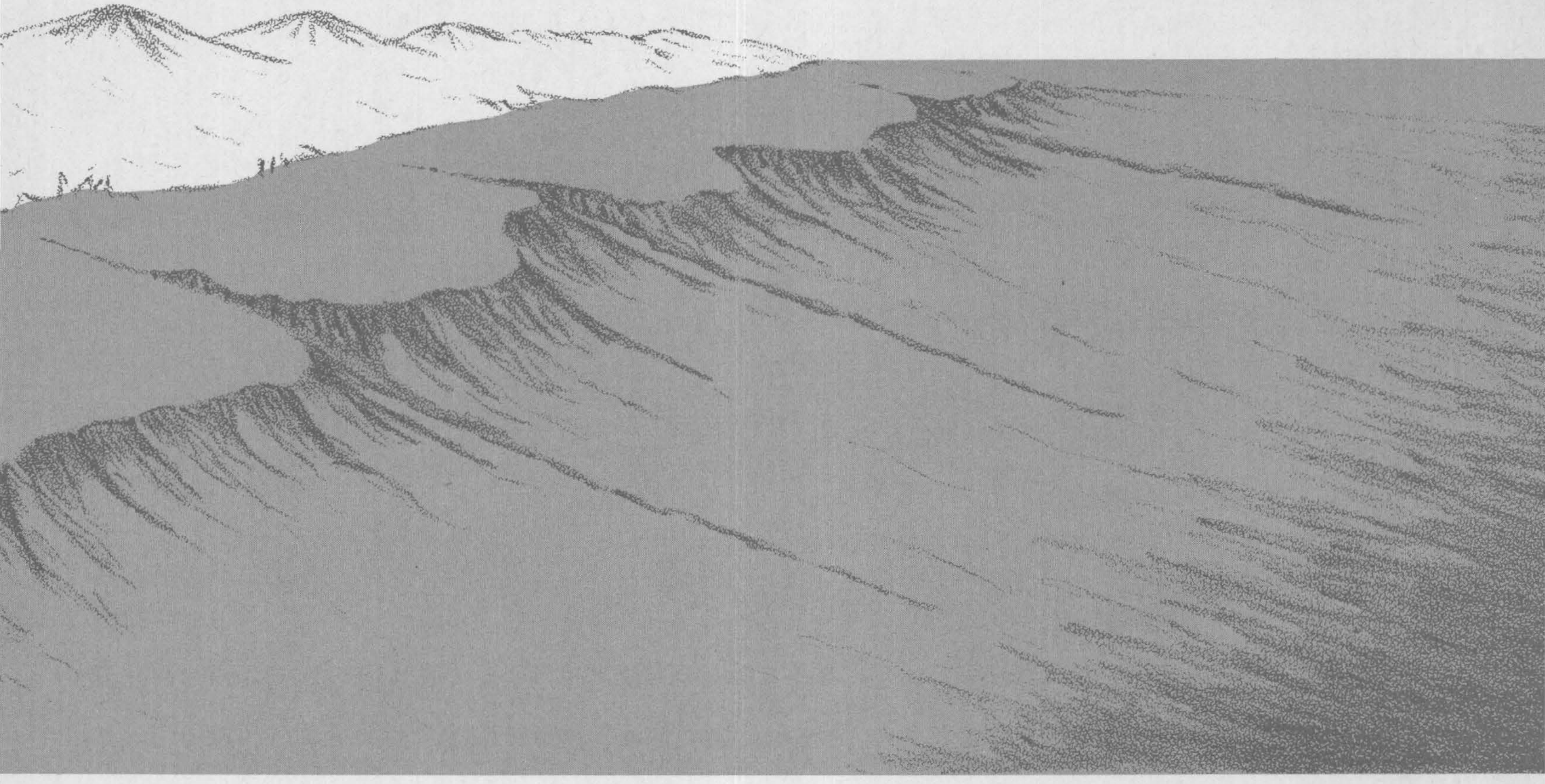
Atlantic Continental Shelf and Slope of the United States



Nineteenth Century Exploration

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-F

Atlantic Continental Shelf and Slope of the United States— Nineteenth Century Exploration

By THOMAS J. M. SCHOPF

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Prepared in cooperation with the Marine Biological Laboratory and the Woods Hole Oceanographic Institution

A synthesis of early work on topography, sediments, biology, bedrock geology, and water studies

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ABSTRACT

Two periods of exploration of the east coast of the United States are prominent. The first (1807–70) was characterized by initial broad surveys of underwater topography by the U.S. Coast Survey and of sediments, especially by J. W. Bailey and L. F. de Pourtalès. It ended with publication by Pourtalès of the first map summarizing sediment distribution on the continental shelf from Florida to Cape Cod. The second period (1871–87) coincided with the existence of the U.S. Fish Commission and was a time during which great emphasis was given to description of the offshore fauna of the shelf, especially the invertebrates. A. E. Verrill was foremost among those who documented this faunal diversity. By 1878, rocks dredged by fishermen had led to a correct interpretation of the origin of Georges Bank and other fishing banks though the bedrock geology of the rest of the shelf remained little known. Water studies were of little value until the introduction of a reliable reversing thermometer in 1878, and few systematic studies were made of water temperature and currents until the 20th century. The effects of continental glaciation as a major factor influencing the history and present environment of the shelf were usually misunderstood.

INTRODUCTION

A comprehensive geological-biological survey of the American Atlantic continental margin (Emery, 1966a; progress summarized by Emery, 1965, 1966b) has been in progress for 5 years. It is the logical continuation of pioneering investigations of middle and late 19th-century and early 20th-century naturalists (Colton, 1964). Foremost among these early scientists of the last century were Jacob W. Bailey, Louis F. de Pourtalès, and Addison E. Verrill. The work of these men and their contemporaries helps to provide a basis for understanding the importance of present work on the continental shelf (fig. 1).

This paper is organized by the subjects that these men investigated. The reader will note, however, that there were two periods of early exploration. The first (1807–70) was characterized by initial broad surveys of underwater topography and sediments; it began with the establishment of the "Survey of the Coast" in 1807 and ended with the publication of the first map to show sediment distribution on the continental shelf from Cape Cod to southern Florida (Pourtalès, 1870). The second period (1871–87) was one during which major attention was given to description of shelf organisms; immense collections of animals and plants greatly extended early ideas in faunal diversity and faunal provinces off the east coast of the United States.

ACKNOWLEDGMENTS

For suggestions about the way in which the topics discussed here should be handled, I wish especially to thank the following persons: K. O. Emery and Elazar Uchupi, Woods Hole Oceanographic Institution; James V. A.

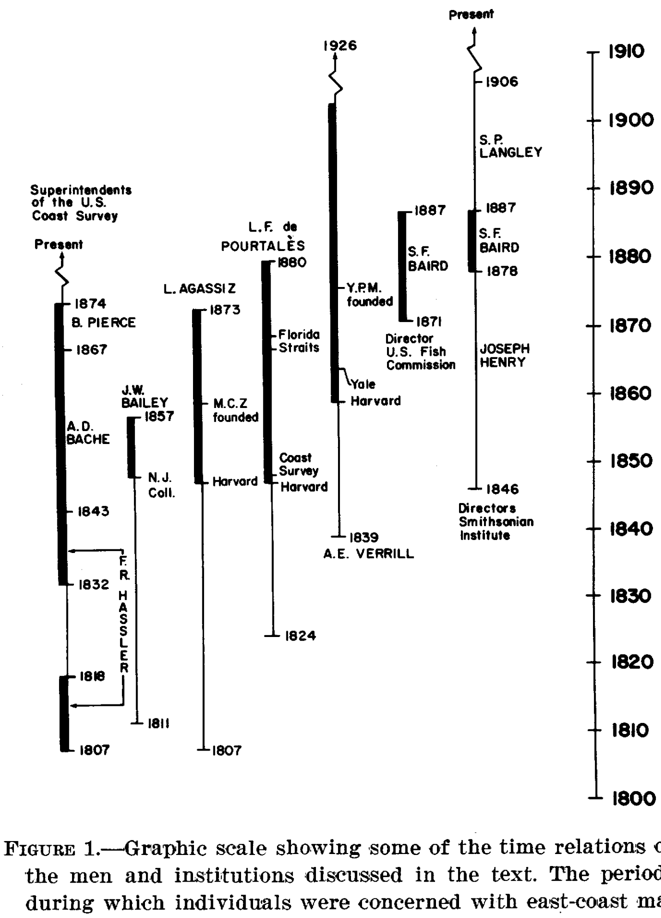

Figure 1.—Graphic scale showing some of the time relations of the men and institutions discussed in the text. The periods during which individuals were concerned with east-coast material are indicated by heavy lines. Life spans of Bailey, Agassiz, Pourtalès, and Verrill are shown. N.J. Coll., New Jersey Collections; M.C.Z., Museum of Comparative Zoology, Harvard; Y.P.M., Peabody Museum, Yale.

[1] Contribution 107 of the Systematics-Ecology Program. Contribution 1964 of the Woods Hole Oceanographic Institution.

[2] Lehigh University.

Trumbull and J. E. Hazel, U.S. Geological Survey; John B. Colton, Jr., Bureau of Commercial Fisheries, Woods Hole; Daniel A. Merriman, Yale University; Melbourne R. Carriker and Barry A. Wade, Marine Biological Laboratory; and J. William Schopf, University of California at Los Angeles. The work was supported by a grant from the Ford Foundation to the Marine Biological Laboratory, Systematics-Ecology Program.

TOPOGRAPHY

A period of 27 years (1807–34) was needed to initiate a bathymetric survey for America's east coast. In 1807, during Jefferson's administration, the U.S. "Survey of the Coast" (later "Coast Survey" in 1835 and "Coast and Geodetic Survey" in 1878) was established by the Treasury Department. It was responsible for determining coastal elevations, charting islands, shoals, and places of anchorage, and currents, and recording depths on what is now known as the continental shelf.

Ferdinand Rudolph Hassler (1770–1843), an immigrant Swiss engineer, was responsible for its organization and early growth. Wraight and Roberts (1957) acknowledge their scientific debt to him by writing: "Though he was proud and intolerant, constantly drawing down official censure upon himself by his irascibility, he nevertheless had an understanding of sound technical procedure and a sense of lasting values. By his strength of will and his sincerity, he successfully resisted those who wanted a quick and cheap job."

Initially the survey was beset with many difficulties that were not Hassler's doing. All instruments had to be newly designed or imported from Europe, and there were few trained people in the United States. Congress no sooner granted funds than it wanted to know when the job would be completed. The first series of shore elevations were determined in 1817 in Rhode Island, New York, and New Jersey (map published by Hassler, 1834). However, work was barely begun when the activities were transformed to the Navy (1818), and civilian personnel including Hassler could not be hired. In 1832, the Treasury Department reestablished control of the Survey of the Coast and, with Hassler back in charge, surveying extended north and south along the coast. Bathymetric surveying began in 1834 (Shalowitz, 1964, p. 214).

In 1843 Hassler helped to plan a major expansion of the Coast Survey but later in the year he died following an injury sustained during fieldwork. For the next 24 years, Alexander Dallas Bache (1806–67) was superintendent. Bache was the great-grandson of Benjamin Franklin and "chief founder" and first president of the U.S. National Academy of Sciences (Conklin, 1941). His first annual report in 1844 initiated a policy of yearly publication of charts that showed survey progress. He divided the Atlantic and Gulf coasts into nine sections, each to be mapped by separate parties (Colbert, 1941). In this way, many persons from different regions could be pleased, and indeed southern ports and populated regions were surveyed before the intervening uninhabited areas. Of additional interest at this time was the discovery of the Blake Plateau (see Pillsbury, 1883) by soundings of Lieutenants Craven and Maffitt that revealed a bank seaward of the Gulf Stream off Florida and South Carolina (Bache, 1854). In sum, a large body of new information was accumulated each year of Bache's administration.

Harvard mathematician and astronomer Benjamin Peirce (1809–80) was superintendent of the Coast Survey from 1867 to 1874. He sponsored intensive work aboard the *Corwin* (four stations, 1867) and *Bibb* (212 stations, 1868–70) in the Straits of Florida; these cruises resulted in an important series of bottom profiles (Pourtalès, 1871a, pl. 8) and the discovery of Pourtalès Plateau (named by L. Agassiz, 1869), later to be called Pourtalès Terrace (Jordan and Stewart, 1961). The general description of topography and sediment in that area by Pourtalès (1870, 1871b) was not greatly improved upon until recent detailed work of Jordan, Malloy, and Kofoed (1964).

Although soundings of water depth existed for much of the continental shelf in 1870, contours apparently were rarely shown for depths greater than 8 meters (Shalowitz, 1964, p. 252). Not until 1939, when echo-sounding provided continuous measurements over large areas, were charts published that showed contours in preference to sounding depths (Shalowitz, 1964, p. 284). Verrill and others who used 19th century charts had no real idea of local submarine canyons off New England, although Pourtalès (1870) and Dana (1880, p. 244) knew that the Hudson River valley extended seaward into the Hudson Canyon to depths of more than 200 meters. Veatch and Smith (1939) finally established the importance of these canyons.

In 1870, L. F. de Pourtalès, a zoologist and geologist associated with the Coast Survey and Harvard, summarized bathymetry and sediment distribution from Florida to Cape Cod. Areas north of this region were not described, probably because of greater bathymetric and sediment complexity. Encouragement from a growing fishing industry (especially persons engaged in catching cod and mackerel, and in whaling—see McFarland, 1911) in the later part of the 19th century resulted in exploration of the Gulf of Maine, but only in 1874 did its bathymetry become known in a general way. Indeed, the distribution and bathymetry of basins of the Gulf of Maine, which composes about 30 percent of its area, were compiled for the first time in 1965 (Uchupi, 1965).

By the summer of 1871 when A. E. Verrill began his collaboration with the U.S. Fish Commission, most of the major bathymetric features of the east coast continental margin had been mapped. The edge of the continent was known to occur at approximately the 200-meter line and not near the present shoreline. Extensive offshore soundings existed for the regions from Georges Bank to Delaware Bay, from southern North Carolina to northern Florida, and off southern Florida. Scattered soundings had been made for much of the remainder of the continental shelf and only the area off eastern Florida was virtually unsounded (Peirce, 1874, sketch no. 1).

Although gross bathymetric features were known, their origin was not well understood by Verrill. For example, he thought that the present surfaces of Nantucket Shoals, Georges Bank, and other banks were probably once islands "which have been worn down by the waves below the level of the sea." (Verrill, 1875b, p. 368). Although he was a student of Louis Agassiz (who developed the glacial theory) and a colleague of Dana (who strongly supported it), Verrill did not comprehend the consequences of continental glaciation either in supplying sediments or in modifying what is now submarine topography. He did recognize pre-Recent marine deposits above present sea level, and the erosional origin of fiords below present sea level, but he erroneously thought that land rather than sea level was the predominant unstable element. This assumption also appears as a premise in some of Verrill's notions about the distribution of animals.

The Coast Survey collected data chiefly from the continental shelf, but in addition excellent bottom profiles of the shelf, slope, and rise resulted from cruises of the *Blake* in 1880–83. Pilsbury (1883; republished anonymously, 1883) prepared 27 profiles covering transects from Georges Bank to Puerto Rico, some extending as far seaward as Bermuda. The Navy worked more extensively in deeper water than on the shelf. Among important deep-water soundings were those taken by the Brooke sounding apparatus in 1852–53 on Lieutenant Berryman's Newfoundland-to-Ireland cruise to locate the best place for the transatlantic telegraph cable (Williams, 1963). Based on these soundings, the first bathymetric chart of the North Atlantic Ocean showing depths at 1,000-meter contour intervals was prepared by Matthew Fontaine Maury (1861) of the "Depot of Charts and Instruments" (later the U.S. Navy Oceanographic Office).

SEDIMENTS AND BIOLOGY

Three men, J. W. Bailey, L. F. de Pourtalès, and A. E. Verrill, were responsible for many of the fundamental advances in the knowledge of distribution of sediments and organisms in the middle to latter part of the 19th century. At that time, those who studied sediments also studied animals and plants, and indeed larger sediment samples included a significant collection of organisms.

WORK OF J. W. BAILEY

Bailey (fig. 2), Professor of Chemistry, Mineralogy, and Geology at the U.S. Military Academy from 1838 to 1857 was the first worker to describe sediment composition from the American Atlantic Continental Shelf and Slope. Early in his career, he published papers on taxonomy and distribution of fossil and living plants, especially diatoms and other algae. In 1848, Bailey collected lead line samples at depths of approximately 20, 40, 100, and 200 meters on transects extending seaward from four locations along the New Jersey coast. The expectation was that quartz sands or muds, similar to the nearshore deposits, would occur in deeper water.

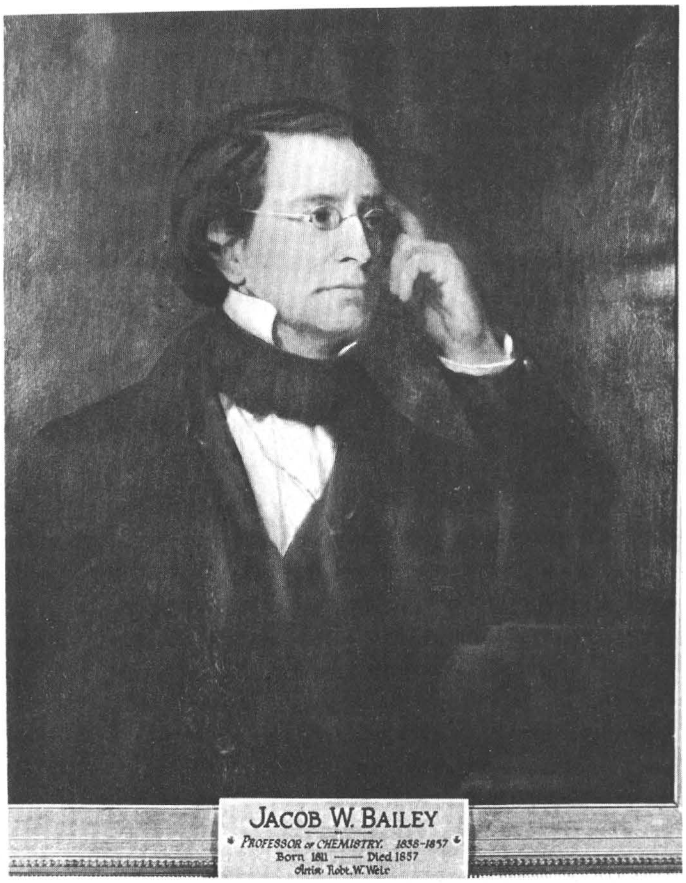

FIGURE 2.—Jacob W. Bailey by Robert W. Weir. From U.S. Military Academy Archives.

Bailey (1851) was greatly surprised to find Foraminifera dominating the 100- and 200-meter samples.

Later, Bailey showed that deeper water samples from other temperate latitudes differed greatly from shoreline deposits. From sediment collected by the Brooke sounding apparatus in 1852–53 from depths of 2,000–4,000 meters in the North Atlantic, Maury sent five samples to Bailey. In these, Bailey found abundant complete Foraminifera that were different from species previously seen in New Jersey shelf deposits. A few diatoms, sponge spicules, and radiolarians, as well as broken Foraminifera, constituted the finer sediment fraction (Bailey, 1854). In 1855, he discovered that Foraminifera were dominant in samples from 300 to 400 meters off Key Biscayne, Fla., (Bailey, 1856a). In 1856, he described the process of glauconite formation in deposits near the seaward limit of the shelf off eastern Florida. This description confirmed the hypothesis previously suggested from rock samples by the paleontologist Ehrenberg in Europe (Bailey, 1856b). In fact, so extensive were the discoveries of Bailey, that at his death, the prominent taxonomist Augustus Gould (1857) referred to him as the "Ehrenberg of America."

WORK OF COUNT L. F. de POURTALÈS

Pourtalès (fig. 3), a student of Louis Agassiz at Neuchâtel, Switzerland, followed his mentor to the United States in 1847, and the following year entered the service of the Coast Survey (A. Agassiz, 1881). In an 1850 paper, Pourtalès "confirmed and extended" Bailey's 1848 observations on depth zonation of Foraminifera on the New Jersey continental shelf (Bailey, 1854; Bache, 1851). However, although Bailey and Pourtalès had shown that tests of Foraminifera and other organisms occurred in deeper water, the question remained whether these organisms lived at the greater depths or were only accumulated there. From samples obtained by Craven and Maffitt (Bache, 1854) from the Blake Plataeu, Pourtalès reported that Foraminifera, which accounted for 95 percent of the samples, were probably alive. In addition he discovered "some delicate shells of molluscs from depths beyond [1,000 meters], where they were certainly living" (Pourtalès, 1854).

Between 1867 and 1869, Pourtalès carried out pioneer studies in the use of a dredge to obtain large benthic organisms in the Florida Straits. This was one of the early attempts to find out whether or not larger organisms lived at depths as great as 200 meters and paralleled the investigation aboard the H.M.S. *Lightening* and *Porcupine* on the eastern side of the Atlantic (Herdman, 1923, p. 41). Pourtalès was greatly impressed when he discovered that "*animal life exists at great depths* [200–500 meters], *in as great a diversity and as great an abundance as in shallow water*" (Pourtalès, 1867; italics his). Later he wrote:

> The discovery of so varied a fauna at such great depth is an unexpected result in the history of the geographical distribution of organized beings. The examination of numerous specimens of seabottom brought up by the lead has made us acquainted with a fauna very rich in individuals, though poor in species, and indeed confined almost entirely to one of the lowest classes of the animal kingdom, the foraminifera. The dredge has shown us now that they form but the lowest step, and that above them rise representatives of all the higher branches, except perhaps the vertebrata, (fishes,) and of the presence or absence of the latter we have no proof, probably only because we have as yet employed no means to procure it (Pourtalès, 1869).

It is not surprising that Louis Agassiz (1869) concluded that "we owe to the Coast Survey the first broad and comprehensive basis for an exploration of the sea bot-

FIGURE 3.—L. F. de Pourtalès. From archives of the Museum of Comparative Zoology, Harvard University.

tom on a large scale, opening a new era in zoological geological research."

The first extensive collections of sediments and organisms from off eastern North America were made by the U.S. Coast Survey during Bache's administration (1843–67), but they were not described until 1870 and 1872. Pourtalès (1867, p. 104) stated that from eight to nine thousand samples had been obtained from the sounding lead from depths down to 2,700 meters by hydrographic parties. These samples formed the basis for his 1869 report to the Coast Survey in which he summarized the distribution of shelf sediments, including types of foraminiferal oozes, from Florida to Cape Cod (Pourtalès, 1872). The color maps that were prepared for this summary were not published by the Coast Survey but did appear with the German translation in Petermann's journal (Pourtalès, 1870). This pioneering work, essentially correct in its main features, is comparable to the map of Uchupi (1963), compiled from the literature 90 years later. The main features unrecognized by Pourtalès were the increase in coarseness of sediments going seaward on the shelf, which indicates that shelf deposits are mainly of relict origin (Shepard and Cohee, 1936; Emery, 1965), and extensive manganese and phosphorite deposits of the Blake Plateau (Pratt and McFarlin, 1966).

WORK OF A. E. VERRILL

Verrill (fig. 4) extended knowledge of marine biology off the New England coast more than any other 19th-century scientist. Born in Greenwood, Maine, his earliest publications dealt with minerals and birds collected in his youth. At the age of 20, he went to Harvard to continue his studies of natural history under the direction of Prof. Louis Agassiz, Director of the newly founded (1859) Museum of Comparative Zoology. Verrill joined Alpheus Hyatt, Nathaniel Southgate Shaler, E. S. Morse, and others in working with one of America's best natural history libraries and collections. However, the young scientists were forced to restrict their professional advancement in favor of that of the museum and its director. When Verrill and his colleagues came to independent scientific judgements, especially on the theory of evolution (which Agassiz strongly opposed), the association became unbearable and several students revolted against Agassiz and left in 1863–64 (Dexter, 1965). Thus at the age of 25, Verrill went to Yale as the first professor of zoology in the United States. He was hired by the eminent zoologist and geologist James Dwight Dana (1813–95), and Verrill taught zoology and some geology until his retirement in 1907 (G. E. Verrill, 1958).

In contrast to another famous 19th-century naturalist, Charles Darwin, Verrill did not construct major theoretical systems and develop his work around them as Darwin had done, for example, with his theories of evolution, natural selection, sexual selection, and coral-reef origins. Verrill's approach to scientific problems was much less theoretical. The major theme in his work was the documentation of the diversity of life (independent of the reasons for this) and the relationships between these organisms and the physical environment which they inhabit. His best contributions to science were in making intelligent observations on the life history of individual species, such as his excellent work on the squid *Loligo pealeii* (Verrill, 1882), in describing the fauna from many localities, and in forming inductive generalizations based on his observations.

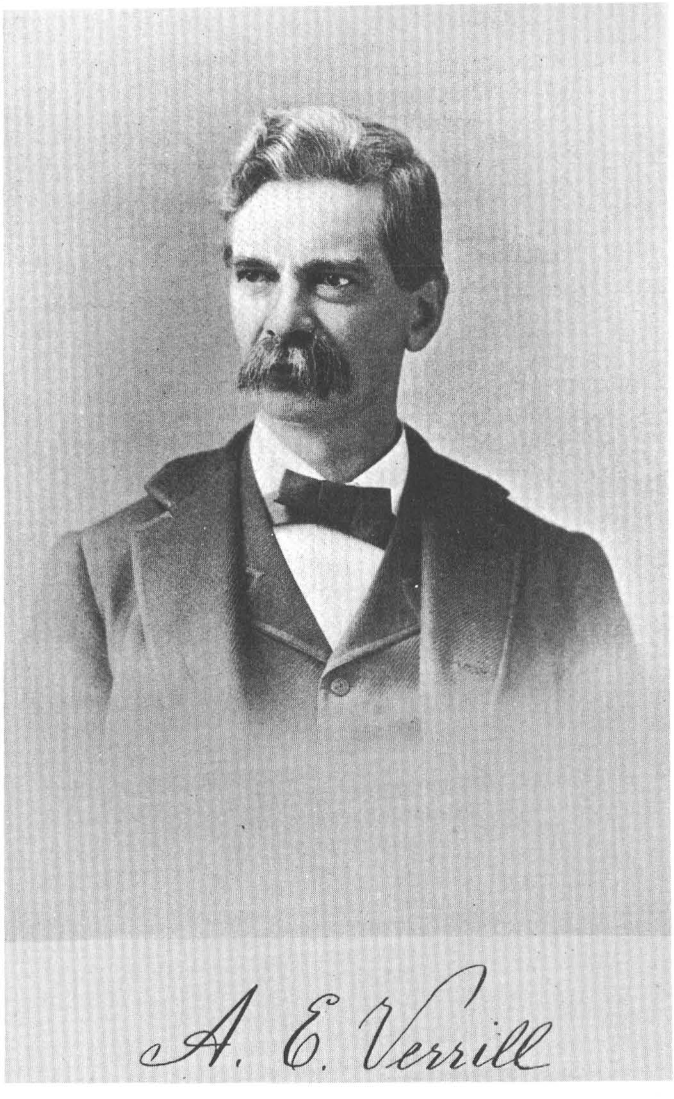

FIGURE 4.—Addison Emery Verrill. Reproduced from frontispiece in "The Ancestry, Life and Work of Addison E. Verrill of Yale University" by George E. Verrill (1958).

His general view of biology was well stated by Coe (1930):

> Verrill did not directly participate in * * * more modern phases of biological research and had little patience with those who were acquainted with animals only under laboratory conditions. He sought always to emphasize the fact that much of the more recent work has been possible only because of the foundations laid by a small group of able men who, since the middle of the last century, have explored the vast fields containing previously undiscovered forms of life and have thereby made known the morphology, natural history and relationships of the organisms available for more specialized and experimental investigations.

In his career, Verrill published more than 300 articles with 800 plates, mostly of organisms (G. E. Verrill, 1958, p. 71). He described "well above a thousand" species (Coe, 1930, p. 30) belonging to all major animal groups except the protozoa. His geological contributions were summarized in a six-chapter "Science" article (Verrill, 1883a, b, c, 1884a), and republished with few changes in the report to the Fish Commission (Verrill, 1884b).

Verrill's work on sediments consisted chiefly of explanations for the origin of anomalous marine deposits. He did not attempt to synthesize available data on sediment distribution. Verrill thought it strange that sand should be found in sea water far from shore and decided that

> Another way, generally overlooked, in which fine beachsand can be carried long distances out to sea, is in consequence of its floating on the surface of the water after it had been exposed to the air, and dried on beaches. The rising tide carries off a considerable amount of dry sand, floating in this way. In our fine towing-nets we often take more or less fine siliceous sand which is evidently floating on the surface, even at considerable distances from the shore (Verrill, 1883c, p. 153).

More recently, Hume (1964) described chert pebbles and sand floating on sea water near shore in an area of glacial debris.

Verrill recognized that the occurrence of large igneous and metamorphic boulders in muddy sediment is anomalous. In describing substrates 15–30 miles southeast of southern Maine, Verrill (1874c, p. 345) wrote, "On one occasion we brought up in the trawl from [118 meters] an angular bowlder, estimated to weigh over 500 lbs. These bowlders were probably transported from the adjacent coast by shore-ice in spring." Similarly in describing substrates from the continental slope south of Cape Cod, Verrill (1883c, p. 153) wrote,

> In many instances, even in our deepest dredgings [about 1,300 meters], * * * we have taken numerous pebbles, and small rounded bowlders, of all sizes, up to several pounds in weight, consisting of granite, syenite, micaschist, etc. * * * Probably, while frozen into the shore-ice in winter and spring, they have been recently floated out from our shores and rivers, and dropped in this region, where the ice melts rapidly under the influence of the warmer Gulf-Stream water. Probably much of the sand, especially the coarser portions, may have been transported by the same agency.

These coarse deposits are now considered to have been transported by glacial ice and melt water. This idea was understood by Dana (1873, p. 210) who wrote that the shallowness of the continental shelf waters off Long Island "is probably due partly to deposits from the glaciers; and also that of the waters between Cape Cod and Nova Scotia, where the part of the glacier over Maine is supposed to have terminated." Just as in explaining the *origin* of present submarine land forms, Verrill did not appreciate the concept of continental glaciation.

From 1871 to 1887, by far the most important east coast biological collections were made by the U.S. Fish Commission from New England waters. Spencer F. Baird (1823–87), the first Director of the Fish Commission and the second Director of the Smithsonian Institution, undertook a sampling program that yielded 3,000 dredge hauls, more than 2,000 invertebrate species and several hundred thousand specimens (G. E. Verrill, 1958, p. 68). The invertebrates and many of the more significant geological specimens were studied by Verrill and his associates at Yale. In addition, the Fish Commission arranged for Verrill to receive and describe any unusual specimens brought in by fishermen at the famous port of Gloucester, Mass., and several extensions in the ranges of organisms were thus published (anonymous, 1882). Regions from which Verrill had material are summarized in table 1 and figure 5. Prior to 1882, dredging was conducted from naval tugs (A. Agassiz, 1888), but thereafter vessels specifically built for oceanographic work were used: the *Fishhawk* (1882) and the *Albatross* (1883). Until the present continental margin program (Emery, 1966a), no naturalist since Verrill has had the opportunity to work with such diverse and abundant collections of the invertebrate fauna from the American Atlantic Shelf and Slope.

A good example of Verrill's inductive generalizations is his conclusion that "* * * the climatic distribution of most marine animals seems to depend mainly on the temperature of the season at which reproduction takes place" (Verrill, 1874c, p. 375). Generalizations that Verrill proposed based on a reconstruction of past physical conditions were notably less successful because he thought that land rather than sea level had greater vertical mobility. For example, after noting the anomalous warm-water elements of the Casco Bay, Maine, fauna, he remarked that "* * * a rise of the land in the region of Saint George's Bank, to the extent of 250 feet [75 meters], would produce an island quite as large as the State of Massachusetts, and would thus very

TABLE 1.—*Summary of base of operations, areas dredged, number of stations, and ships used by the U.S. Fish Commission from 1871 to 1887 on the continental shelf and slope off eastern United States*

[Summarized from Smith (1889)]

Year	Base of operations	Area dredged	Number of stations	Ship
1871	Woods Hole, Mass	Vineyard Sound	348	Sailboat, steam launch, and *Moccasin.*
1872	Eastport, Maine	Eastport, Grand Menan, Bay of Fundy	15	Sailboat and *Mosswood.*
		Georges Bank, Le Havre Bank	19	Bache.
1873	Peak Island, Casco Bay, Maine.	Casco Bay, off Portland	112	*Bluelight.*
		Gulf of Maine, especially Jeffreys and Cashes Ledges; Massachusetts Bay.	37	*Bache.*
1874	Noank, Conn	Fishers Island Sound, Long Island Sound, Block Island Sound, adjacent bays.	180	*Bluelight.*
		Gulf of Maine	41	*Bache.*
1875	Woods Hole, Mass	Vineyard and Nantucket Sounds, Buzzards Bay, Nantucket shoals.	169	*Bluelight.*
1876	None.			
1877	Salem, Mass., Halifax, N.S	Massachusetts Bay, off Cape Ann, Cape Ann to Cape Sable, off Halifax.	128	*Speedwell.*
1878	Gloucester, Mass	Massachusetts Bay, off Cape Ann	110	Do.
1879	Provincetown, Mass	Massachusetts Bay, off Cape Cod	140	Do.
1880	Newport, R.I	Narragansett Bay, Sakonnet River, off Block Island, 3 Gulf Stream trips, off Chesapeake Bay.	147	*Fish Hawk.*
		Georges Bank to Cape Hatteras	47	*Blake.*
1881	Woods Hole, Mass	7 trips to Gulf Stream, Vineyard Sound, Buzzards Bay, off eastern Cape Cod.	133	*Fish Hawk.*
1882	do	5 trips to Gulf Stream	101	Do.
		Vineyard Sound off eastern Cape Cod; South of Martha's Vineyard.	5	*Josie Reeves*
1883	do	Washington D.C. to Woods Hole	116	*Albatross.*
		Off Nantucket and Martha's Vineyard	21	*Fish Hawk.*
1884	do	Cape Hatteras to Georges Bank	194	*Albatross.*
		Off Martha's Vineyard, Buzzards Bay	15	*Fish Hawk.*
1885	do	20°–47° N., 49°–87° W	318	*Albatross.*
1886	do	23°–47° N., 44°–82° W	121	Do.
		Off Martha's Vineyard	5	*Fish Hawk.*
1887	do	Vineyard Sound, Block Island Sound, Nantucket Sound.	55	Do.
Total			2,577	

materially alter the climatic conditions of the Gulf of Maine, between it and the New England Coast" (Verrill, 1874c, p. 377). He thought the effect of this would be to diminish the force and height of tides along the coast and thereby "allow greater differences between the temperatures of the shallow water and deep waters, and would thus favor southern species inhabiting shallow water." Present explanations of this kind of anomalous faunal distribution depend upon the effects of warming of the ocean combined with higher stands of sea level that would put the present Cape Cod land barrier underwater.

Having worked in detail with marine invertebrates off New England for 35 years, Verrill often remarked on faunal affinities of various collections, but he never summarized his observations. Based on his papers, a map of faunal regions is presented (fig. 5) as Verrill might have considered them.

The difference in the fauna on the north and south sides of Cape Cod, which Verrill well documented, had been noticed in previous studies (Gould, 1840, 1841; Dana, 1852, p. 1451, 1853a, 1853b) and has been supported by more recent work. Allee (1923), in a nine-summer study of invertebrates of Woods Hole, Mass., characterized the fauna (241 invertebrate species) as 55 percent south ranging and 30 percent north ranging, the remainder being in the middle of their ranges. Additionally, 40 percent of the species was not known north

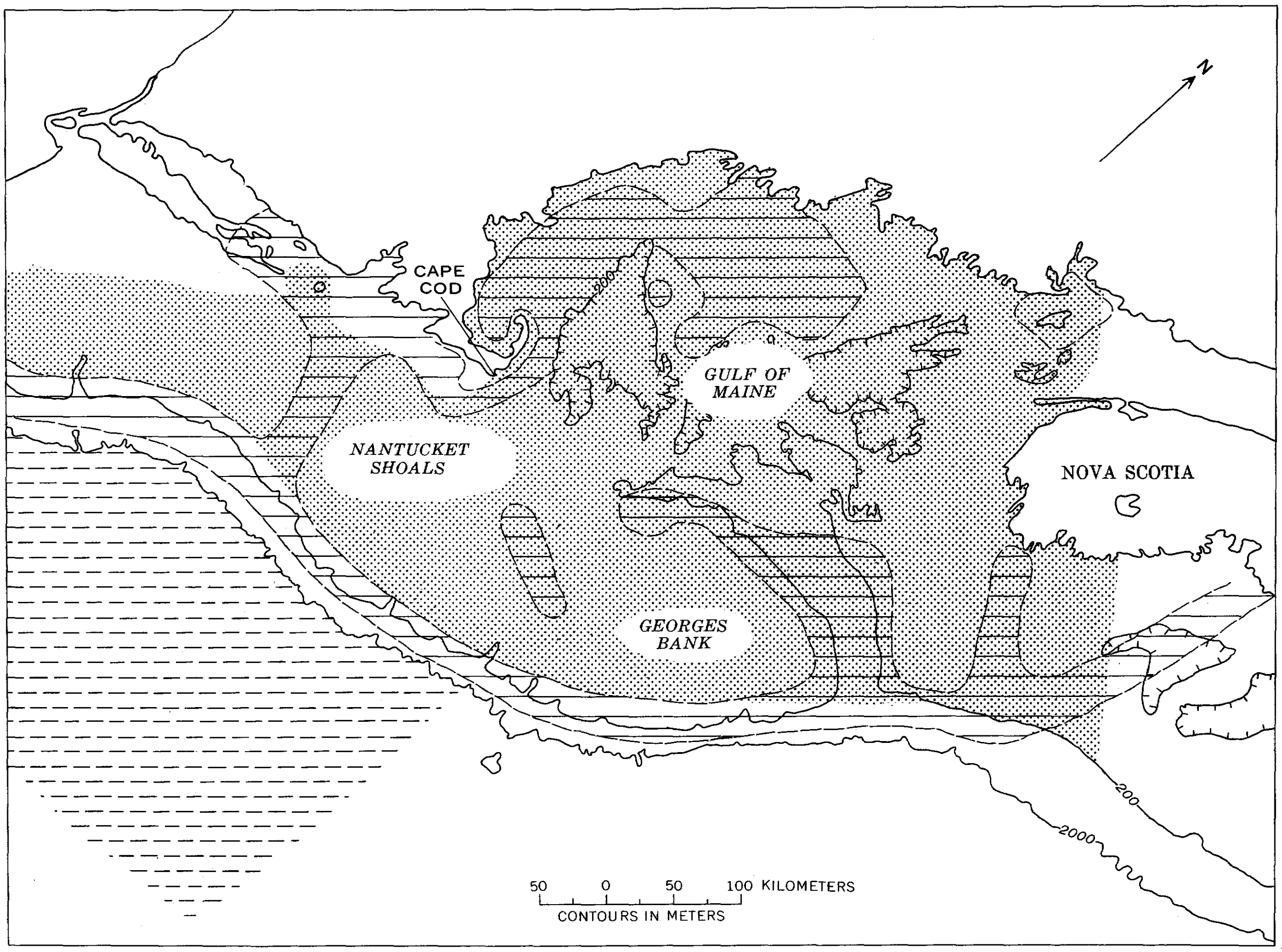

FIGURE 5.—Faunal regions postulated by A. E. Verrill, prepared from scattered comments in papers of the 1870's and 1880's. The stippled pattern represents Verrill's idea of the Acadian or arctic faunal region. The clear area southwest of Cape Cod is the northern extension of his Virginian faunal region. Areas from which Verrill had collections are horizontally ruled in water shallower than 2,000 meters and dashed for water deeper than 2,000 meters. Collections from the deeper water were notably more scattered and fewer than those in shallower water.

of Cape Cod and 11 percent not known south of Vineyard Sound, which borders the south side of Woods Hole. Setchel (1922) discussed Cape Cod as a barrier for nearshore algae. He indicated that approximately 25 percent consists exclusively of northern forms, 20 percent exclusively of southern forms, with 55 percent occurring on both sides of the Cape, often sparingly. More broadly speaking, of all Cape Cod algae, 47 percent is considered north ranging, 50 percent south ranging, and 3 percent of uncertain range.

On a broader scale, Verrill probably considered the organisms off Nova Scotia, in the Gulf of Maine, and on Georges Bank and Nantucket Shoals as parts of a general arctic fauna. The region east of Nova Scotia was called arctic. The Gulf of Maine was considered "almost purely arctic." The northeastern part of Georges Bank was considered "more boreal" than the southeastern part.

Published reports of offshore collections over wide areas are still very limited, but at the present time the chief change in Verrill's faunal provinces would be to relate Nantucket Shoals and Georges Bank much more closely to the Virginian fauna than to the Acadian fauna. For the offshore, the data of Fritz (1965) for groundfish, Parker (1948) for benthic Foraminifera, Petersen (1964) for hydroids, and Schopf (1965) for bryozoans suggest that the faunas northeast of the Cape are decidedly different from these south and southwest of it. The distribution of groundfish and bryozoans in particular indicate that the fauna of Georges Bank has more in common with Nantucket Shoals than with the Gulf of Maine or the Nova Scotia shelf.

The factor controlling the southern distribution of colder bottom water currents is the land barrier of Cape Cod and Georges Bank which turns and confines them and sets up a large counterclockwise gyre in the Gulf of Maine (see Bumpus and Lauzier, 1965). Some of the shallower water appears to spill from the Gulf of Maine into Georges Bank or southward onto Nantucket Shoals, but this water is warmed rapidly in the shallower areas (see Schopf, 1967).

CONTINENTAL MARGIN BEDROCK GEOLOGY

By the 1870's and 1880's, enough was known of marine sediments off New England to indicate that rocks of different composition and origin underlay surficial deposits in different areas. Indeed, rock samples dredged by the Fish Commission and Gloucester fishermen permitted Verrill and others to arrive at an essentially correct understanding of the basic geological structure of Georges Bank, the Canadian fishing banks, and Cashes Ledge in the Gulf of Maine.

Several early writers have mentioned the origin of Georges Bank and other fishing banks. Upham (1894) stated that Hitchcock (1877) wrote that the fishing banks were at Terteriary age and that Louis Agassiz "much earlier * * * had taught his classes that they must consist superficially of drift, the eastern continuation of the drift sheet of the northern United States and Canada." From fossiliferous blocks obtained by Gloucester fishermen, Verrill supported a "Miocene or later Tertiary" age for this "hitherto unknown geological formation" (Verrill, 1878). He thought that the formation extended "at least several hundreds of miles in length * * * from off New England nearly to Cape Cod, and perhaps constitut[ed] in large part, the solid foundations of these remarkable submarine elevations." Emery and Uchupi (1965) recently showed by continuous seismic reflection profiles that this explanation is correct at least for Georges Bank.

The composition and regional relationships of ledges and banks within the Gulf of Maine were little examined by the early workers, and not much more is known at the present time. However, for Cashes Ledge, Verrill (1874b) wrote:

> Since it is in range with the extensive belt of syenitic rocks which, running in a southwestern direction, terminate in the mountains of Mt. Desert and the smaller island situated farther south, Cashes' Ledge is, in all probability, a sunken island belonging to the Mt. Desert group. The rocks of Mt. Desert are mostly massive reddish colored syenites, often passing into granite and hyperite. Many of the fragments brought up on the dredge at Cashes' Ledge are of the same kind of rock and the mud of the same region is reddish brown * * * and under the microscope shows minerals characteristic of this granitic formation.

Toulmin (1957) described a rock dredged from Cashes' Ledge as a peralkaline granite of a type that is quite similar petrographically to granites from eastern Maine, eastern Massachusetts, and the New Hampshire White Mountains. Uchupi (1966) used results from seismic surveys to suggest that the bulk of Cashes Ledge is granite. Toulmin's and Uchupi's data emphasize Verrill's conclusion that rocks of this granitic type extend farther seaward than is generally recognized.

WATER STUDIES

Bigelow (1927) wrote that surface temperatures in the Gulf of Maine were obtained as early as 1789 but that "the first attempt to measure the temperature of the gulf below the surface was made in the summer of 1870, when Verrill (1871, p. 3) found the water virtually homogeneous, surface to bottom, in Passamaquoddy Bay, though readings with thermometers of the maximum-minimum type established a considerable range of temperatures on the offshore slope of Georges Bank (Verrill, 1873a, b, c; Smith, 1889, p. 887) * * *." Additionally in 1872, Verrill (1874a, p. 408; 1874c, p. 345) "was able to bring to scientific attention the contrast between the low bottom temperature and the warm surface of the western side" of the Gulf of Maine (Bigelow, 1927). Indeed, Verrill tried to relate bottom temperatures to the distribution of benthic animals. Verrill was most successful in this in nearshore areas where the most complete temperature data were available.

Verrill (1873a, p. 3; 1874a, p. 406; 1875a, p. 413) recognized the need for improving the Miller-Casella maximum-minimum thermometer currently in use, which registered the lowest temperature reached and not necessarily that of the depth to which it was lowered. Reversing thermometers were perfected during cruises of the *Blake* (1877–80) (Sigsbee, 1880), and Verrill adopted their use in the Gulf of Maine. Accordingly, Bigelow (1927) concluded that "modern oceanographic research in the Gulf of Maine may * * * be dated from the summer of 1878" when Nagretti-Zambra reversing thermometers were used in the Coast Survey ship *Speedwell.*

Surprisingly little was known of surface or bottom circulation in the Gulf of Maine and connected water bodies in Verrill's time. As late as 1881, Mitchell was unraveling problems of tidal drift and there was almost no information on nontidal drift. Verrill mentioned that there was a southward flowing cold current on the shelf south of New England and landward of the Gulf Stream, but he erroneously thought this derived directly from a cold current flowing southwestward along the seaward side of Nova Scotia. Drift bottles were first systematically used in circulation studies in 1919 (Bigelow, 1927); this and later drift-bottle work are summarized by Bumpus and Lauzier (1965).

Verrill (1883b) observed the effect of Gulf Stream water in warming slope water but made no other general observations on it. The history of ideas concerning the cause of the Gulf Stream, and in particular those that were expounded by Verrill's contemporaries, is given by Stommel (1950, 1958).

SUMMARY AND CONCLUSIONS

Information on bottom topography of the Atlantic Continental Shelf was first obtained in 1834—27 years after founding of the "Survey of the Coast." Throughout the 19th century, detailed bathymetric charts were limited to near-coastal areas. Despite excellent bottom profiles, some extending seaward to Bermuda (Pillsbury, 1883), local shelf and slope bathymetry was not known because lack of soundings did not permit accurate contouring in deeper water. Hence, submarine canyons were not recognized as important physiographic features as they are today (Veatch and Smith, 1939).

Knowledge of shelf sediments and organisms was initiated by the studies of Bailey about 1850 in transects off New Jersey. During the next 20 years, eight to nine thousand samples were obtained from the sounding lead from Florida to Cape Cod. Pourtalès (1870) summarized the sediment distribution for this area, and his maps are comparable to those made nearly a century later (Uchupi, 1963). In 1867–69, the Coast Survey gave Pourtalès the opportunity to dredge for large benthic organisms in a few hundred meters of water off Florida. The presence of large animals was a revolutionary discovery which the Fish Commission and Verrill were later to exploit.

From 1871 to 1887, most of the new information of continental shelf biology, water studies, and geology was based on data collected off New England. Using the several hundred thousand specimens from the more than 3,000 dredge samples, Verrill and his Yale colleagues systematically described the New England inshore and offshore fauna. Many remarks were made on the faunal affinities of various collections, but a map of faunal provinces was never constructed. Such a map is presented here to summarize Verrill's comments on this subject.

Verrill initiated modern oceanographic research in the Gulf of Maine by the use of accurate thermometers to record surface and bottom temperatures, but unfortunately no method was devised for following surface or bottom currents. In matters of geology, he correctly surmised that Georges Bank was underlain by Tertiary rocks, but he did not understand the effects of continental glaciation in supplying sediments, shaping land surfaces, or altering sea level. This was perhaps Verrill's most serious mistake because he came to the erroneous conclusions that present sediments had been largely formed by in situ erosion, that anomalous large boulders had been chiefly carried seaward by recent spring ice flows, and that warmer water faunal enclaves in a few Gulf of Maine bays were due to faunal migrations in past times when Georges Bank had risen high enough to diminish the influence of the colder water.

The pioneering work of Bailey, Pourtalès, and Verrill on the continental shelf was not substantially improved upon until at least the second quarter of the 20th century. The chief advance in topography is the work of the Coast and Geodetic Survey summarized by Uchupi (1965, 1968). The chief modern water studies of the shelf are those of Bigelow (1927) and Bumpus and Lauzier (1965). Outstanding new work in sediments, bedrock geology, and biology promises to result from the current Woods Hole Oceanographic Institution-U.S. Geological Survey Program for the Atlantic Continental Margin (Emery, 1966a). Biological collections made during this survey are being analyzed by more than 25 taxonomic specialists, and their effort is being coordinated by Roland L. Wigley of the Bureau of Commercial Fisheries, Woods Hole.

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