officers in the Commissioned Corps. Colbert was born in Cambridge, Massachusetts, and graduated in engineering from Tufts University in 1907. He joined the Survey later that summer and remained with the Survey for the next 43 years. From the beginning he was drawn to service aboard ships. He rose through the ship commanding positions, serving in virtually every part of the planet where the Coast and Geodetic Survey worked, including the waters of Alaska and the Philippines, soon to be arenas of war.

Colbert's skills as a ship's officer were developed in all waters the Survey sailed in, but particularly in the Philippines. One of his first commands as a Captain was aboard the ship Fathomer serving from the base of the Coast Survey of the Philippines in Manila. The difficulties of Philippine service ashore led to a unique situation: the wives of Survey officers could accompany their husbands living aboard ship while their husbands were on duty. The women developed uniforms worn aboard ship, a unique development. In this regard, the Survey was a true pioneer; for the US military, it wasn't until World War One

[1] Letter from Paul A. Smith to Commander R.R. Lukens, Feb. 11, 1941. See Smith materials.

that women were officially associated with the services and allowed to wear their own uniforms.[2]

Captain Leo Colbert and his wife Florentine aboard the Fathomer, off Cebu, the Philippines, 1912.

When the US entered World War One, under the program that Superintendent Jones developed, Colbert transferred to the US Navy as a Lieutenant Commander, serving as the officer in charge of navigation of the troop transport ship USS Northern Pacific. In the 18 months of US service in the war, his ship made 9 round trips between New York City and France sailing through submarine-infested waters. After he mustered out of Navy service, he received a certificate as a Master of Steam Vessels, Unlimited Tonnage, Any Ocean.[3]

Colbert returned to the Survey as part of the first group of officers in the Survey's Commissioned Corps, and he remained in the Corps until he retired. He served as

[2] See Vining and Hacker, 2001.
[3] Anonymous,The Buzzard, 1950.

Director from 1938 to 1950, so he was the Survey's leader in World War II and the early Cold War. Like his predecessor and mentor Raymond Patton, he commanded ships, but then transitioned into office work leading the charting division, and especially aeronautical charting. Patton became the first Rear Admiral of the Survey, and Colbert was the second.

Colbert's Term as Director of the Coast and Geodetic Survey

Colbert's pre-war directorship (1937-1941) began with a smooth, albeit sad, transition following the death of Director Patton. The major activities of the Survey did not change. The Survey's ranks remained at high levels with new personnel hired through the WPA and other federal programs to create productive work for unemployed Americans with the requisite skills to complete the kinds of work the Survey performed; and the Survey continued to use and improve a key set of new technologies, most of them begun or imagined under the direction of E. Lester Jones, and completed under Patton.

Division of Geodesy

The Division's activities in the pre-war period can be divided into two parts, directed mainly within the continental United States, or directed to the rest of the world. First Survey personnel worked on densification and 'in-filling' work within the United States, in which monuments and buildings and dams, etc. were positioned horizontally relative to the Survey's North American Horizontal Datum (NAD 27) and vertically relative to the Vertical Datum (NAD 29), as well as the growing system of state plane coordinate systems, as well as more specialized datums for cities and counties[4]. Second, Survey members worked on the projection and extension of the Survey-designed US Military Grid System outside the country as the World Military Grid[5]. The World Military Grid, like the North American prototype, divided the world in between the high latitudes into north-south zones about 7 degrees of longitude wide. For each zone, the Survey computed, using staff from the WPA Mathematical Tables Project, the specifications for special maps using Hassler's polyconic projection. These maps and projections were to be used for a variety of military applications. It isn't clear how much use the system received in the war, but another Survey map projection system, for the World Aeronautical Charts, to be described later, was used extensively by Allied air forces and continues to the present as the standard system for global aeronautical charts.

Division of Tides and Currents

The Survey's involvement with coastal geomorphology and coastal engineering declined under Colbert for two reasons. First, Director Patton had been the major expert and champion of the new work, but he died. Second, the Army Corps of Engineers and

[4] See Adams, 1937; Meanie, 1937; Bowie, 1938; and Colbert, 1940.
[5] See Corps of Engineers, War Department, 1941.

its Beach Erosion Board dominated the entire subject as it continued to do until the rise of the postwar environmental movement.

In terms of the traditional activities of Tides and Currents as such, the major activities were, as in other parts of the Survey, continuous improvement in new and traditional technologies with a recurrent theme of "automating" equipment that recorded continuous data so that the data could now be transmitted automatically by telephone or radio signals. The inventive Survey instrument designer Douglas Parkhurst perfected a new lightweight portable tide recorder which would soon prove useful in wartime science—and post war would be absolutely foundational to the Survey's postwar tsunami warning system[6].

Division of Topography

The Survey's 9-Lens Camera, developed in Patton's era, allowed vast areas of land to be photographed and rectified to photographic prints with very little distortion. It had numerous applications in terrain reconnaissance and for photo-mapping very dynamic environments such as US cities. This was highly desirable, especially in a prewar context, in which the US was beginning to realize how little of the national territory had been adequately mapped for various purposes and at various scales compared to European nations[7].

However, by its nature, the 9-Lens Camera was not really a topographical instrument as such. Instead, vertical aerial photography, obtained with stereo overlap, was the major data source for photogrammetric mapping by all US military and civilian agencies. There was a major convergence in techniques and equipment at work, not just in the United States but the rest of the photogrammetric world. The American Society of Photogrammetry was founded in 1934; the first article in its first News Notes was a paper on proposed activities for the Society, written by Lieutenant O.S. Reading of the Coast and Geodetic Survey, the major developer of the 9-Lens Camera[8]. Here, and everywhere, Fairchild cameras and the Zeiss multiplex camera, and mathematical models for rectifying topographical distortion, were creating literal mountains of topographic information.

But how could topography be best displayed? Here, the early investment of money and interest in John Braund's Reliefograph, made by the Survey under Patton, was beginning to yield dividends.

[6] See Parkhurst, 1938.
[7] The report published in the Military Engineer by the Secretaries of War, Commerce, and Interior, 1939, is a careful description of the state of the problem, as they saw it, and their strategies to address the lack of adequate mapping in a rapid yet coordinated way.
[8] See Reading, 1934.

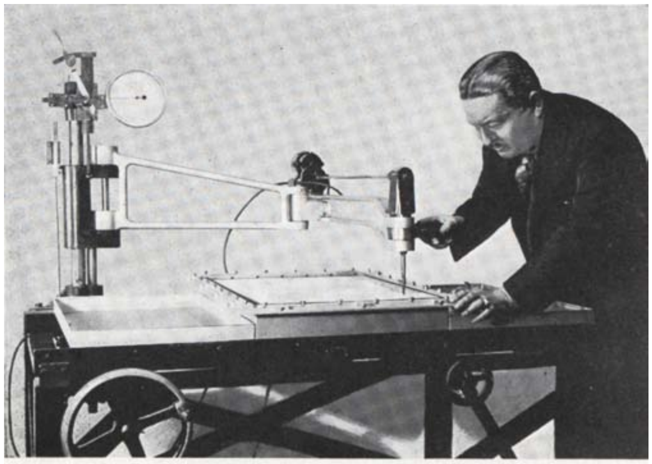


Figure 3. Braund Reliefograph

John Braund (possibly) demonstrating the Reliefograph embossing machine to create the master plate

There were two critical sub-systems to the Reliefograph process that made it superior to traditional methods of defining and detailing vertical relief. First, it offered a carefully controlled method of turning topographic contours into a physical 3-D master plate. Second, using Braund's system and the Survey's excellent map printing systems, a finely detailed multi-colored map could be printed on flat stock and then molded using the Braund master plate and pressure to create a 3-D model that retained all the cartographic information from the printed map. On the eve of the war, the reliefograph system offered a superior and cheap way to make many multiples of terrain models of the kind that would be critical for the war[9].

Division of Hydrography

These technologies, described in detail in the Patton chapter, include a suite of technologies for hydrographic surveying including steady incremental improvements to wire drag, Radio Acoustic Ranging (RAR), the Radio Sono Buoy, taut-line winches for establishing hydrographic baselines, and various models of Dorsey fathometers or echo sounders. During Colbert's term, though, a new Dorsey fathometer, the model 808 was developed. The 808 had three important "breakthrough" characteristics: it was small and light weight, so it could be used from a survey launch, it was accurate in very shallow water, as well as deeper water, and finally, it was the Survey's first recording fathometer. The 808 would prove indispensable in hydrographic surveying from the tropical Pacific waters to the Aleutians during the war.

[9] See Blee, 1940.

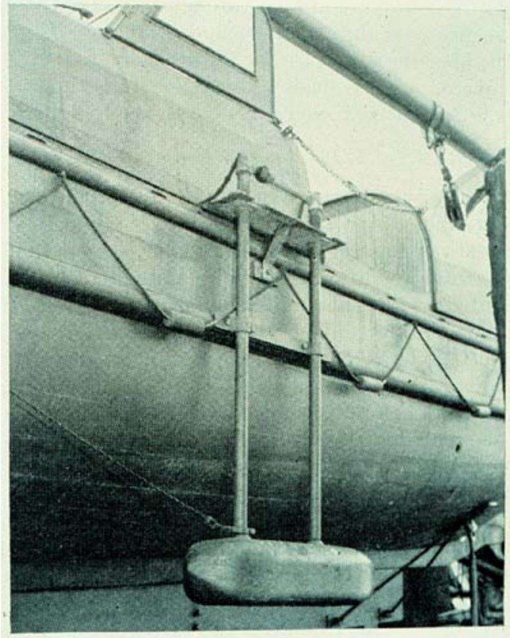


FIGURE 101.—Fish of 808 Fathometer mounted on hydrographic launch.

Dorsey Fathometer Model 808

The combination of the great extension of accurate horizontal positioning on the sea surface offshore, from the convergence of RAR and its ancillary technologies with the accurate and precise vertical depth profiling with the Dorsey fathometers, now extended the Survey's hydrography past the Atlantic continental shelf and thereby brought their major hydrographers into a fruitful and historic period in global geology. Chief amongst these in the prewar period was Lieutenant Paul A. Smith, who used the new Survey technologies to great effect in this period, before shifting his attention and considerable cartographic skills to aeronautical charting during World War II.

Paul Smith had an older friend and mentor in the Survey, Commander Richard Lukens, who was mainly posted to work in and around the Pacific. Paul Smith preserved copies of his major correspondence with Lukens during the critical pre-war period, which were later donated to NOAA by Smith's widow. Smith's lively intelligence comes through with great candor.

> "This job is an interesting one. Most of our work is in the comparatively shoal regions off Delaware Bay and northward of that. Later in the season we may go up to the deep work off the south shore of Long Island. I once thought the shoal regions of the shelf were relatively featureless and monotonous, but with the Dorsey no. 1 fathometer reading to about a tenth of a foot, there is such a wealth of detail as to make plenty of work for chart makers, if we wish to prepare charts with enough depth curves on them. I suppose with this, the need for this most reliable

> method of navigation[10] will become recognized. Even now we have the data to publish charts which would be infinitely more valuable than those we now issue. The problem of cartography – to show the information without a radical transition from the old to the new is really all that should cause any heavy thinking"[11].

The "deep work" off Long Island brought Smith into collaboration with the great, and elderly, geologist A.C. Veatch, whose studies of Long Island dated back almost 40 years earlier.[12] Veatch had become interested in the geology of submarine valleys or canyons. Together, the two scientists created a monumental publication on submarine valleys on either side of the Atlantic Ocean, which also turned out to be Veatch's last major enterprise, as he died before publication was complete[13]. Interestingly, the co-authors single out for special praise Rear Admiral Colbert: "… he, more than any other man, made it possible to carry out the work".[14] Colbert had commanded the Oceanographer during the submarine valley surveys, and he oversaw the work to make RAR work as accurately in the Atlantic as it had in the Pacific.

Submarine Valley of the Hudson River and topography offshore from Long Island. Veatch and Smith, 1939.

[10] Smith was referring to navigation by bathymetry, in which the ocean depth below the vessel, continuously displayed by the fathometer, was correlated with bathymetric charts to determine the ship's approximate position.

[11] Letter to: Commander R.R. Lukens, June 2, 1938.

[12] See Veatch, 1903.

[13] See Veatch and Smith, 1939.

[14] Ibid., p. xi.

The publication was a major contribution to the subject of the geomorphology and mechanisms of ocean basins. It was also the arena of major cartographic innovation by Paul Smith. Smith adapted newly available sheets of near-transparent celluloid to the process of making camera-ready separates for the plates used in color printing of the map. Multiple layers of celluloid could be overlaid and combined, then re-photographed for other plates. The innovation shortened the plate-making process considerably. As Smith explained to Lukens two years afterwards:

> "Alaska came first [Smith is here referring to multi-color aeronautical chart production covering Alaska], and thanks to experience with a scheme which I used in compiling one of the GSA charts on celluloid two years ago we have been able to cut the time of production of these charts in half or better. Even so, I can see no end to our headaches for at least two years to come"[15].

By 1941, Paul Smith had directed his considerable skills away from hydrography to another cartographic arena entirely. That would become all consuming, for him and the Survey, for the duration of the war.

Division of Charting

Publication of Survey maps and charts by the Survey itself began in the 19th century under Bache. In the 20th century, E. Lester Jones had elevated charting to the status of a division itself answering directly to the office of the Director. Jones' successor, Raymond Patton, had been head of the Charting Division, as was Patton's successor Leo Colbert. Clearly, cartographic production and printing had become increasingly important in the suites of activities of the Survey well before the war came. Why was this?

First, nothing succeeds like success. Under Jones the Survey had finally acquired offset lithograph presses from the Harris Company, and the successors of these presses, also from the Harris Company, are still used to publish NOAA charts in the 21st century. The application of photography to cartographic production and printing, pioneered under Bache, continued and accelerated under the direction of Jones and Patton and Colbert. And the projection ruling machine, described in the Patton chapter, in conjunction with the mathematical models and projections of the computers of the Division of Geodesy, allowed maps and charts in virtually all projections, covering all parts of the world, to be developed. As a result, a cascade of new multi-colored lithographed maps flowed from the presses in the basement of the Commerce Building. These new maps attracted new users and customers who in turn stimulated other new users.

[15] Smith to Lukens, February 11, 1941.

Second, the Survey's cartographic production helped fill the holes in national map production in the prewar period. In 1925, as a part of the same federal mobilization in surveying and mapping that led to the Survey's assignment to produce civilian aeronautical charts, the Temple Act mandated a complete topographical survey of the United States to be completed within 20 years. Sufficient funds to accomplish this were never provided. Nevertheless, as Paul Smith pointed out, the necessities of air navigation required the Survey to develop a cartographic model of the entire country adequate for civil aviation. Once the Survey shifted from the airways strip maps to the system of space-filling maps for the country called the regionals, the topography of the whole country had to be defined adequately enough for the scale of the maps and the necessities of aviation. As Smith pointed out, when the initial series of the Regionals, 87 maps at 1:500,000 scale, had been completed in 1937, the main goal of the Temple Act had been achieved by other means. "...it may be said that the Sectional Aeronautical Charts provide the only available topographic map of the entire United States on so large a scale"[16].

An experimental regional aeronautical chart, the Seattle section, without the usual radio corridor overlay markings, 1940.

Third, well before the war, the Survey had already become the largest supplier of maps to the US military itself. As Director Colbert wrote in 1939:

> "The essential nature of accurate charts and maps for naval and military operations is axiomatic. The extent of this service in peacetime is illustrated by the fact that each year the Bureau supplies the Navy Department with over 100,000 nautical charts, constituting abut 30 per cent of the annual output; and the air services of the Army and Navy utilize over 200,000 copies of aeronautical charts, approximately 72 per

[16] Smith, 1940, p. 324.

> cent of the yearly production. A considerable number of the latter are supplied with an overprint of special information required for military purposes".[17]

Therefore, well before the war, the Survey had shifted substantially in its cartographic activities to serve national military needs. This would only increase as the global political situation deteriorated. As Colbert also noted:

> "The Survey constitutes a valuable adjunct to our armed services. In time of national emergency its materials and highly trained personnel are available on short notice, either to carry on its regular activities, as required to meet naval and military needs, or to perform specialized duties as part of combatant forces. Experience shows that the facilities of the Bureau can be used to advantage in both respects"[18].

As the national emergency developed, the demands of aeronautical chart development and production seemed paramount, as the coming war was a world war that would be fought in the air in ways unimaginable compared to the use of airplanes in the last world war. Yet still there was an interplay between all the types of maps and charts the Survey produced. Specifically, major progress in nautical charting in Colbert's prewar era was driven by the idea that ships could navigate by depth finding if the ships were given access to well-designed maps populated by the enormous quantities of depth information that RAR and the Dorsey fathometers provided, so long as that data was represented cartographically in a manner that made the data useful and accessible to mariners. The Survey's nautical chart no. 5101A, the first published Survey chart designed for bathymetric navigation, covered the California seas offshore from Santa Rosa Island to San Diego. It was first presented in a paired contrast with a chart derived from the same dataset yet presented in the then "traditional" style for a nautical chart[19].

[17] Colbert, 1939, p. 398.
[18] Ibid., p. 400.
[19] See Green, 1938.

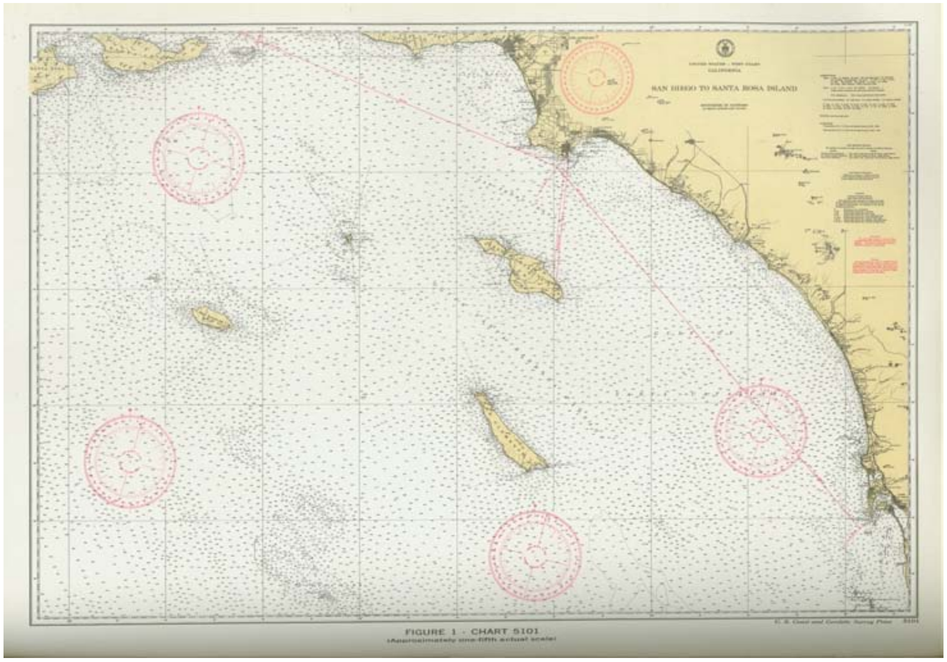


Chart 5101, San Diego to Santa Rosa Island, 1938

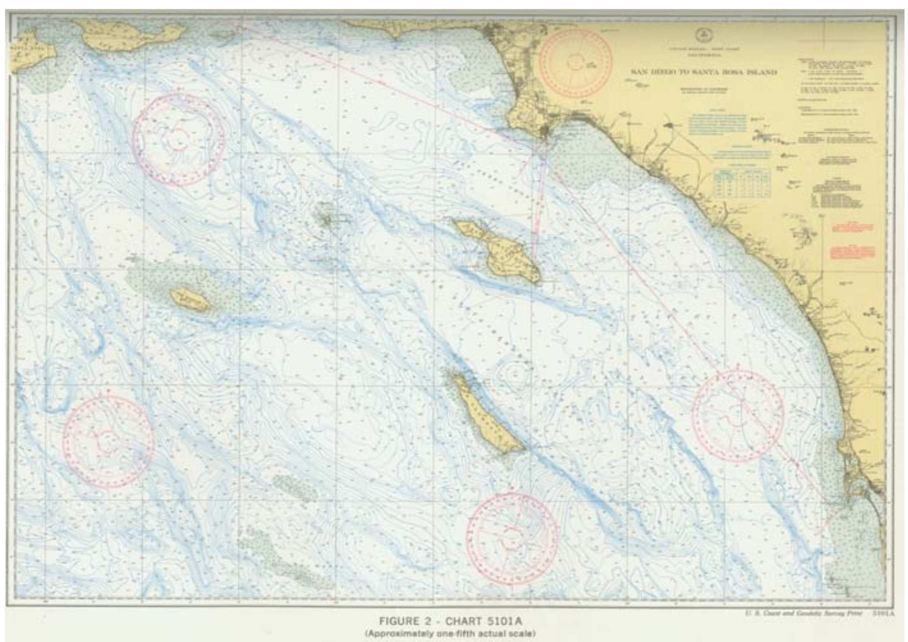


Chart 5101A, San Diego to Santa Rosa Island, 1938

As it turned out, surface navigation by depth finding was made obsolete by radio and electronic positioning systems developed during the coming war. Yet the technique had so much promise in the prewar period that the application even influenced approaches to aeronautical chartings. As Paul Smith noted to his mentor Lukens:

> "The method of navigation by echo sounding has a potential field in aeronautical navigation, especially since development of the "terrain clearance indicator". This, as you probably know, is essentially a "depth finder". Kay, our flight checker, recently volunteered to be taken aloft with a U.S.G.S. quadrangle sheet and a terrain clearance indicator, and altho completely shut in from seeing the ground around the plane, and without any other means of position finding, accurately kept track of the plane's course over a considerable trip. This is probably somewhat confidential information, so you can use your own judgment about repeating it. Bell Laboratory engineers were quite astonished at the possibilities it offers. I mention it here to show that nautical navigators are not the only ones who will have need for such principles and charts".[20]

But of course, for such an approach to work for a given area on the ground, the cartographers would need detailed topographic information about the ground. This would prove challenging as the Survey moved "offshore" in its mapping in anticipation of the conflict. As Smith noted again to Lukens two years later:

> "The nautical world has charts of a usable quality or plates from which nautical charts can be printed in a reasonable time. Imagine, if you can, an air corps their ideas and plans to cover at least a hemisphere, and parts of the other hemisphere shouting suddenly for aeronautical charts right now. The realization that you cannot buy time in the matter of charts is dawning on those officers, but it is up to us to exhaust our ingenuity to produce charts in the minimum of time". [21]

The Time Comes

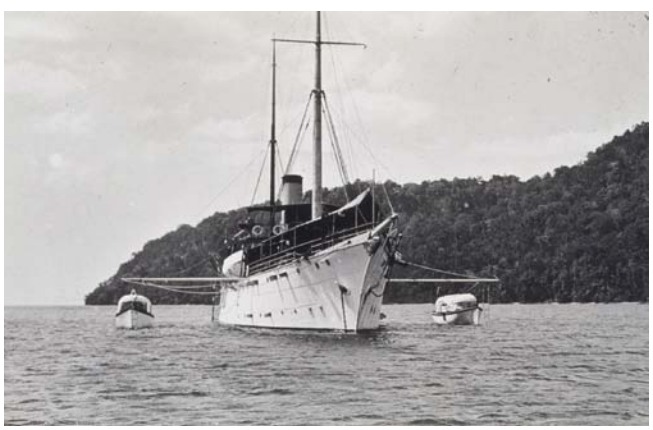
By 1940, Survey officers and other personnel were integrated into direct service in various military units, and the fruits of their work were adopted for military use. The third revised edition of Thoburn Lyon's manual *Practical Air Navigation*, which was Survey Special Publication No. 197, was adopted as a standard text at Randolph Field, the main training base of the Army Air Force[22]. Comparably, Captain Gilbert Rude's guide for maritime celestial navigation, Rude's *Star Finder and Identifier*, was acquired by the US Navy Hydrographic Office. Rude had developed the concept while serving in naval military service as navigation officer of troop transport ships in World War I. In 1921 he patented the key concepts for the guide, which was to position the 55 major navigation stars on a star base of a stereographic projection with "cooperative transparent celluloid templates constructed for various degrees of latitude"[23]. These guides by Lyon and Rude, both civilian scientists in the Survey, proved indispensable to thousands of soldiers and sailors in the war.

[20] Smith to Lukens, November 18, 1939.
[21] Smith to Lukens, February 11, 1941.
[22] Lyon, 1939.
[23] Rude, 1952, p. 20.

Also in 1940, commissioned Survey personnel including Albert Hoskinson, Jeremiah Morton, Carl Aslakson, and William Russell were assigned to US Army Artillery training facilities in Fort Bragg, North Carolina. Later in 1940, Hoskinson and Russell were assigned to Fort Benning, Georgia, and then Hoskinson was sent to Fort Sill, Oklahoma in charge of the Field Artillery Survey School. Out of his lecturing at these bases, he wrote "Outline of Survey Notes for Field Artillery Use", which distilled and simplified geodetic surveying and precise leveling techniques and equipment used by the Survey for use in positioning and aiming artillery. His publication, like Rude's and Lyon's, became an indispensable aid.[24]

In other fields as well, scientific instructional manuals originally developed for "in-house" use by the Survey were quickly published or adapted and re-published on the eve of the war. One was Paul Schureman's manual on harmonic analysis and tide prediction, originally published in 1924, but revised and republished in 1940[25]. Another was Deetz and Adams' Elements of Map Projection with applications to map and chart construction, originally published in 1921, but revised and republished many times, especially the 1938 republication.[26]

Survey ships and men were dispatched for special hydrographic surveys in anticipation of the conflict. Under Lieutenant Charles Pierce, USC&GS, the *Pathfinder*, which had been renamed the *Research*, after a period of inactivity in the 1930s, was used to survey Mariveles Harbor across from Corregidor Island in Manila Bay on Luzon in the Philippines. At this point, the ship was in its fourth decade of service in that nation.



The Pathfinder at anchor in the Philippines, 1911

As the United States scrambled to muster resources to Great Britain while still remaining out of the war, some artful exchanges occurred. The US traded 50 destroyers to the United Kingdom in exchange for access to naval bases on British possessions in the Caribbean. The hydrographic surveying ships *Oceanographer, Hydrographer,*

[24] Hoskinson, 1941.
[25] Schureman, 1940.
[26] Deetz and Adams, 1938.

Lydonia and *Gilbert* were sent to the area in November to survey the bases and their environs.

Back on the Pacific, in November, 1941, the *Explorer* was dispatched to Midway Island for special surveys for the Navy. Following completion of that survey, it was en route to Johnson Island when Pearl Harbor was bombed on December 7, 1941, the day that will live in infamy. It is probable that the Japanese fleet passed within 300 miles of the *Explorer* prior to its departing Midway. The *Explorer* was diverted to Honolulu instead. Manila was bombed by the Japanese on December 8. Later Commander Cowie, the leader of the Survey in the Philippines, was killed in another bombing raid that fateful December. And, during the month of crisis, the *Research* (formerly the *Pathfinder*) was lost in Manila Bay.

Meanwhile, a new Coast and Geodetic Survey ship had been under construction at the Lake Washington shipyards at Seattle since February, 1941. It was launched on January 11, 1942, barely a month after the bombing of Pearl Harbor. Eleanor Roosevelt Boettinger, grand-daughter of President and Mrs. Roosevelt, christened the new ship—as the new *Pathfinder*. The U.S. Coast and Geodetic Survey was now at war.

The Launching of the Pathfinder at the Lake Washington shipyard in Seattle, Washington, 1942

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