Bathymetry: History of Seafloor Mapping

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Abstract

Terrestrial geography, including the outline of continents, islands, mountain chains, and great plains, was clearly known by the mid-19th century. However, the configuration of the seafloor was unknown and, even if there had been need, no technology was capable of accurately and quickly measuring the depths of the sea. This situation began changing in the 1840s, as both scientific and commercial interests began investigating the sea. Depth measuring technology progressed from point sounding line-and-sinker methods to primitive acoustic methods in the early 20th century. Line-and-sinker technology was capable of discovering most of the large features of the seafloor. Acoustic methods, by virtue of continual profiling with single-beam systems and with 100% bottom coverage capability with multibeam swath-mapping systems, have filled in the blanks of much of the detail of the world ocean. Our present world view and understanding of earth processes is a direct result of the mapping and understanding of the nature of the seafloor.

EARLY EFFORTS

The beginning of modern seafloor mapping coincided with the advent of systematic oceanographic observations (i.e., modern oceanography), deep-sea scientific dredging, and the commercial desire to lay deep-sea telegraph cables. Within a century, the concept of a featureless and static seafloor was shattered and the findings of a detailed ocean bathymetry were revealed (Fig. 1). Some of the first recorded measurements of bathymetry were made by the British explorer Sir James Clark Ross in 1840, by the U.S. Coast Survey beginning in 1845 with systematic studies of the Gulf Stream, and by the U.S. Navy, under the guidance of Matthew Fontaine Maury, beginning in 1849.[1] A weighted hemp or flax rope was dropped over the side of a vessel "lying to" (drifting) and the length of the line recorded once the sinker or lead weight reached the bottom. From a few such measurements, the first bathymetric map was produced and published by Maury in the 1853 Wind and Current Charts of the North Atlantic Ocean (Fig. 1A). Although this particular map was not very accurate, many important seafloor features were discovered from such measurements. For example, the first map showing the full extent of the Mid-Atlantic Ridge was produced in 1877 by Wyville Thomson from measurements made on HMS *Challenger* supplemented by additional soundings made by British vessels and those of the United States and other nations[1] (Fig. 1B). In 1875, HMS *Challenger* also discovered the first indication of the Mariana Trench with a measured depth of 4475 fathoms although it was another 30 years before the true configuration of the trench was understood.[2] Just two years later in 1877, the German geographer, Augustus Petermann, produced the first bathymetric chart of the Pacific Ocean with many features including the "Challenger Tiefe" or "Challenger Deep," and the then deepest known spot in the ocean, the Tuscarora Deep, named after the USS Tuscarora, which had sounded in the Japan Trench in 1874.

PIANO-WIRE SOUNDING SYSTEM

The problems and inaccuracies inherent to making "line and sinker" measurements (e.g., angled line due to currents and vessel drifting, determining precisely when the sinker reached the bottom, etc.) led to the development of the piano-wire or Thomson sounding system in the 1870s by Sir William Thomson (later Lord Kelvin) (Fig. 2A). The piano-wire sounding system was a line-and-sinker technique but approximately three times faster than the old hemp rope system. Because of smaller cross-section of

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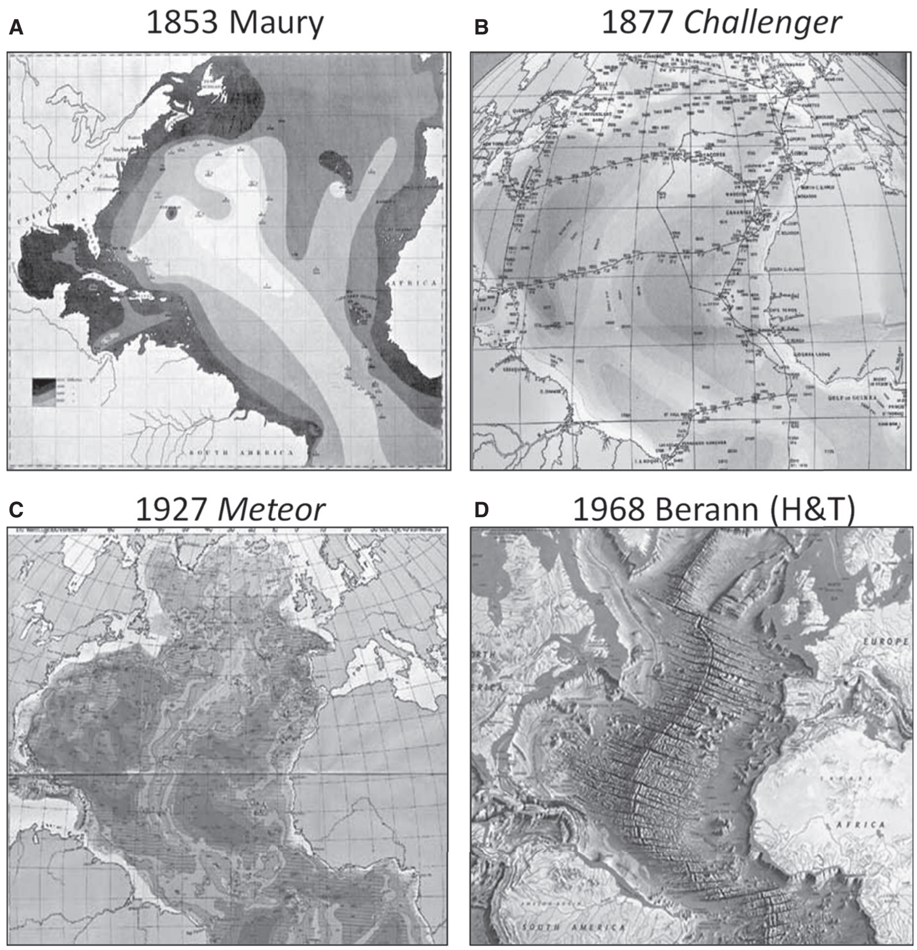

Fig. 1 In roughly one century, the mapping and conceptual understanding of ocean bathymetry were revolutionized as shown in the sequential maps of the North Atlantic. (**A**) First recorded bathymetric map created in 1853 by Maury in collaboration with the U.S. Navy only hints at the mid-ocean ridge. (**B**) Excerpt from the 1877 Thomson map based on the HMS Challenger measurements with line-and-sinker techniques shows the first continuous mapping of the mid-ocean ridge. (**C**) Echo sounding techniques allowed for increased frequency and a higher definition of the mid-ocean ridge, as shown in Theodor Stocks map from the Meteor cruises in 1927. (**D**) This 1968 Berann illustration, based on the Heezen and Tharp physiographic maps, outlines the ridge system in the North Atlantic (National Geographic Stock).

wire (vs. hemp rope) to be affected by surface and subsurface currents, less time to observe sounding, and exact indication of when the weight hit bottom, this method was approximately an order of magnitude more accurate than hemp rope sounding (10–20 m in 2000–3000 fathom vs. 100 m or more error with hemp rope sounding). It was the Thomson sounding machine and its variants, the Sigsbee Sounding Machine developed in the U.S. Coast and Geodetic Survey (USC&GS) (Fig. 2B) and the Lucas Sounding Machine developed by British surveyors, which outlined the great features of the world ocean prior to the introduction of acoustic sounding systems following the First World War.

The continental shelves and slopes, mid-ocean ridges, enclosed basins, and major trenches were discovered as a result of the nearly 20,000 soundings made in the deep ocean by the early 20th century. As a result of these discoveries, the 7th International Geographic Congress held in Berlin in 1899 appointed a committee on the nomenclature of undersea features and also formed a commission, under the chairmanship of Prince Albert I of Monaco, to publish a General Bathymetric Chart of the Oceans (GEBCO). This first GEBCO chart was published in 1905 and such charting has continued to modern day (Fig. 3).[3] From this early work, the significance of the seafloor features and their relationship to modern day plate tectonics began to unfold and in 1910 Frank Bursley Taylor wrote: “It is probably much nearer the truth to suppose that the Mid-Atlantic Ridge has remained unmoved, while the two continents on opposite sides of it have crept away in nearly parallel and opposite directions.”[4] Shortly thereafter in 1912, Alfred Wegener first proposed the theory of the continental drift. Another notable landmark from the piano-wire era was the construction in 1884 of the first 3D

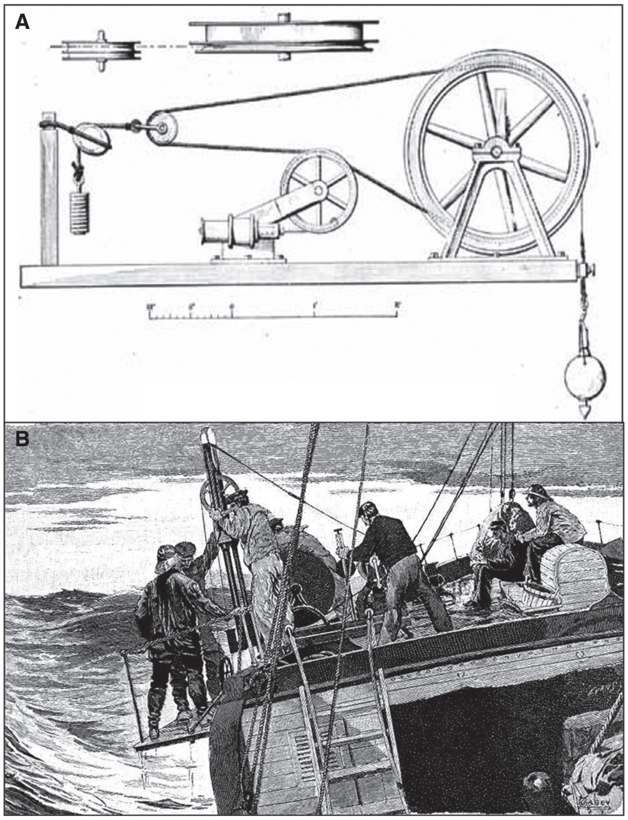

Fig. 2 (**A**) Diagram of the original version of the piano-wire sounding machine or Thompson Sounding Machine invented by Sir William Thomson (later Lord Kelvin) in 1872. (**B**) "The United States Fish Commission" by Richard Rathbun. Century Magazine, Vol. 43, issue 5. 1892. "Sounding the abyss with piano-wire." This image is among the most realistic representations of sounding with the Sigsbee Sounding Machine.

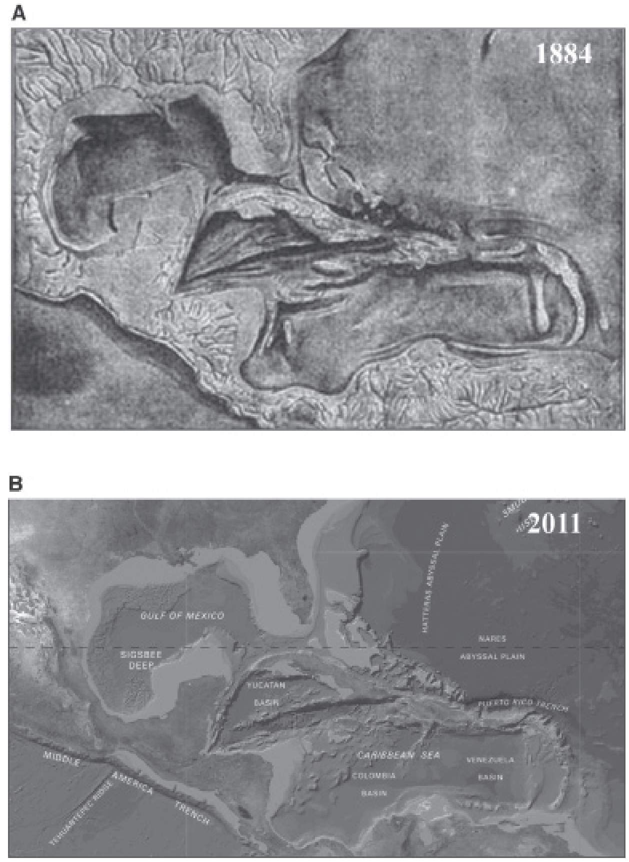

Fig. 3 Early mapping efforts along coastal margins were quite accurate, particularly as shown in (**A**) the first 3D rendition of ocean bathymetry of the Gulf of Mexico and Caribbean Sea produced in 1884 from the Blake soundings. (**B**) Same region highlighted from current bathymetric maps has many of the same features.
Source: Image reproduced from the GEBCO gridded bathymetric data.[3]

view of the seafloor from soundings made aboard the USC&GS steamer *Blake* in the Gulf of Mexico and western Atlantic Ocean (Fig. 3A). This ship also pioneered deep-sea anchoring and current measurement techniques while engaged in classic Gulf Stream studies.[1]

ACOUSTIC SOUNDING SYSTEMS

In the early 1900s, Submarine Signal Company, a forerunner of Raytheon Corporation, developed an underwater acoustic navigation system that was deployed from buoys and lightships for helping ships equipped with hydrophones to safely navigate to port during periods of reduced visibility. A similar system was also developed for ship-to-ship communication. Following the *Titanic* disaster, Reginald Fessenden of Submarine Signal Company developed an acoustic transducer that could both transmit and receive sound for the purpose of detecting objects in the water. During tests on the U.S. Revenue Cutter *Miami* in March 1914, reflections were obtained from an iceberg and, unexpectedly, from the bottom. Echo sounding was born. German, French, and American investigators modified and improved this technology for use in both outward looking antisubmarine warfare systems and downward-looking depth finding systems during the First World War. By 1922, the first truly functional acoustic depth measuring devices were in use making piano-wire sounding systems obsolete overnight.

The first issue of the International Hydrographic Review, the publication of the newly formed International Hydrographic Organization, contained a profile of the Atlantic Ocean seafloor from Boston to Gibraltar obtained by a U.S. Navy-developed Hayes Sonic Depth Finder mounted on the U.S.S. *Stewart* in 1922 (Fig. 4A). This profile was derived from over 900 soundings taken during the transit proving both the efficacy of acoustic sounding (the word sounding does not refer to sound; it is derived from the Old French word *sonder* meaning, "to measure") and its ease of use and accuracy.

Overnight, echo sounding became the standard technique for observing bathymetry. Echo sounding

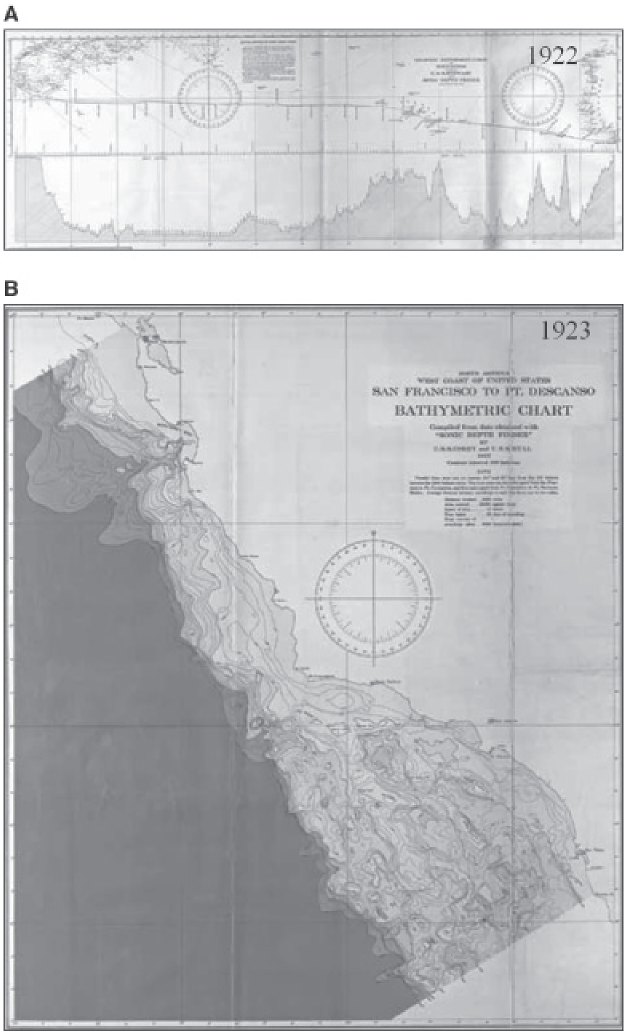

Fig. 4 (**A**) This profile illustrates the first acoustic line of soundings across the Atlantic Ocean obtained by the *USS Stewart* in 1922. (**B**) Published in 1923, Hydrographic Office Miscellaneous Chart 5194 showing the detailed coastal bathymetry of California from San Francisco Bay southward to San Diego, U.S.A. was the first bathymetric chart to be produced solely from acoustic soundings. NOAA/Department of Commerce.

determines bottom depth from measuring the time required for a sound pulse to be emitted from a transmitter, travel to the bottom and be reflected, and then travel back to a receiver unit. Dividing this time by 2 and multiplying times the velocity of sound in sea water gives the measure of the depth.[5] Contemporaneous with the *Stewart* work, the U.S. Navy also equipped U.S.S *Corry* and U.S.S. *Hull* with echo sounders for conducting a survey of the California coast. This survey resulted in the first bathymetric map produced solely by acoustic technology (Fig. 4B). These successes were followed by the famous German Meteor Expedition (1925–1927), which resulted in over 67,000 soundings of the Atlantic Ocean. In addition to mapping the axis of the Mid-Atlantic Ridge (Fig. 1C), this expedition delineated for the first time the abyssal hills extending outward from the ridge axis. With the invention of the radio-acoustic ranging navigation system by the USC&GS in 1924, the position of a ship could be determined accurately and literally, millions of soundings were made on the continental shelf and slope of the U.S. prior to World War II.[1] This navigation system was the first ever devised of sufficient accuracy for use in offshore bathymetric surveying operations. The combination of acoustic sounding and precise navigation led to the discovery of many mesoscale features that otherwise would have been impossible solely with the use of celestial navigation.

The 1930s saw a rapid advance of knowledge of the seafloor. The British Egyptian John Murray Mabahiss Expedition to the Indian Ocean discovered the first indications of the median valley of the mid-ocean ridge system; the German *Meteor* expeditions continued and, in 1937, the German oceanographer Gunter Dietrich discovered the median valley of the Mid-Atlantic Ridge; the USC&GS, in addition to its continental shelf and slope surveys, made a number of transects across the Gulf of Alaska discovering lineal chains of seamounts and also flat-topped seamounts, later termed guyots. The USC&GS also made detailed surveys of the bathymetry of the Aleutian Trench. As a result of its continental shelf and slope surveys, the C&GS discovered many large canyons on the east coast of the United States, the Mendocino Escarpment off the California coast which was the first indication of the great lineal features now known as fracture zones, and, of great commercial significance, salt domes on the Texas-Louisiana continental shelf and slope.

The exploration and mapping of the seafloor was interrupted by World War II except for isolated efforts such as the serendipitous discovery and mapping of seamounts and other features by Dr. Harry Hess (serving as a naval officer during the war) in the western Pacific Ocean. He discovered many flat-topped seamounts and called them "guyots." He coined the term "guyot" after Arnold Henry Guyot and in honor of the flat-topped building at Princeton University, which also gets its name from Arnold Henry Guyot.

COLD WAR YEARS AND BEYOND

Because of the rise of strategic submarine defense needs during the Cold War years, knowledge of bathymetry and other oceanographic parameters became critical. As a consequence, the world view we have of the seafloor today primarily stems from those of U.S. Navy-supported marine geologists and geophysicists from government agencies and major U.S. oceanographic institutions following World War II. Beginning in the late 1940s, ships from Columbia University's Lamont Geological Observatory, the Woods Hole Oceanographic Institution, and the Scripps Institution of Oceanography fanned out over the world ocean collecting bathymetry, geophysical data, and other oceanographic information. For the next quarter century, these institutions delineated the abyssal plains, the flattest surfaces on earth; mapped the full extent of the world-girdling ridge system; defined the great fracture zones and their accompanying scars; surveyed hundreds of seamounts; and established that abyssal hills were the most abundant landform on earth, particularly because of their widespread occurrence in the Pacific Ocean, where they covered approximately 85% of the seafloor.[6] Other nations and institutions took part in this endeavor. Notably the British *Challenger* II expedition, which established the Mariana Trench as the deepest spot in the ocean; the Swedish *Albatross* expedition; the Danish *Galathea* expedition; Japanese surveys of the northwest Pacific Ocean; and Seamap surveys by the USC&GS in the North Pacific Ocean all contributed to furthering knowledge of the seafloor and ocean in general. Both U.S. Navy and Russian surveys of most of the world ocean were also made, primarily in support of submarine warfare requirements, throughout most of the Cold War era but even today, most of those data remain classified.

Among the most widely known maps of the ocean basins are the iconic physiographic maps produced by Bruce Heezen and Marie Tharp, researchers at Columbia University's Lamont Geological Observatory, beginning in the early 1950s and subsequent collaborative illustrations of H.C. Berann in the 1960s and 1970s (Fig. 1D). These physiographic illustrations were based on data collected primarily from academic and military surveys conducted during the early Cold War era during which, due to U.S. national security restrictions, new bathymetric maps of many areas were "classified" and not available to the public.[7] The physiographic approach used by Heezen and Tharp portrayed physical features from an oblique perspective and an exaggerated vertical scale, and made detailed extrapolations between the soundings following from their burgeoning knowledge of geomorphology. Marie Tharp wrote: "I had a blank canvas to fill with extraordinary possibilities, a fascinating jigsaw puzzle to piece together: mapping the world's vast hidden seafloor. It was a once-in-a-lifetime—a once-in-the-history-of-the-world—opportunity for anyone, but especially for a woman in the 1940s".[8] During this same era, investigators from the Scripps Institution of Oceanography, such as H. W. Menard and T. E. Chase, were producing lesser-known atlases and physiographic diagrams of the Pacific Ocean basin.

CONCLUSION

The world view and regional views of bathymetry produced by these investigators were instrumental in helping form concepts of seafloor spreading, continental drift, and the theory of plate tectonics as we know them today. The advent of multibeam sonar in the civil mapping community, access to the remarkably accurate global positioning system, satellite altimetry remote sensing technology, and computer-aided analysis and interpolation has led to further advancements in bathymetric mapping in the last quarter of the 20th century. These advances have had implications in nearly every field of oceanography. The foundation for today's conceptual understanding of seafloor bathymetry, plate tectonics, and related bathymetric effects on many aspects of oceanography and marine ecology was laid down within one century by intensive effort from many talented individuals and institutions.

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REFERENCES

1. Theberge, A. Appendix: The History of Seafloor Mapping. *In Ocean Globe*; ESRI Press: Redlands, CA, Breman, J., Ed.; 2010; (ESRI Press): 237–274.
2. Theberge, A. Thirty Years of Discovering the Mariana Trench. Hydro, Int. **2008**, *12*, 38–41.
3. *GEBCO_08 Gridded Bathymetry Data,* General Bathymetric Chart of the Oceans, 2008.
4. Taylor, F.B. Bearing of the tertiary mountain belt on the origin of the Earth's plan. Bull. Geol. Soc. Am. **1910**, *21*, 179–226.
5. Dierssen, H.M.; Theberge, A.E. Bathymetry: Assessing Methods. *Encyclopedia of Ocean Sciences*; Taylor and Francis: New York, NY, 2012.
6. Dierssen, H.M.; Theberge, A.E. Bathymetry: Features and Hypsography. *Encyclopedia of Ocean Sciences*; Taylor and Francis: New York, NY, 2012.
7. Doel, R.E.; Levin, T.J.; Marker, M.K. Extending modern cartography to the ocean depths: military patronage, Cold War priorities, and the Heezen-Tharp mapping project, J. Hist. Geogr. **2006**, *32*, 605–626.
8. Tharp, M. Connect the dots: mapping the sea floor and discovering the Mid-Ocean Ridge. *Lamont-Doherty Earth Observatory of Columbia Twelve Perspectives on the First Fifty Years* 1999, *31*–37.