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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 Celest*e[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

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[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

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[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.

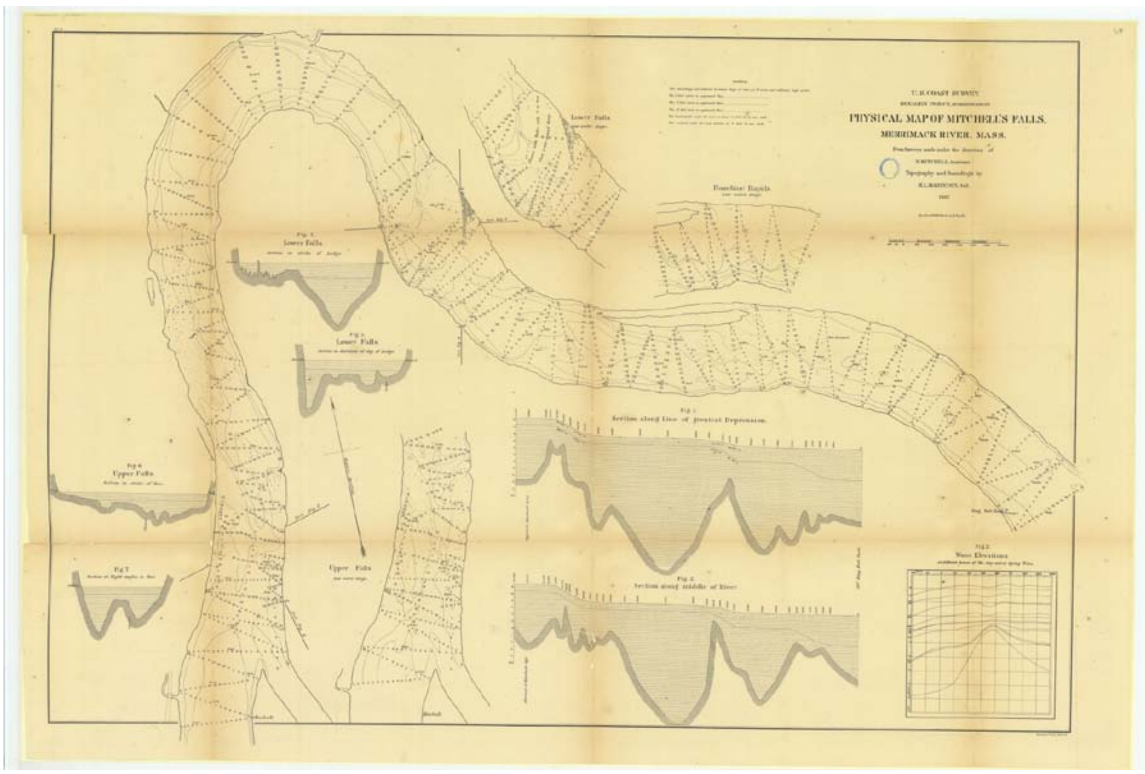
For the Survey, railroads connected to ships at harbors and ports, which needed continual re-surveys as they changed and expanded. Railroads required positioning, and they were accompanied by telegraph lines, and telegraphs allowed positions to be determined by the telegraphic method, Bache's "American 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.

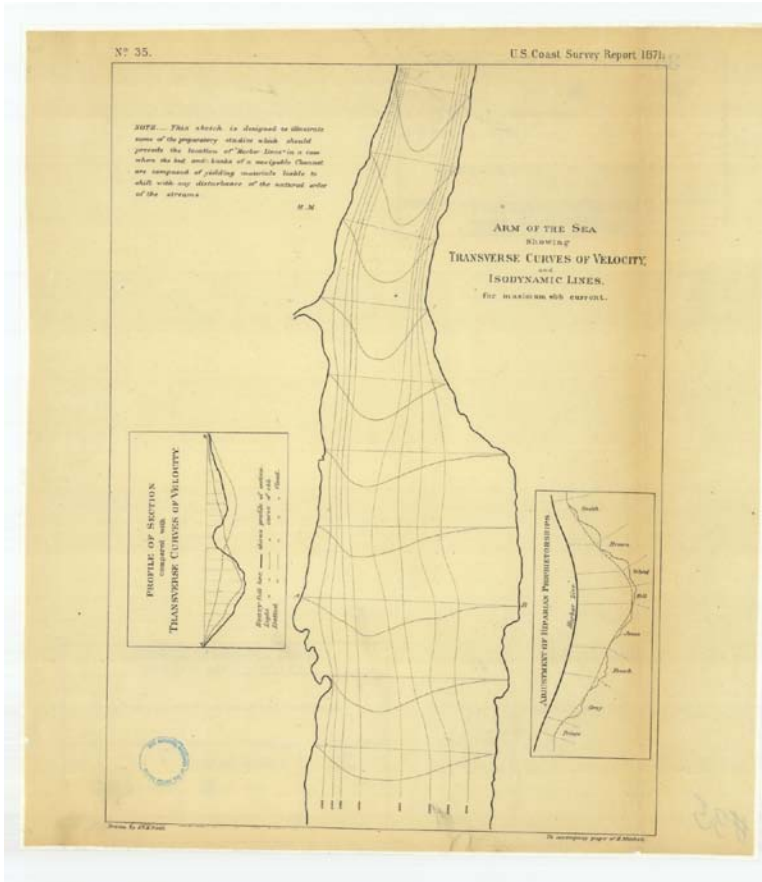
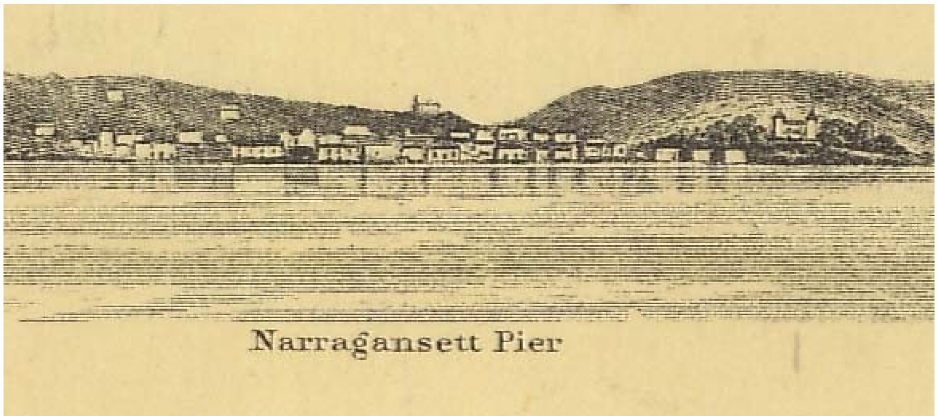


Figure 35, to accompany Appendix 10, “Hints and suggestions upon the location of harbor lines” by Henry Mitchell (1871)

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

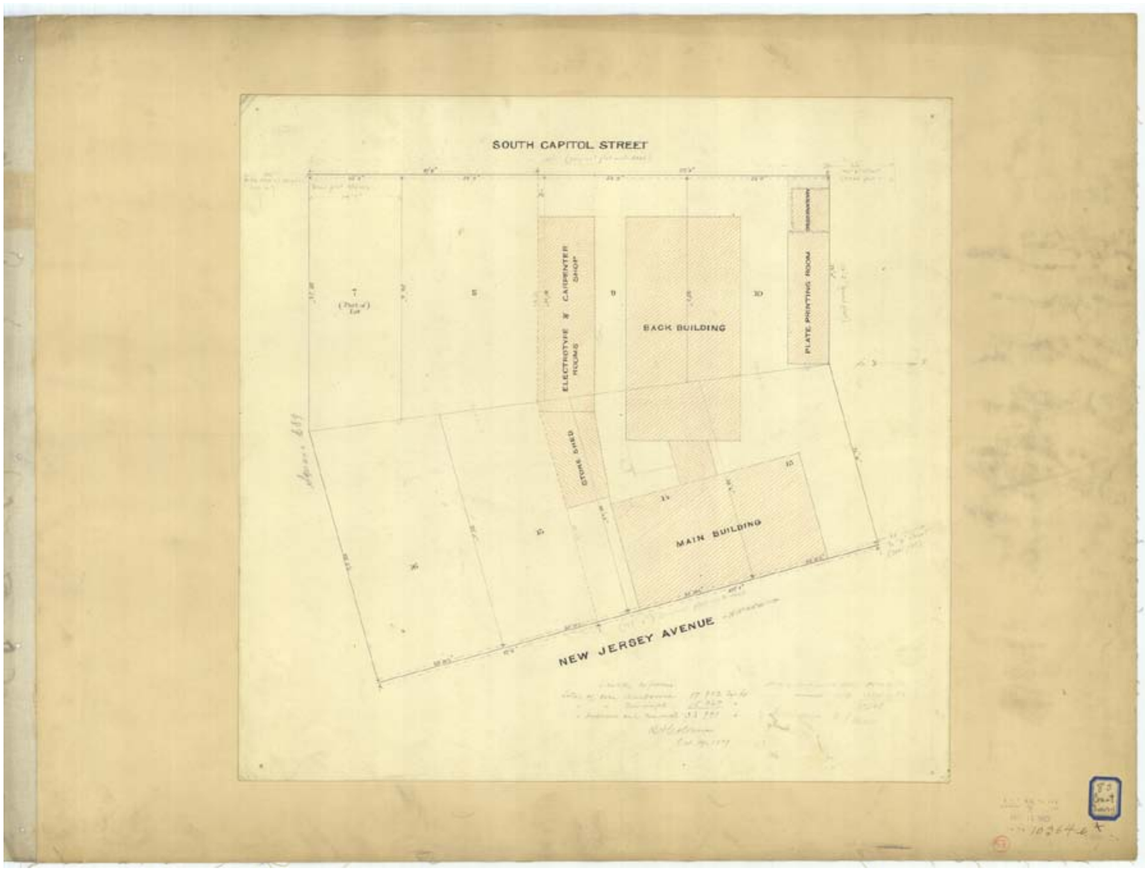
Cramped and inadequate quarters for work and research have been a recurrent theme in the history of the Coast Survey since the beginning. The Civil War was particularly difficult, both in the field, which meant on battlefields, and in the office, which generally meant in Survey buildings in the crowded, 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

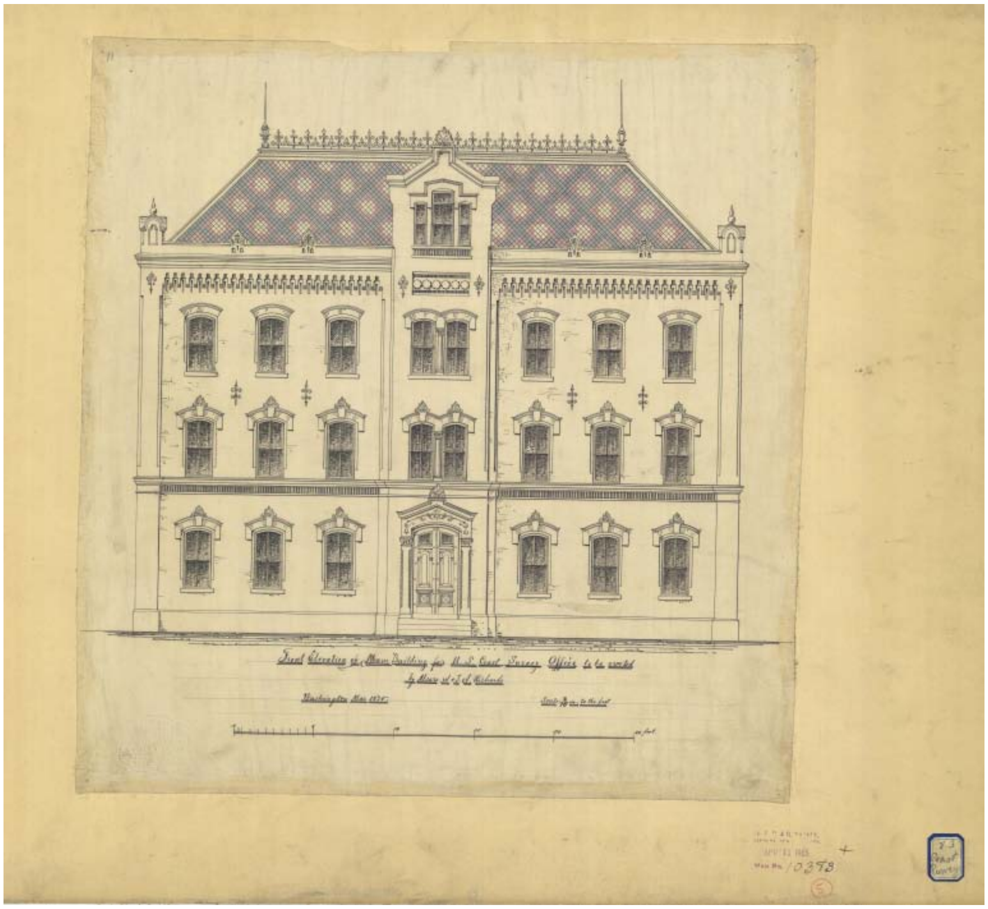
[22] Peirce, 1873, Annual Report for 1870. p. 50.

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.

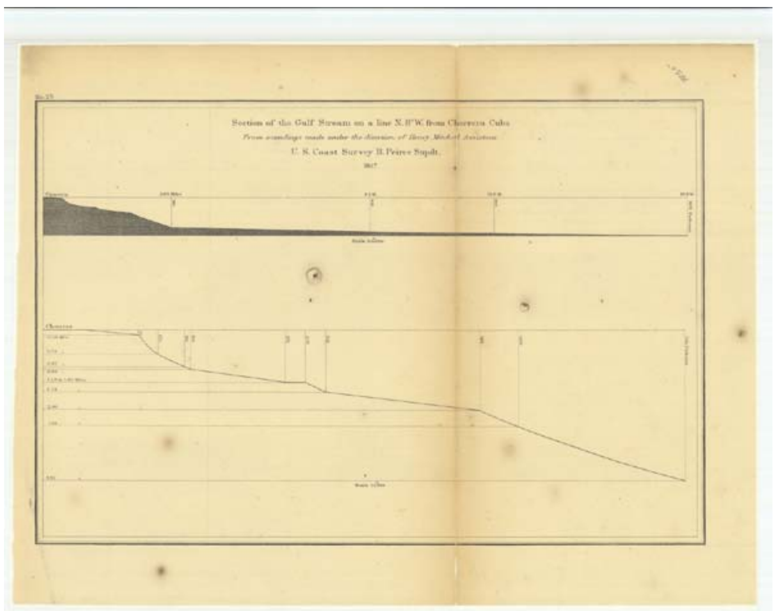
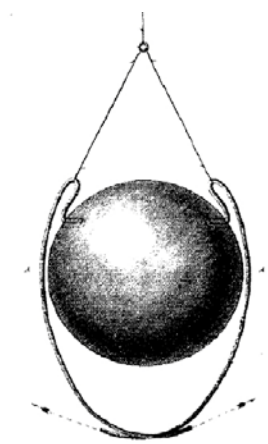


Figure 25 Section of the Gulf Coast on a Line N 8 Degrees West of Chorrera, Cuba from soundings made under the direction of Henry Mitchell (1867)

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]

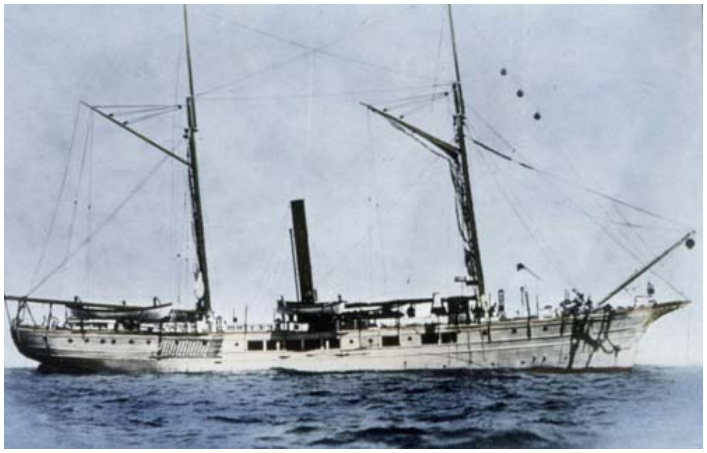


Handy Method of Detaching Shot
in Deep Sea Sounding
Proposed by Lieut. Comdr C.D.Sigsbee U.S.Navy
Assist Coast Survey
The wires should be close to the shot at the points A A and so bent that the lower ends on striking bottom will be forced in a direction indicated by the arrows.

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



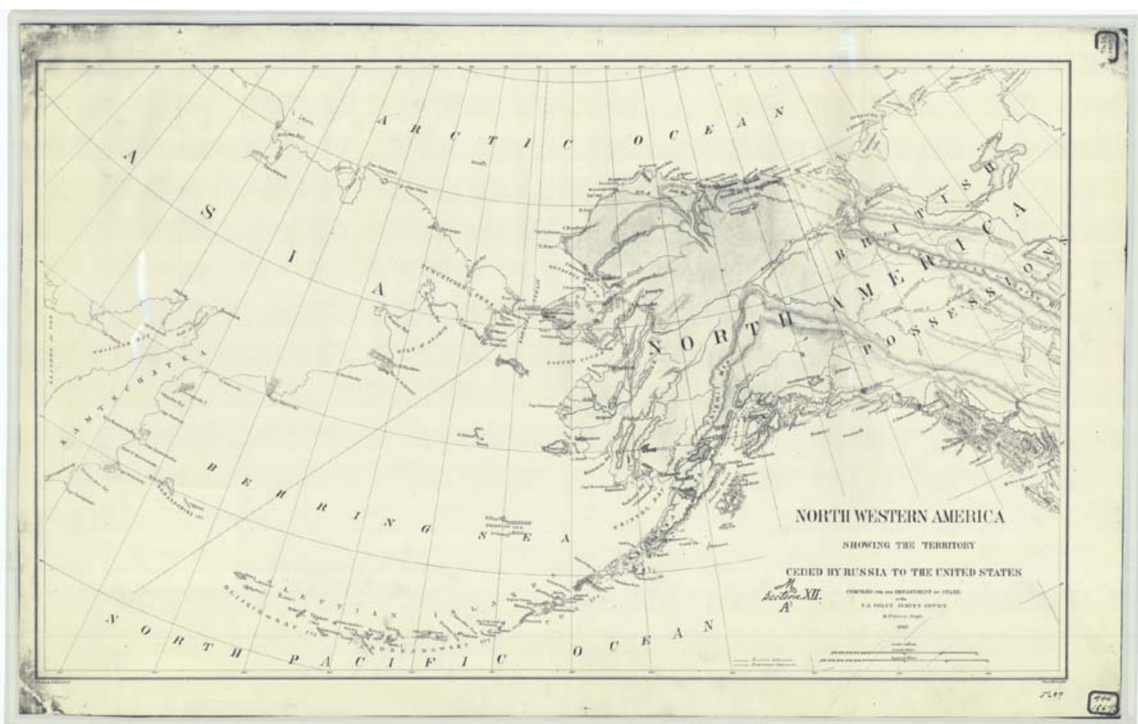
The steamer *Blake* (1874-1905)

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.

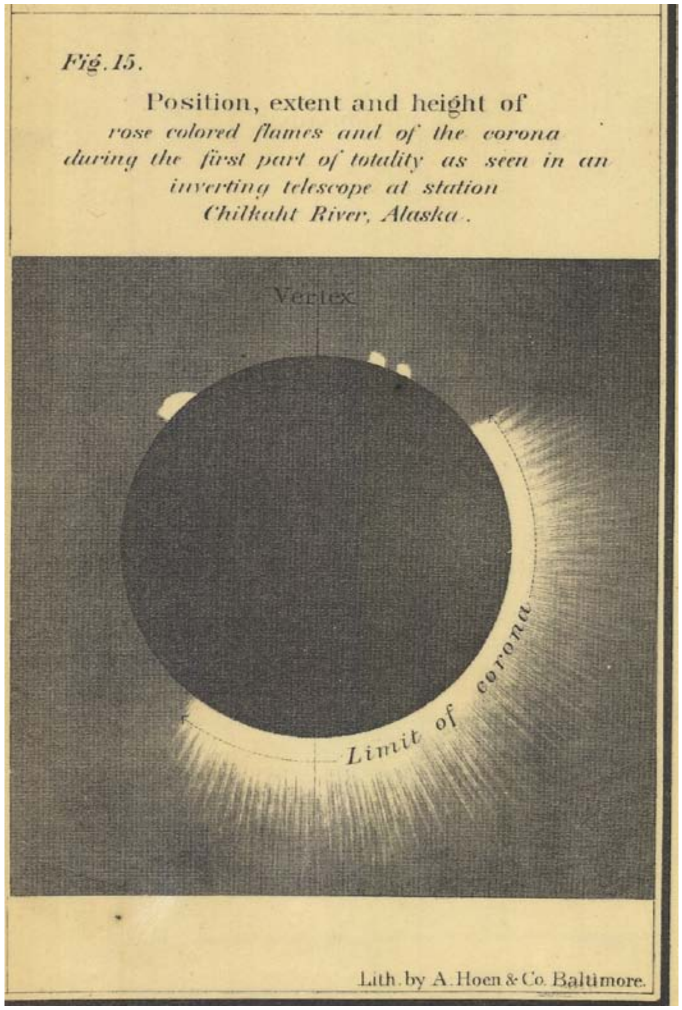
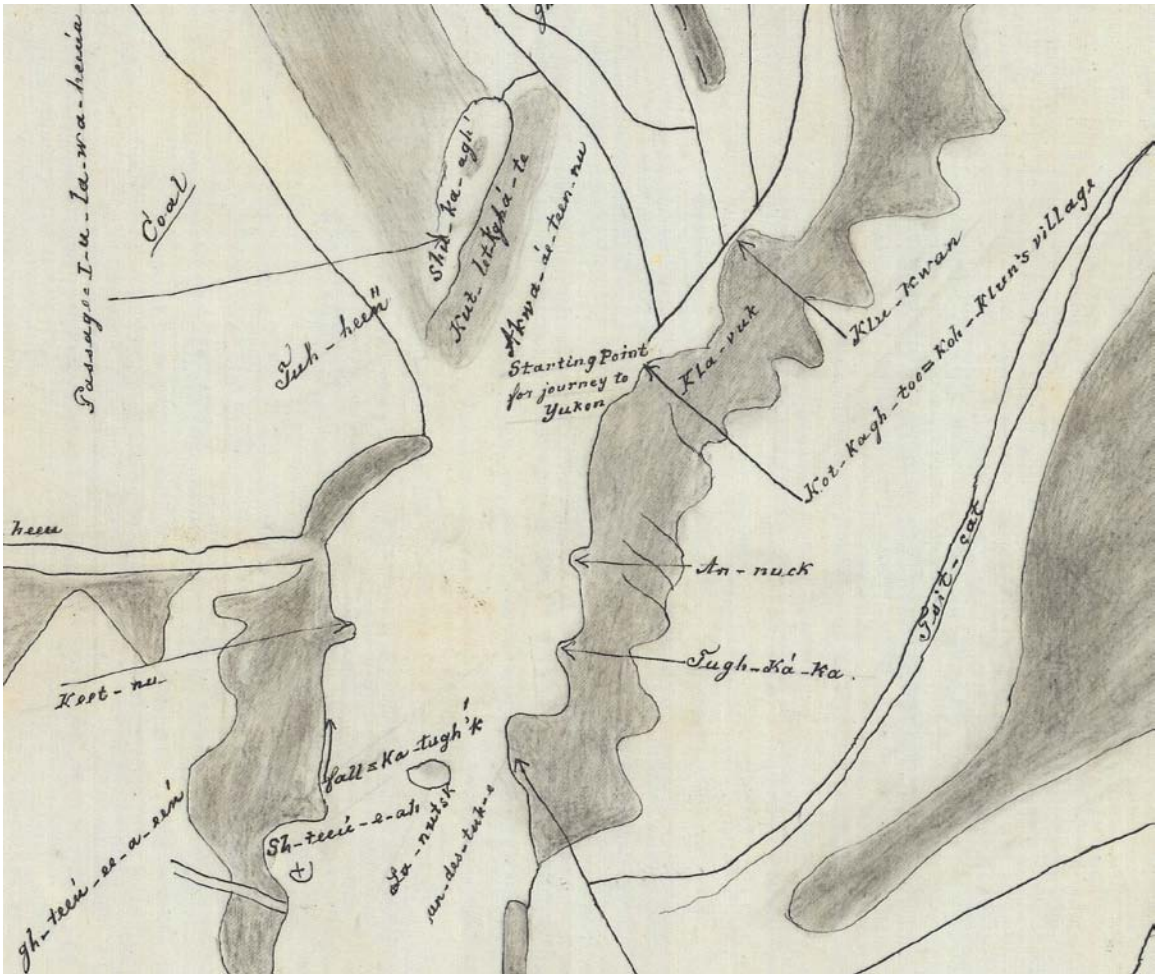


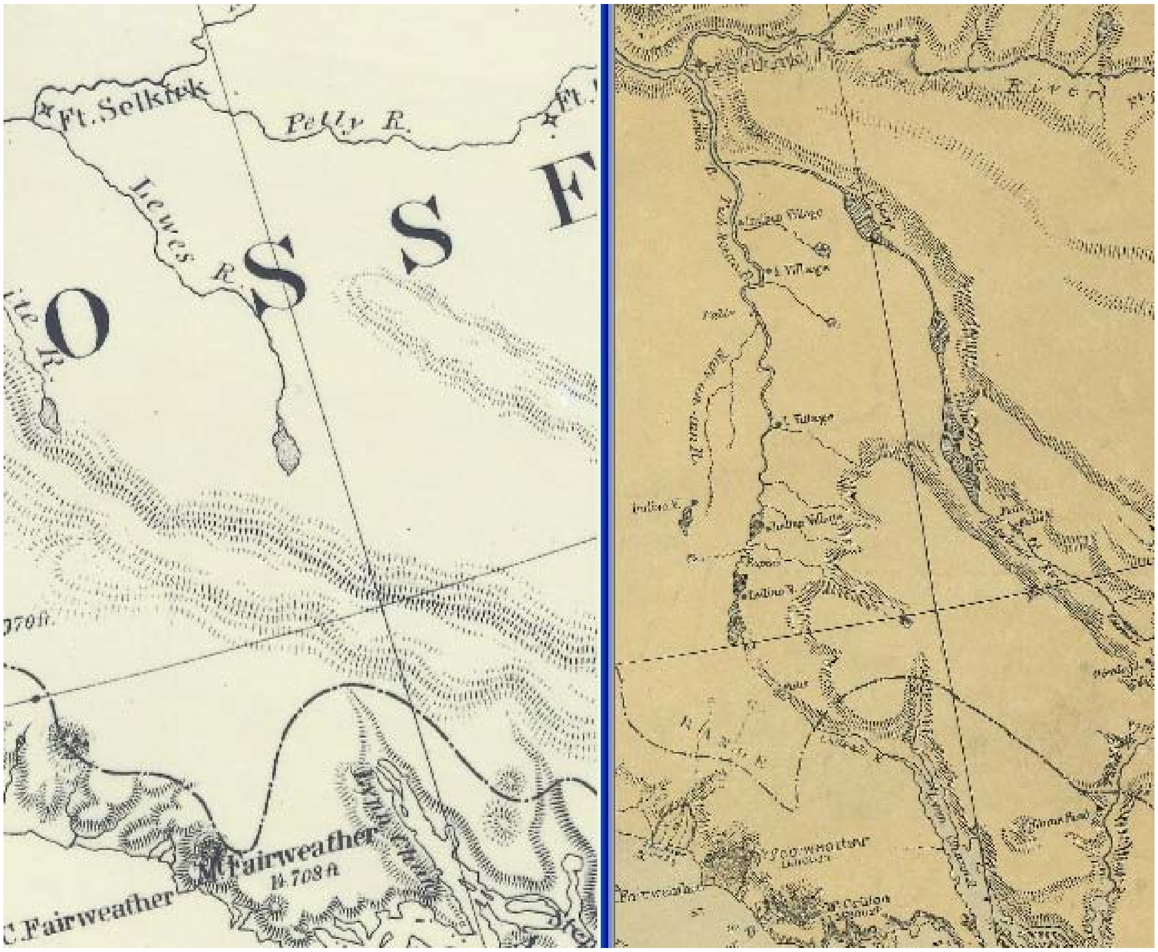
Figure No. 15, from Appendix No. 8, "Reports of Observations of the Eclipse of the Sun on August 7, 1869, etc." Annual Report of the Superintendent for 1869

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.

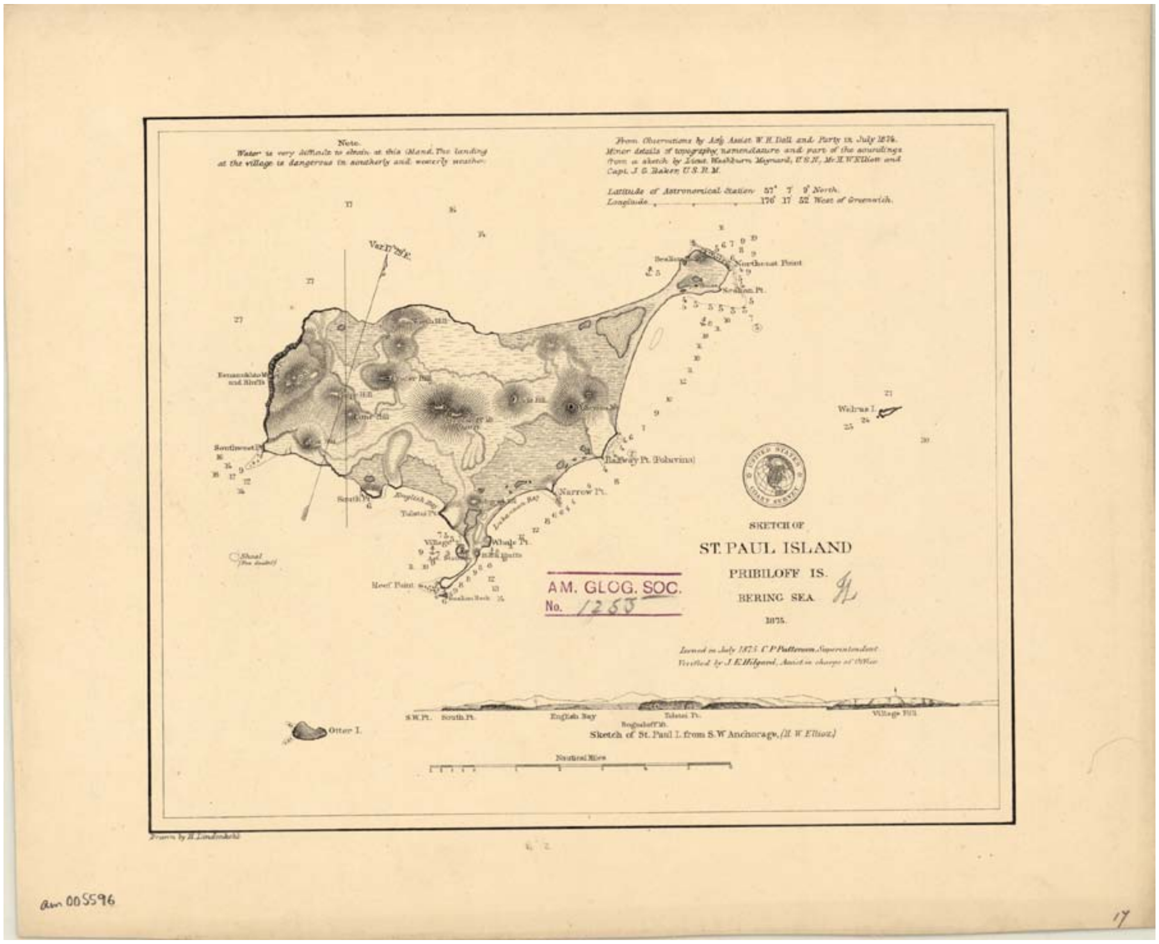


The terrain between the Lynn Canal and Fort Selkirk, in the Yukon, from the 1867 and 1869 editions of the Survey's map of Russian America/Alaska

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

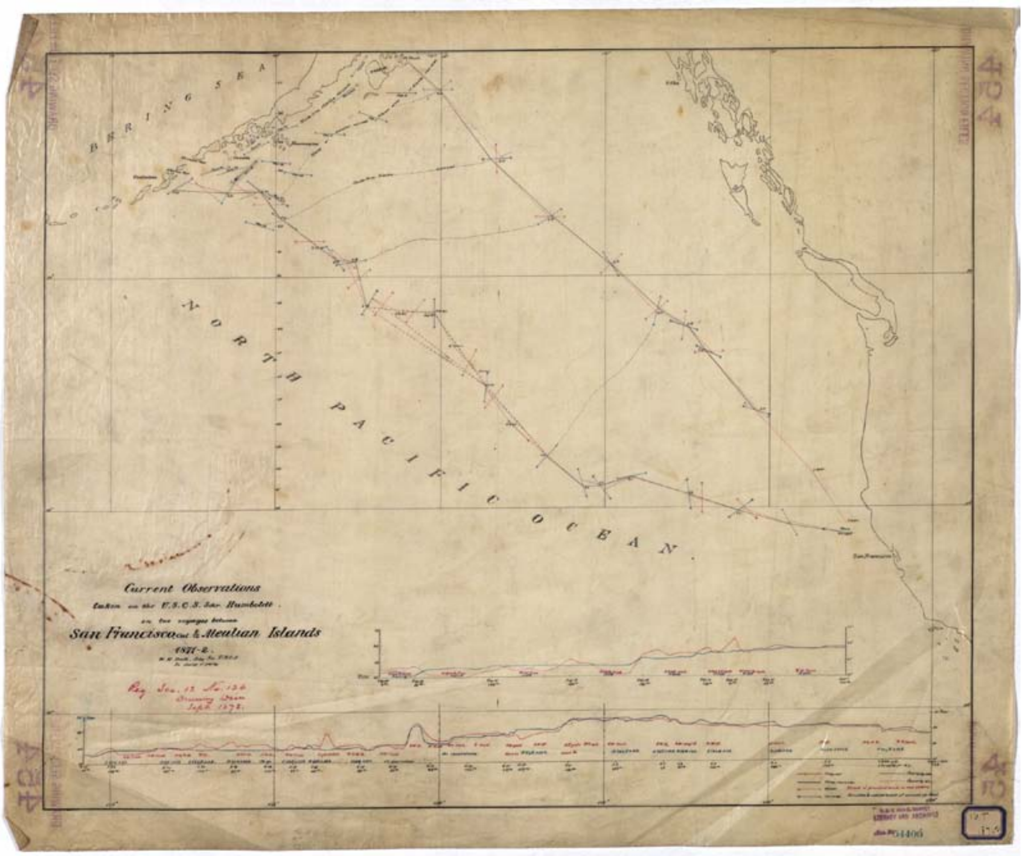
One of the most immediately critical environmental problems that the United States acquired with the purchase of Alaska was the disposition of the vast but shrinking populations of fur seals, whose major breeding grounds were limited to rookeries on the shores of St. Paul and St. George Islands in the 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.

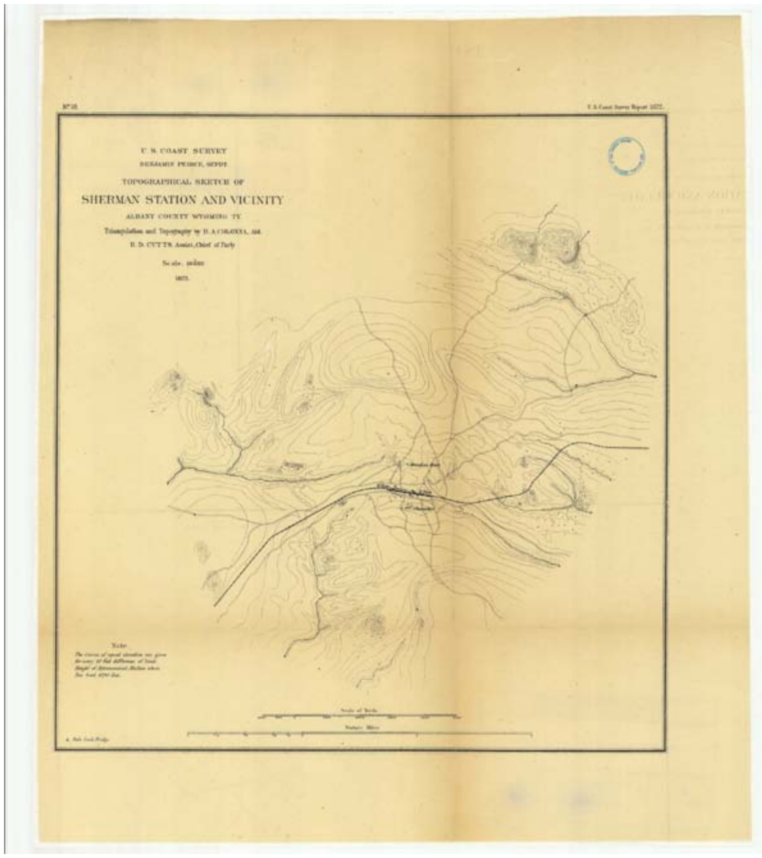


Figure 18: Observations at Sherman Station and Vicinity, Wyoming Territory, 1872

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

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[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.

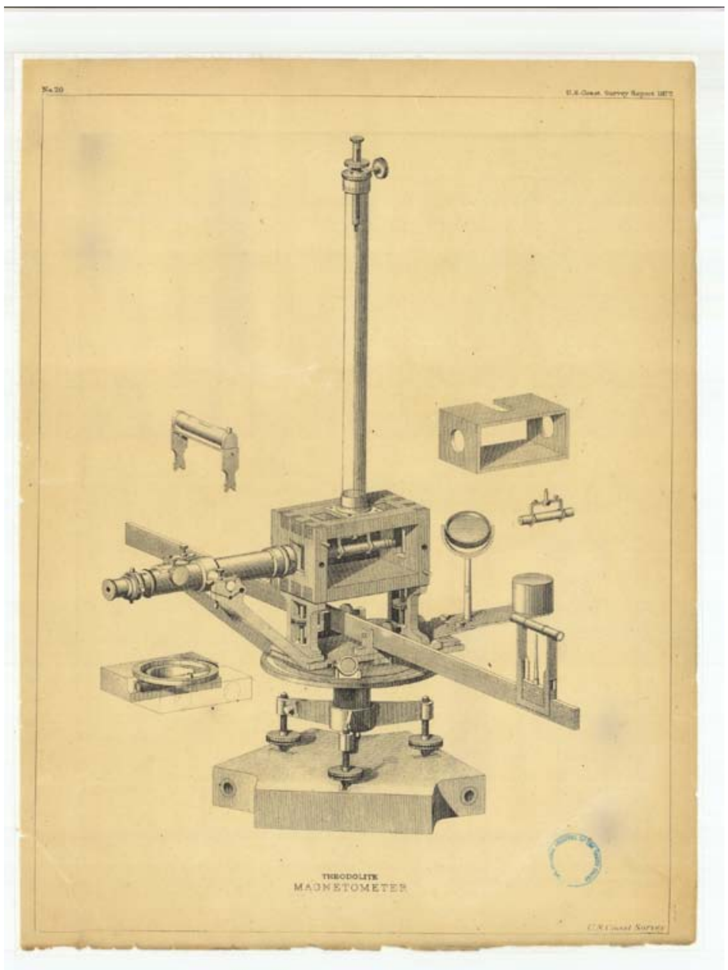


Figure 20: Theodolite Magnetometer (1872)

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.

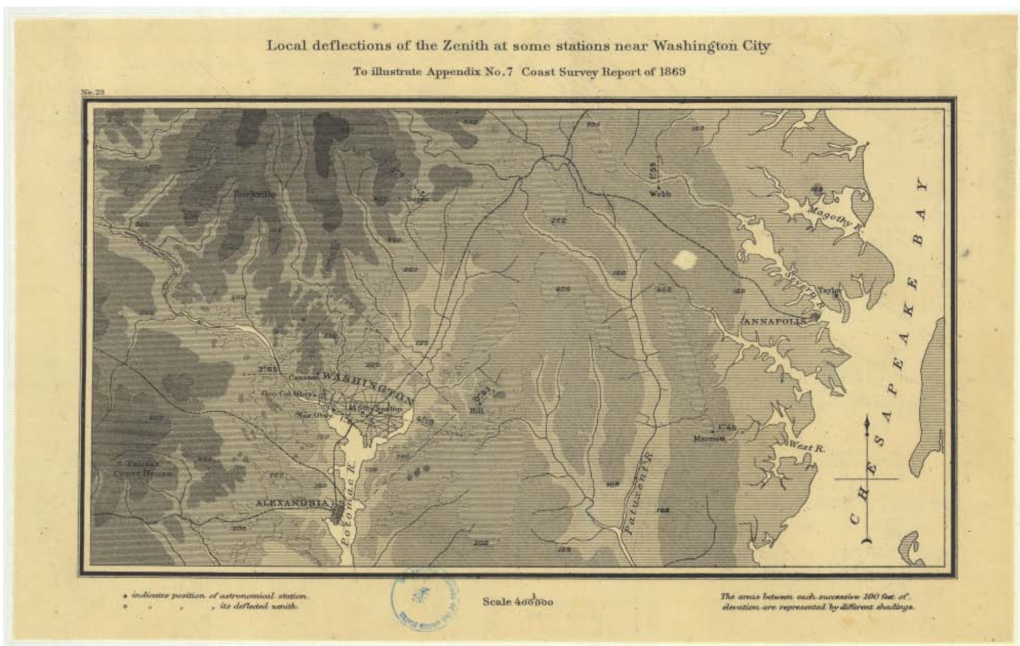


Figure 23: Local Variations of the Zenith at some stations near Washington City (1869)

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.

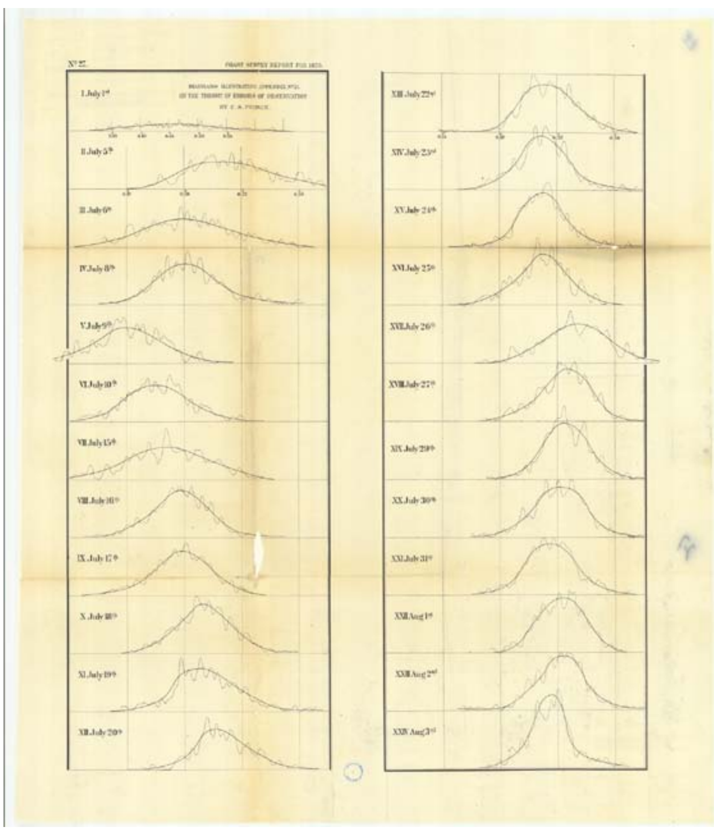


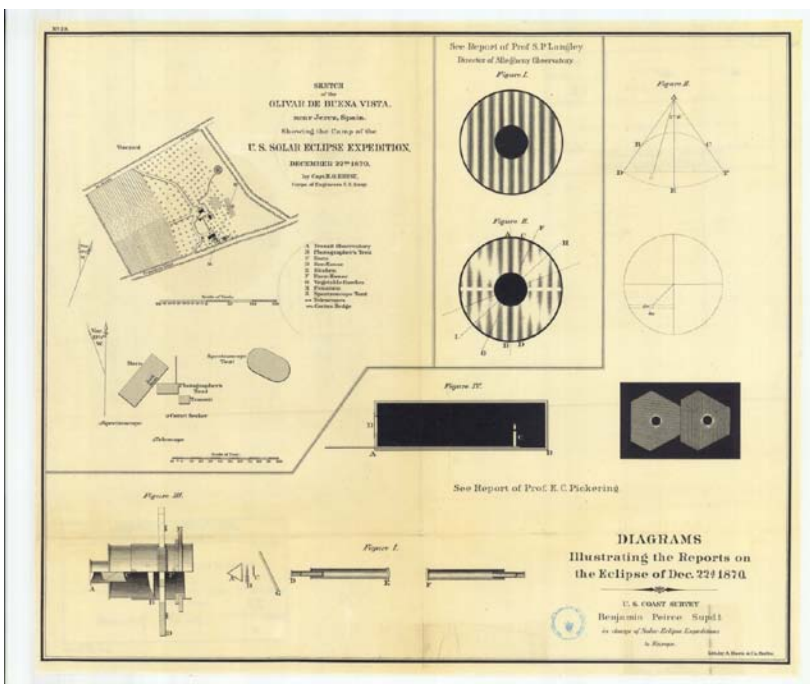
Figure No. 27 Diagrams illustrating App. No. 21 on the theory of errors of observation by C.S. Peirce (1870)

[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]

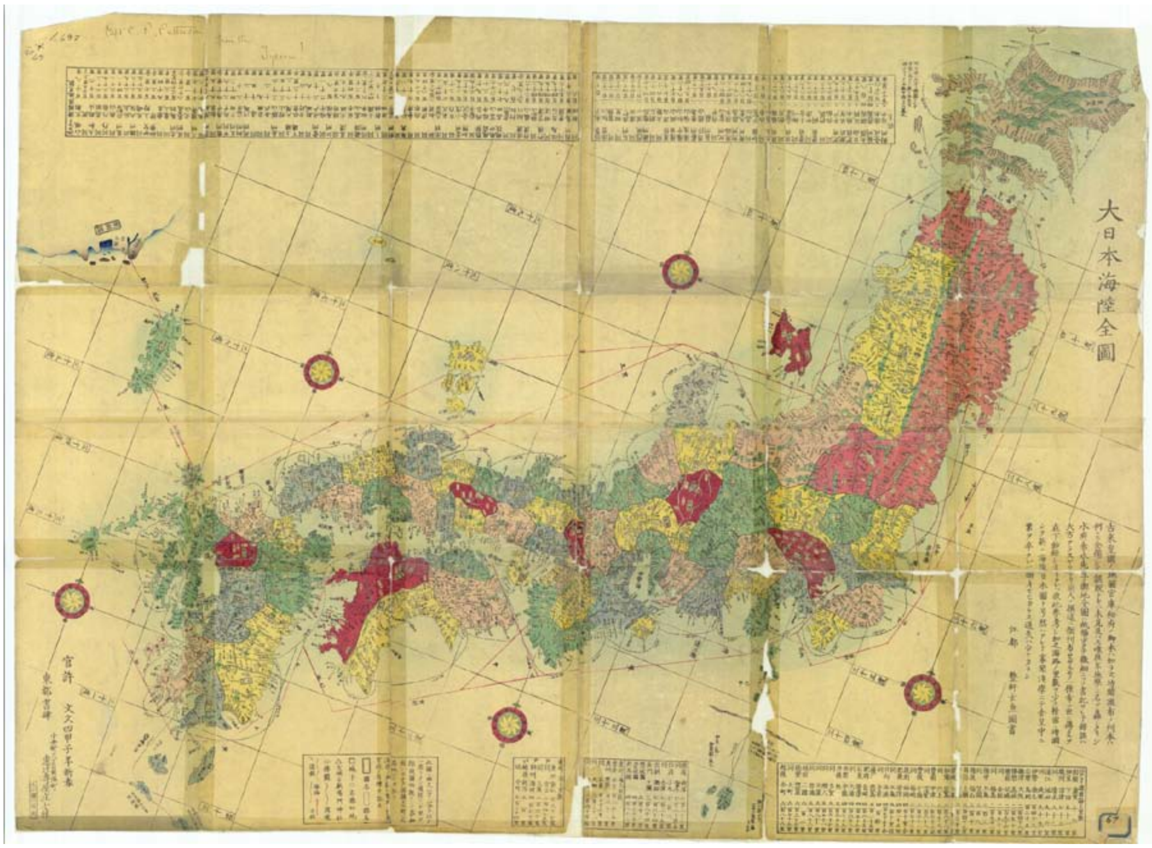
Davidson reflected on his astronomical experiences at higher elevation in the California Sierras, and across to the east along the 39th Parallel Arc, about the importance of obtaining observatory sites at high elevation if possible. This also reflected the meticulous comparative astronomical work that 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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