Georges Bank

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Georges Bank

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This work is dedicated to Canadian/American friendship

and to an American Canadian, Gordon A. Riley (1911–1985),

innovative and productive student of Georges Bank.

This whole book is but a draught—nay, but the draught of a draught.

Oh, Time, Strength, Cash, and Patience!

–Moby-Dick

Contents

IV CONFLICTING USES

Foreword

Richard H. Backus

When the United States Department of the Interior first announced its plans for the leasing of tracts for petroleum development on Georges Bank in 1974, the bank already had yielded Yankees rich harvests of codfish year after year for a century and a half and for some lesser time halibut and haddock, flounders, swordfish, and scallops. It was little wonder, then, that fishing interests became alarmed at the prospect of sharing the bank with the oil companies, perhaps to the point of substantial damage to themselves. Also, environmentalists feared that petroleum would damage the bank, perhaps permanently, and harm the adjacent coasts as well. It was not long before these concerns were organized and formalized and carried to the United States District Court in Boston, where on 19 January 1978 the Conservation Law Foundation (in behalf of seven fishermen's and environmental organizations) and the Commonwealth of Massachusetts brought suit against the secretaries of the Departments of Commerce and the Interior and the administrator of the National Oceanic and Atmospheric Administration. But for this and the consequent delays, exploratory drilling on Georges Bank, which began on 24 July 1981, might have begun two or three years earlier and under a different set of rules.

Furthermore, when the United States and Canada extended their jurisdiction over fisheries to 200 nautical miles in 1977, these management zones overlapped in the Gulf of Maine and on Georges Bank, and the international boundary came into dispute. In 1979, the two nations signed two treaties; one concerned the conservation and management of fisheries in the boundary region, and the second agreed that the boundary would be fixed by third-party adjudication. Neither treaty was to go into force without the other. Pressure from New England fishermen prevented ratification of the fisheries treaty and President Ronald Reagan withdrew it in March 1981. Canada, though displeased, agreed to a separate settlement of the boundary dispute, which was heard by the International Court of Justice in 1984.

These disputes, particularly the "oil/fish" one, drew the attention of the New England public to Georges Bank as nothing had before and also focused new attention from the Atlantic seaboard's oceanographers. Not that oceanographers were newcomers to the bank; they had made the elemental oceanographic measurements of temperature and salinity and some preliminary estimates of net current 60 years before. Also, from about 1930 on, fishery scientists of the federal government had worked patiently there, trying to understand the disconcerting ups and downs that all large populations of fish seem to make. Further, the basic matter of the rate at which the bank's microscopic plants multiply in the presence of sunlight and certain essential nutrient chemicals (what we would call fertilizer in a corn field) had been studied since about 1940. This primary production, as it is known, is fundamental to the bank's wealth, of course, for everything that eats there, man included, is consuming these little plants, though often indirectly. Finally, there had begun early in the 1970s a general and rapid increase in studies of the nation's continental shelves, of which no part was more interesting than Georges Bank.

The "oil/fish" dispute on Georges (it had been going on elsewhere for some time) spurred further physical, chemical, geologic, and biologic studies on the bank—research that for the most part would have been done eventually, but at a somewhat lesser pace. Many of these studies were funded by the Department of the Interior's Bureau of Land Management, the federal instrumentality that then oversaw preparations for petroleum exploration on the outer parts of the nation's continental shelves.

Late in 1979, when the oil/fish dispute on Georges Bank was hot, the Woods Hole Oceanographic Institution (WHOI) set up a Coastal Research Center for multidisciplinary studies of salt marshes, beaches, estuaries, fishing banks, and the continental shelves generally—studies that because of their breadth normally would not be undertaken within the individual departments of the institution. One of three projects initially conceived by the center's planners was a long-term study of Georges Bank centered on a question around which oceanographers of all stripes could rally: "Why is Georges Bank so productive?" It was thought that a good start on this would be some sort of summary of what was already known about the bank. Too long to be a good summary, perhaps, this book is the result. It seemed simple enough when we sketched it out on a sheet or two of paper in September 1980, and it is fortunate, perhaps, that we didn't know then how much of Herman Melville's cardinal elements eventually would be consumed.

The book's planners hoped not only that such a work would enable better conceived multidisciplinary studies on Georges Bank, but also that the book-making process itself—even in its early stages—would foster immediate cross-disciplinary connections. Considerable progress toward that end had already been made through a series of informal workshops on the "Oceanography of the Gulf of Maine and Adjacent Seas" organized by Canadian and American scientists. The first of these, held in Woods Hole in April 1977, was concerned mainly with physical oceanography. The second, held at Dalhousie University in May 1979, was thoroughly interdisciplinary, and the third, held at the University of New Hampshire in March 1981, began with nine "tutorial" lectures on broad aspects of physical, chemical, and biologic oceanography. Early in 1982, the editorial board for the present work arranged smaller, more narrowly focused, day-long meetings for exchanging ideas and information about Georges Bank as well as for organizing the writing of the book. The most profitable exchanges were at meetings on the phytoplankton and its chemical environment, benthic ecology, and chemistry. Each of these was attended by 10–20 physical, chemical, and biologic oceanographers.

The book's ambition, then, was to treat all aspects of the natural science of the bank, describe its rich resources insofar as they are known, and consider the public policy questions surrounding the exploitation of those resources. The book's style is unavoidably technical, but authors and editors have tried to keep jargon to a minimum and to see that each chapter has been written not for the specialist, but for a somewhat more general audience. We hope that this policy, together with "plain language" introduction/summaries, not only will help oceanographers and social scientists interested in the ocean to become better acquainted with distant parts of their broad fields but also will be of value to students, legislators, fishermen, resource managers, engineers, lawyers—indeed anyone interested in Georges Bank.

Generally, this book, like most reviews, contains information that already has been published formally elsewhere—it was editorial policy that this be so. But the flow of new information about Georges Bank has been so great in recent months that some of it inevitably appears here for the first time. Contents and the selection of authors and reviewers ultimately were decided by the editorial board, often with the advice of principal authors. Each chapter (and some of the vignettes) was read and criticized by one or more appropriate authorities, all but a few of whom are noted. The effort of almost every one of these readers was substantial; in many cases it was huge. The editors believe the system used to be far superior to the usual one that relies on nameless experts; while criticism was candid, often bruising, it was never irresponsible as anonymous reviews sometimes are. Some reviewers were so disapproving that they made rereview a prerequisite for allowing their names to appear. Most objections by most readers were eventually met, but a few reviewers cannot be acknowledged, and not everything said is necessarily agreed with by the reviewers.

Two chapters have been especially difficult because they deal with controversial subjects having complex political ramifications. One is by Robert W. Howarth, "The Potential Effects of Petroleum on Marine Organisms on Georges Bank," the other by Patricia E. Hughes and Katrina Van Dusen on the history of the leasing of tracts for petroleum development on the bank. Some, perhaps many, readers will find the first too speculative and borrowing of trouble, but the editors feel that such a chapter should be conservative, as it is—not underestimating possible hazards in the face of very imperfect information. At least one reader found the chapter by Hughes and Van Dusen "anti-federal government and anti-oil company"; time may have to pass before a treatment deemed evenhanded by one and all is possible.

The base maps used in the book are Lambert's conic conformal projection at the scales of 1.2, 1.4, 1.5, and 1.75 million to one with water depth in meters. The new bathymetric map at the back of the book is on the same projection at a scale of 1 : 500,000. Maps produced on other bases have been adjusted to match our scales.

The direct (and considerable) expenses of preparing the book came mostly from the general funds of the Coastal Research Center, principal endowers of which have been the Andrew W. Mellon Foundation and the Culpepper Foundation. The Coastal Research Center laboratory was built with funds from the Mobil Foundation, Inc., the Kresge Foundation, and Percy Chubb II. We stress that all of these donors gave to the Coastal Research Center, not to the Georges Bank book directly. The National Sea Grant College Program of the National Oceanic and Atmospheric Administration (NOAA), under grant numbers NA80-AA-D-00077 (R/B-38) and NA83-AA-D-00049 (R/B-38); the Northeast Fisheries Center of the National Marine Fisheries Service (NMFS); and the Marine Policy and Ocean Management (MPOM) Center of the WHOI gave funds specifically for the book project. In addition, the MPOM Center lent space for map preparation. The NMFS and the United States Geological Survey (USGS), particularly their Woods Hole offices, made very large contributions to the planning of the book as well as to the writing and reviewing of numerous chapters and in the preparation of graphics. The all-important support that individual authors received is acknowledged within chapters. Conspicuous there, in addition to the organizations just mentioned, are the Department of Energy, the National Science Foundation, the Office of Naval Research, and the Minerals Management Service. Also acknowledged within chapters are those who, in addition to the formal reviewers, helped authors by criticizing their manuscripts.

We should add thanks, here, to the authors themselves, although their chapters are perhaps sufficient testimony to their effort. For most the writing of a chapter was a substantial imposition, adding to their work and requiring a rescheduling of it. Authors, particularly those at Woods Hole, also served the editors as reviewers of introduction/summaries and as special consultants on numerous other occasions.

The editors were also helped in diverse ways—large and small—by Judith A. Ashmore, David H. Backus, Denise F. Backus, Nell G. Backus, Ann Banks, Martin R. Bartlett, Patricia Bartlett, Thomas Blanding, Ray E. Bowman, Judith Brownlow, Sandra L. Cadwalader, Peggy A. Chandler, James E. Craddock, William Cumming, Mary Ann Daher, William M. Dunkle Jr., Barbara Erkkila, Carl Fefe, Thelma S. Fenster, Jane Fessenden, Brenda Figuerido, Barbara P. Gaffron, Arthur G. Gaines, Jr., Ellen M. Gately, John W. Gilbert, Ann R. Goodwin, Joel C. Goldman, Bernard L. Gordon, Lisa Hirsh, Colleen D. Hurter, Lenora Joseph, Susan Kadar, Ethel F. Lefave, Charlene M. Lewis, Martha Oaks, P. Michael Payne, Eleanor Reichlin, William Rockett, David A. Ross, Gilbert T. Rowe, Richard Rybacki, Thomas J. Scott, P. K. Smith, Susan M. Smith, Derek W. Spencer, Anne B. Wanzer, John Waterhouse, Nicholas Whitman, Carolyn P. Winn, and Daniel G. Wright. We thank them. There surely were many more, and we hope that those of whom we have lost track will forgive us. Margaret S. Dimmock and Jane M. Peterson typed most of the manuscript into the word processor. Graphic services at the WHOI were particularly helpful.

Robert C. Ayers, Jr., H. Suzanne Bolton, Bradford Butman, Piet deWitt, Douglas I. Foy, Patricia E. Hughes, Robert W. Knecht, Lawrence Susskind, Virginia K. Tippie, and Alan C. Weinstein reviewed a chapter that ultimately was dropped. We are indebted to them for their hard work.

We are grateful to the many institutions that helped us locate illustrative materials. These include the Cape Ann Historical Society, the Old Dartmouth Historical Society (New Bedford Whaling Museum), the *Gloucester Daily Times*, the Hart Nautical Museum (MIT), the Manomet Bird Observatory, the *National Fisherman*, the Society for the Preservation of New England Antiquities, and the William A. Farnsworth Library and Art Museum.

Finally, we would like to thank our friends at the MIT Press—especially Larry Cohen and Diane Jaroch—for the skillful execution of their part, the good help with our part, and a substantial contribution to the fun.

Georges Bank

I

Scientific Exploration

W. Redwood Wright

In some measure the impetus for scientific exploration of Georges Bank has derived from its rich store of resources. At first these resources were seen simply as something to be exploited; but they have come to be regarded as something to be managed and conserved. The resources sought earliest were fish and shellfish, and they continue to be of great value; but today oil, gas, and other mineral resources are at the center of public attention. Whether Georges Bank can help to supply these without undue risk to the fisheries is an open and sometimes hotly argued question. Indeed, even the extent of such resources on Georges is not yet established.

Today few would argue that a broad interdisciplinary understanding of the Georges Bank region is necessary for sound decisions on exploiting and managing its resources. But this philosophy is not new. Georges Bank has long been studied as an ecosystem, a microcosm of the world ocean.

Much of the early scientific work was based in Woods Hole, from which Georges is readily reached. For 30 years, from 1912 to the beginning of World War II, most of it was done either directly by Henry Bryant Bigelow or with his inspiration and guidance. Rarely has a field of study been dominated so completely and for so long by a single individual. Bigelow's influence continues today, as the references and bibliographies in this volume attest.

Research on the Georges Bank region can be divided into five periods: (1) the early years, covering exploration by the U.S. Coast Survey and the U.S. Fish Commission,[1] mainly under the leadership of Spencer F. Baird and A. E. Verrill, 1853–1912; (2) the Bigelow years at Harvard's Museum of Comparative Zoology (MCZ), 1912–1930; (3) a second Bigelow era at the Woods Hole Oceanographic Institution (WHOI), 1930–1941; (4) the beginning of modern research (which followed a period of relative neglect), mostly by the Fisheries laboratory in Woods Hole, WHOI, and the U.S. Geological Survey (USGS), 1948–1970; and (5) the present era of intensive investigations, sponsored to a large extent by the U.S. Bureau of Land Management and sparked by the prospect of offshore oil development. Because the many aspects of recent research are the subject of other chapters, they will only be touched on here.

Since investigations began, there have been periods of general quiescence, such as the 25 years between the death of Spencer Baird in 1887 and Bigelow's first cruises, and there were even longer periods during which particular aspects of marine research were neglected. The involvement of different institutions varied. Fisheries investigations were minimal in the 1930s, when WHOI was especially active; thereafter WHOI turned its attention elsewhere, mainly to the deep sea, until the 1970s.

Studies that have provided much valuable information on the region include Bigelow's classics on the plankton, physical oceanography, and fishes of the Gulf of Maine (Bigelow and Welsh, 1925; Bigelow, 1926, 1927); Galtsoff's history (1962) of fisheries research in Woods Hole; Colton's historical review (1964) of research in the Gulf of Maine region through 1960; Schopf's history (1968) of nineteenth-century exploration of the Atlantic continental shelf and slope; Emery and Uchupi (1972) on geologic research; and Schlee (1978) on the early WHOI years. Except for the last, which is an informal biography of the research vessel *Atlantis*, these works have extensive bibliographies. Other good bibliographies are those of Bumpus (1973) for physical oceanography and Theroux and Wigley (manuscript) for benthic fauna.

The Early Years: 1853–1912

Though an outline of Georges Bank was charted as early as 1525 and though American colonists had regularly fished there since the early 1700s, there was no scientific investigation of the region, no systematic accumulation and analysis of data, until the second half of the nineteenth century (figure 1.1). The first chart of Georges Bank to be based on an organized survey was produced in 1837 by Charles Wilkes.

In 1853 the U.S. Coast Survey began to measure depths on and near Georges Bank as part of a major effort to chart the eastern seaboard. There were annual cruises, mostly under the direction of Lt. Comdr. H. S. Stellwagen, until the outbreak of the Civil War, with additional work in 1863 and the early 1870s by Capt. Charles Sigsbee (Sigsbee, 1880). Sigsbee developed or improved several instruments, including a clam-bucket bottom sampler and a sounding machine that registered the length of wire out (figure 1.2); he also measured current using drogues (Wright and Roberts, 1957). Soundings made across the bank in 1883 were published by Lt. John Elliot Pillsbury (1883). Accuracy was poor; depth was measured by lowering a weight on a calibrated line (first hemp and later wire) and position out of sight of land was determined by dead reckoning or star sights. In the strong and erratic currents of Georges Bank, methods of fixing position were unreliable. Nevertheless, except for a few observations in 1907, there were no further bathymetric surveys on Georges Bank until the development of modern echo sounding.

The work of the Coast Survey was not limited to bathymetry; dredge hauls were made routinely to collect bottom sediments and benthic organisms, which were turned over to academic scientists for examination. Louis Agassiz (1869, cited by Schopf, 1968) credited the Coast Survey with "the first broad and comprehensive basis for an exploration of the sea bottom on a large scale, opening a new era in zoological geological research." The first *Coast Pilot*, which covered the Gulf of Maine, was issued by the Coast Survey in 1875.

The earliest current measurements on Georges Bank appear to have been made in the summer of 1877 by the Coast Survey's Robert Platt, master of the schooner *Drift* (Mitchell, 1881). At eight stations along an arc from Nantucket Shoals to Cape Sable, observations were carried out through a complete tidal cycle or longer; however, the method of measurement was not described. The results showed clockwise tidal motions with only a small residual transport, and Mitchell commented, "It appears probable that the ebb and flow currents are exactly equal." Mitchell believed Georges Bank to be "a wasted island" and that its shoals were maintained by tidal ac-

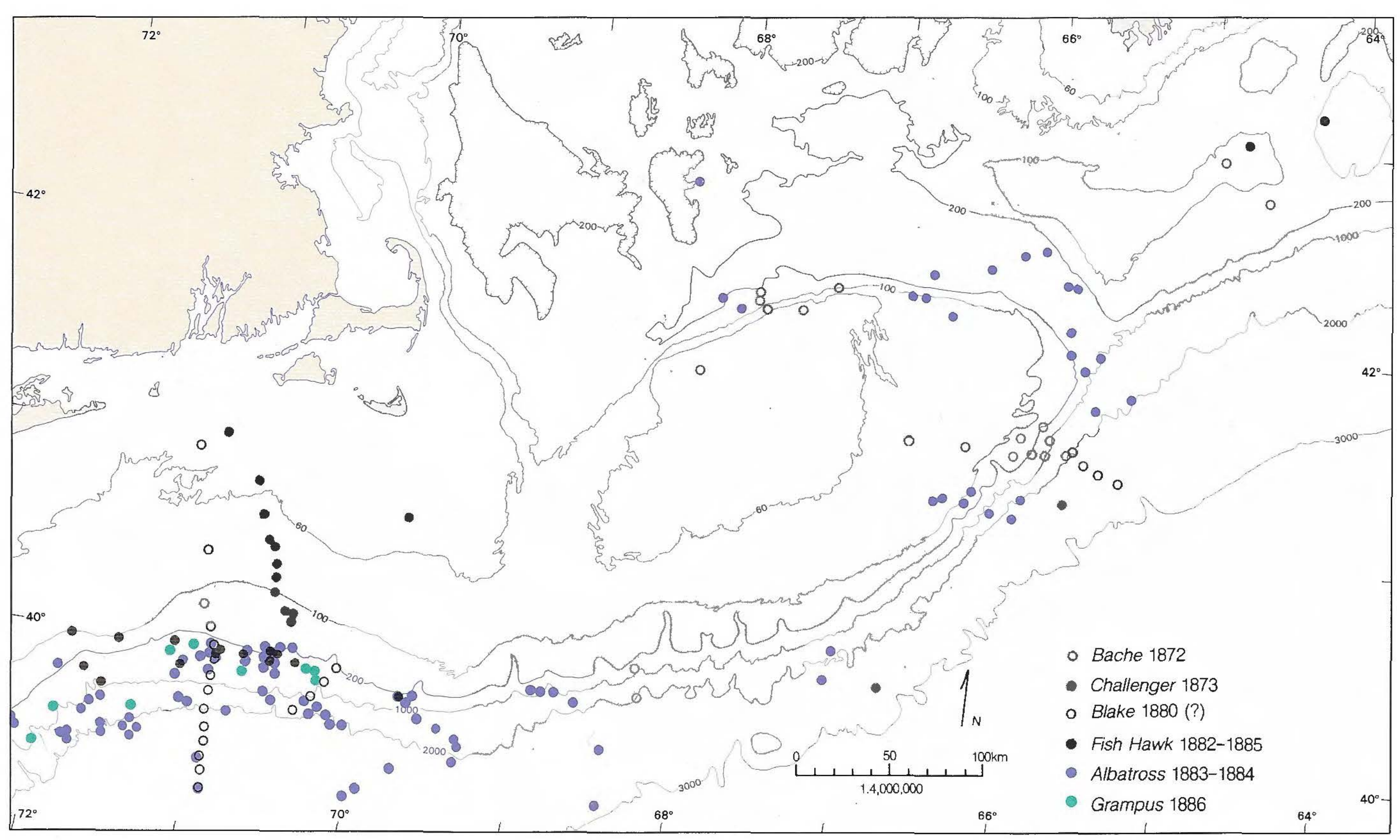

Figure 1.1
Early oceanographic stations in the Georges Bank region. [Compiled by D. W. Bourne]

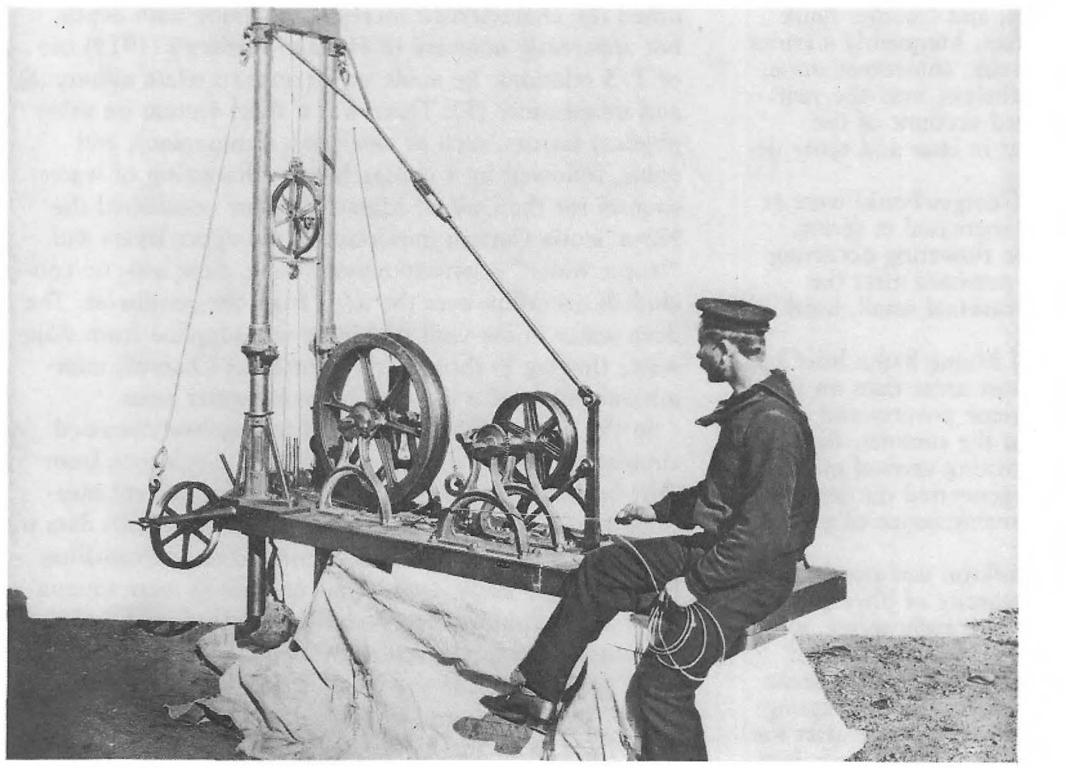

Figure 1.2
The Sigsbee sounding machine used on the U.S. Coast Survey steamer *Blake*. [Courtesy Woods Hole Oceanographic Institution]

tion. (Concerned for the safety of mariners, he once called—in vain—for a lighthouse and horn on Georges Shoal.)

In 1871 a new government agency, the U.S. Fish Commission, was formed as an adjunct of the Smithsonian Institution. Spencer Baird, the first commissioner, established a laboratory in Woods Hole and began to explore New England waters. Extensive collections and the enormous labor of describing and cataloging them were begun; most of the collections were made inshore, but there was also work offshore from chartered fishing schooners and Coast Survey vessels. From the ship *Bache* benthic organisms were dredged from eastern and northern parts of Georges in 1872 (Smith and Harger, 1874); similar collections were made to the east and south from the *Blake* in 1880 (Agassiz, 1888). The U.S. Fish Commission launched its own seagoing vessels, the sail-assisted steamers *Fish Hawk* (156 feet) in 1880 and *Albatross* (234 feet) in 1882; these made regular offshore surveys possible, and the two ships occupied a number of stations on Georges Bank through 1886.

The U.S. Fish Commission collection from New England waters was impressive—some 3,000 dredge hauls, which brought up sediment and rock samples and hundreds of thousands of specimens of more than 2,000 different invertebrates. Many of these were new to science; "type specimens" of these were sent to the National Museum in Washington, and duplicates to Harvard and Yale. Most of the work of describing this extraordinary collection fell to Addison E. Verrill of Yale, who joined Baird in Woods Hole in the summers; it took him until 1908 to complete the job. In the course of his inquiries, he demonstrated differences between the faunas north and south of Cape Cod, from which he concluded that the distribution of marine animals depended mainly on water temperature at the time of reproduction (Verrill, 1874).

Deep-sea reversing thermometers, which permitted the vertical temperature structure of a water column to be described, were not introduced until 1878, when the tug *Speedwell* employed them off Cape Ann. Bigelow (1927) considered this a significant marker in the development of modern oceanography. Nevertheless, Verrill, with far less satisfactory instruments, had measured subsurface temperatures in the Georges Bank region years earlier, using maximum/minimum thermometers there in 1870.

Verrill also studied the collections of rocks and sediments (Verrill, 1884). He speculated (correctly) that Tertiary rocks underlie Georges Bank, but mistaking what the glacier had done, he supposed (incorrectly) that anomalous rocks dredged from offshore waters had been rafted there by seasonal shore ice. Like Mitchell, he believed the offshore banks to be remnants of islands eroded by the sea.

Much of the drive for this kind of exploration died with Baird in 1887. After his death the U.S. Fish Commission was reorganized, and the basic investigations that Baird had so forcefully promoted gave way increasingly to work that could be defended as "practical." For 70 years there was virtually no organized benthic sampling in offshore New England waters. Some work begun under Baird continued, however. He had ordered collection of fishery statistics in the 1880s after a fishing dispute with Canada. Vessel landings for Boston and Gloucester were first published in 1891, beginning a statistical series that has continued more or less unbroken to the present; landings by species have been reported annually since 1893 and monthly since 1898.

In this period, there were occasional scientific trips offshore. Notable was the research of William Libbey (1891a,b) into the disappearance and eventual reappearance of the tilefish population at the edge of the New England shelf. He attributed these phenomena to shifts in a warm band of water over the continental slope, a band in which the tilefish flourished. These shifts, Libbey supposed, might be traceable to the Gulf Stream, since its northern edge was not fixed in position but meandered on- and offshore.

Two developments in this period proved of lasting importance for scientific exploration of the region. One was the founding in 1902, in Europe, of the International Council for the Exploration of the Sea (ICES). The other was the establishment in 1907 at St. Andrews, New Brunswick, of the Atlantic Biological Station. Most of the work at St. Andrews was related to nearshore fisheries, but valuable biologic and physical information was gathered offshore as well, notably by Archibald Huntsman, James W. Mavor, and W. Bell Dawson. ICES, at the outset, concerned itself almost exclusively with problems of the North Sea fisheries; its transatlantic significance lay in its cooperative, international, and multidisciplinary approach to research, which gave North American marine scientists a worthy model.

The Bigelow Years—MCZ and the Fisheries: 1912–1930

An extraordinary period in oceanography began in the summer of 1912 when 33-year-old Henry Bryant Bigelow of Harvard's Museum of Comparative Zoology (MCZ) set sail in the Fisheries schooner *Grampus* to study the oceanography and fauna of the Gulf of Maine/Georges Bank region. From this and subsequent cruises came a series of scientific articles, culminating in three great monographs on the region: Bigelow and Welsh (1925) on its fishes, Bigelow (1926) on its plankton, and Bigelow (1927) on its physical oceanography. In the words of Merriman (1982), these three volumes constitute "a monumental accomplishment . . . the first truly oceanographic study to be completed in North American waters." They were great works not only of exploration and description but of scholarship as well. The volume on fishes was revised and reissued in 1953 with the aid of William C. Schroeder, Bigelow's colleague for 45 years; the others were never revised but remained standard references until the great explosion of modern investigation of the region in the past decade. Bigelow's research and publications on the Gulf of Maine constitute "a monumental job of which any man could be proud even if he had done nothing else in his whole life," according to Graham (1968).

Bigelow first went to sea in 1901, sailing to the Indian Ocean with Alexander Agassiz of the MCZ. In 1908 he took the *Grampus* into the Gulf Stream for a short collecting trip that included one station on the western end of Georges Bank. Four years later he arranged to borrow *Grampus* again and began epoch-making efforts. Bigelow was inspired in part by the research being sponsored in the North Sea by ICES. Like the founders of ICES, he believed strongly in an interdisciplinary approach to marine studies. His major interests were in fish, plankton, hydrography, and their interrelations. He chose the Gulf of Maine and the offshore banks because of the importance of the fishery and the challenge of the hydrography; moreover, these places were easy to reach from Woods Hole and Cambridge, Massachusetts (Schlee, 1973).

The first *Grampus* cruise, in July and August 1912, resulted in 46 stations in the northern part of the Gulf of Maine. Additional *Grampus* cruises were made each spring and summer until 1916, when World War I stopped them; after the war the cruises resumed in other Fisheries ships, extending for the first time into the colder months. Currents were studied with the aid of drift bottles released along several lines across the continental shelf. Finally, after more than 400 stations, the field work ended in 1921. For 9 years Bigelow and his colleagues had New England's waters more or less to themselves (the Coast Survey was not active there at this time), and it was time to sum up what they had found.

Volume 40 of the *Bulletin of the U.S. Bureau of Fisheries* comprised Bigelow's three Gulf of Maine treatises. By his definition, the gulf extended from 65 to 70° west longitude and from the coast out to 150 fathoms; thus

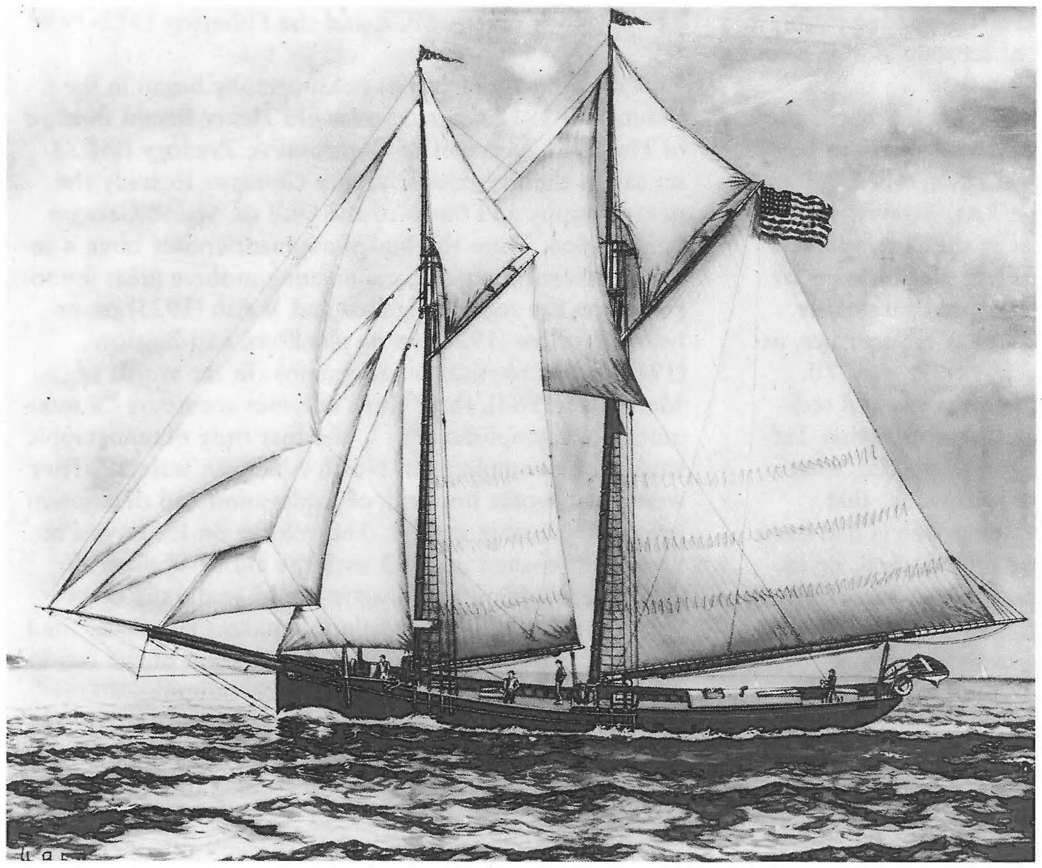

Figure 1.3
The U.S. Fish Commission schooner *Grampus*. Painting by C. B. Hudson, 1888. [U.S. National Museum]

Nantucket Shoals, Georges Bank, and Browns Bank were included, along with the channels separating them. The first volume, on fishes, was offered as "a handbook for ready identification of the fishes of the Gulf of Maine and to present a concise statement of what is known of the distribution, relative abundance and the more significant facts in the life history of each." The description was intended to be as untechnical "as is compatible with scientific accuracy." There were descriptions of 178 species, along with keys for their identification. Detailed life histories were given when enough was known to do so, and for the commercial fishes historical accounts of the fisheries were given as well, reaching back to Captain John Smith in 1616.

Bigelow offered special acknowledgments to his collaborator, William C. Welsh, who died before the work was completed; A. G. Huntsman; and "the many commercial fishermen who have unfailingly met our inquiries in the most cordial way, and who supplied . . . a vast amount of first hand information on the habits, distribution, and abundance of the commercial fishes, which could be had from no other source."

The second volume, on plankton, was based on more than 1,000 tows taken over 10 years. When the collection started, Bigelow noted, "we had no idea what we would catch." This was certainly true in the case of phytoplankton; Bigelow's was the first systematic study in those waters. Riley (personal communication) describes it thus:

Bigelow was examining a large area, and Georges Bank was a minor part of the overall effort. Frequently a cruise had three or four stations on the bank, sometimes none, and seldom as many as ten. Nevertheless, over the years he was able to compile a generalized account of the plankton which was fully borne out in later and more detailed investigations.

Phytoplankton populations [on Georges Bank] were at a minimum level in midwinter and increased in spring, with the peaks of the spring diatom flowering occurring in April. Moderate concentrations persisted after the main flowering, and there were occasional small, local flowerings in summer.

In contrast, much of the Gulf of Maine had a brief but intense spring flowering, later in most areas than on the bank, followed by a period of extreme poverty and a relatively small population throughout the summer. Bigelow of course recognized the fact that strong vertical mixing on the bank and rapid return of regenerated nutrients to the surface were important in the maintenance of a superior summer population.

The winter population of zooplankton was small, as might be expected in view of the scarcity of phytoplankton food. This condition persisted into early spring, when the copepod breeding season began. Abundant nauplii were observed on Georges Bank in March. The increase in copepods was more or less coincident with the spring flowering. The population continued to increase after the termination of the flowering and maintained a fairly high level through the summer. . . . Summer populations on Georges Bank, the Cape Sable offing, and inshore waters of the Gulf appeared to be about an order of magnitude larger than in the deep central basins.

In the third volume, on physical oceanography, Bigelow again drew on a vast amount of information—his own data and all that had been published previously—to present a comprehensive picture of the hydrography and circulation of the region. Although the monograph was almost entirely his own work, he acknowledged the collaboration of R. Parmenter, who worked up some of the later station data; E. H. Smith, who applied some of the developing theories of ocean dynamics to the Gulf of Maine; Henry Stetson and T. C. Graves, who "from their yachts also have taken welcome observations"; and, of course, A. G. Huntsman.

Huntsman (1924) had described what was known and conjectured about the circulation of the western North Atlantic Ocean. He anticipated the Western Boundary Undercurrent in his description of the formation in high latitudes of deep water that flows south along the continental slope and rise, and he introduced the term "slope water." He noted that on the shelf "the horizontal circulation is determined largely by the configuration of the bottom, the water rotating in a contra-clockwise direction around basins, and in a clockwise direction around islands and shoals"; a schematic chart showed circulation in the Gulf of Maine region, with westward flow along the southern flank of Georges Bank and around Nantucket Shoals to the Middle Atlantic Bight. Bigelow's work reinforced that concept.

Bigelow wrote 180 pages on temperature followed by 120 pages on salinity. He treated in detail seasonal cycles and the factors governing temperature distribution. He noted the characteristic increase of salinity with depth, but apparently unaware of Helland-Hansen's (1919) use of T/S relations, he made no attempt to relate salinity (S) and temperature (T). There was a short section on other physical factors, such as alkalinity, transparency, and color, followed by a comprehensive discussion of water sources for the Gulf of Maine. Bigelow considered the Nova Scotia Current important in the upper layers and "tropic water" relatively unimportant; there was, he concluded, no influx over the shelf from the southwest. The deep water in the Gulf of Maine was supplied from slope water flowing in through the Northeast Channel, intermittent pulses of a westward-moving water mass.

In the final section of his treatise, Bigelow discussed circulation, basing this on tidal data, the evidence from drift bottles (figure 1.5), and a handful of current measurements then available. (He reworked Mitchell's data to check the residuals; this was his only direct information from Georges Bank itself.) His conclusions were summarized in his famous chart—endlessly reproduced—of the "dominant nontidal circulation of the Gulf, July to August" (see figure 2 in the introduction "Physical Oceanography" by Butman and Beardsley).

In 1920, with the model of ICES before them, Bigelow, Huntsman, and others laid the groundwork for a cooperative research body for the western North Atlantic, the North American Council on Fishery Investigations, which first met officially the following year. The objectives were to improve statistics for the offshore fisheries, to conduct comprehensive investigations of cod, haddock, and mackerel, and to collect data on oceanographic conditions and their relation to fish life (all to be done informally and at minimum cost). Like ICES, the council served as a forum for oceanographic information and ideas; it encouraged large-scale investigations—notably, tagging haddock and other species. It was a useful beginning, but the council was not to survive World War II.

The Bigelow Years—WHOI: 1930–1941

Two important events in the early 1930s significantly increased research on the geology and general oceanography of Georges Bank. The first was a new and much more detailed USC&GS survey, made possible by the echo sounder, which had been recently invented. The second was the founding of the Woods Hole Oceanographic Institution (WHOI), under the direction of Bigelow, and construction of WHOI's 142-foot ketch *Atlantis*. Bigelow could no longer rely on borrowed vessels for his offshore work; the Bureau of Fisheries, hampered by low funding during the Great Depression, was left virtually without seagoing capabilities after a few haddock surveys made in 1930 and 1931.

The echo sounder, developed just before World War I by R. A. Fessenden, was first used for bottom profiling in 1922; its application to Georges Bank began in 1930. Positions were determined by radioacoustic ranging (Rude,

Figure 1.4
Henry Bigelow aboard the U.S. Fish Commission schooner *Grampus* during the pioneering cruises of 1912–1916. [Courtesy Museum of Comparative Zoology, Harvard University]

Figure 1.5
A member of the scientific party, Richard Bailey, aboard the fisheries research vessel *Albatross II* in 1931, with a bunch of drift bottles for ocean circulation studies. [O. E. Sette Collection, National Marine Fisheries Service]

1932). In addition to soundings, the survey ships took sediment samples, measured temperature and salinity to determine sound velocity, and measured tidal currents at about 50 locations on the bank using a current pole (Haight, 1942). The general chart that resulted from this work (No. 1107) represented a new standard. At the time, Francis Shepard, who sailed with the Coast Survey in both 1931 and 1932, declared it to be "based on probably the best deep water survey in the world" (Shepard, 1934).

Contoured at 25-fathom intervals, the chart revealed what Shepard called "submarine canyons of awe-inspiring proportions" along the southern flank of Georges Bank. "If their features were visible they would compare scenically with the most impressive canyons in the world." They were grand indeed—5–12 miles long, 2–6 wide and 1,200–8,000 feet deep! Using systematic sediment sampling as well as the new topographic information, Shepard and his coworkers (Shepard, Trefethen, and Cohee, 1934) proposed a geologic history for Georges Bank that is now generally accepted: A coastal plain cuesta had become separated from the mainland by glacial and fluvial erosion in the Gulf of Maine; glacial deposition modified it further; then tidal currents and waves had removed most of the fine material, leaving surface sands and gravels.

Shepard was followed by Henry Stetson, who set out in August 1934 in *Atlantis* for closer examination of three Georges Bank canyons now known as Oceanographer, Gilbert, and Lydonia. With him he had a fathometer, a simple coring device, and a heavy box dredge capable of breaking off chunks of rock from the canyon walls (Stetson, 1935, 1936). Collections of glacial debris, sediments, and biologic samples furnished clues to the origin of the canyons. There were descriptive papers based on the biologic collections as well: Bassler's (1936) on bryozoans, Cushman's (1936) on foraminifera, and Stephenson's (1936) on echinoderms and mollusks.

Stetson returned in 1935 with an improved dredge and a Piggott gun corer, and in 1936 with an Ekman current meter, which he lowered to the canyon floors. The speeds measured there were comparable to those elsewhere on the shelf—never more than 13 cm/sec—and Stetson (1937) concluded that although such currents were too weak to have cut the original canyons, they were strong enough to prevent refilling with sediment.

A separate series of *Atlantis* cruises in the region was begun in 1932 under the influence of Bigelow, who kept pushing interdisciplinary studies. The series continued through several summers. Most of the work was done in the Gulf of Maine, with only occasional stations on Georges Bank, but it was on these cruises that instruments and techniques were developed that became standard in oceanographic research. (Colton, 1964, describes the program in some detail.)

In 1936 *Atlantis* was available for extended winter work in New England waters. Columbus Iselin laid out a series of hydrographic sections running across Georges Bank into the slope water. He intended to sail as chief scientist, assisted only by technician Alfred Woodcock, but at the last minute he had to stay behind, and Woodcock sailed in February as a scientific party of one. He made 56 stations by himself before returning to Woods Hole in early April. Two more hydrographic cruises were made to Georges Bank that year, but as winter returned *Atlantis* went south. The next opportunity for year-round study came in the fall of 1939 as war threatened in Europe.

George Clarke planned a series of cruises, to span several years, to explore the relation between biologic productivity and hydrography. Gordon Riley, then at Yale, was interested in nutrients and photosynthesis; he was part of these plans from the beginning.[2] So were Woodcock and D. F. Bumpus. Clarke laid out a series of sections 25 miles apart; these were perpendicular to the axis of the bank, running from deep water in the Gulf of Maine up and over the bank, and back into deep water on the southern side. Stations were 15 miles apart along each section; standard observations included a hydrocast, transparency measurements, meteorologic observations, and plankton tows, including one with the "chariot," a net with wheels mounted on the hoop permitting it to sample just over the bottom without digging in (figure 1.6). Phytoplankton was sampled, and water column analyses were made at about half the stations.

The survey began in September 1939 and ended in 1941; 11 cruises were made, 7–12 days long, and a total of 373 stations were set up. Riley (personal communication) summarized the results:

> Plankton observations were in complete agreement with Bigelow's earlier generalizations but added areal detail and quantitative information. Plant pigment measurements [in January] were near the limit of sensitivity of the method then in use, equivalent to about 0.5 μgC/liter (Riley, 1941).[3] In late March the flowering had started in the central part of the bank, with maximum values about 12 μg. After mid-April it had spread to encompass most of the bank (8–14 μg) and was past its peak and declining in May. Typical values in September and June were 1–3 μgC/liter, but a few individual stations had higher concentrations, which may have been indicative of local blooms of the kind mentioned by Bigelow.
>
> Phytoplankton counts by Sears (1941) on the March to June cruises were essentially in agreement with pigment measurements except that the post-flowering decrease was more marked than that of chlorophyll. The methods Sears used were comparable to those of an extensive survey of the Gulf of Maine (Bigelow, Lillick, and Sears, 1940), permitting regional comparisons. Her comparison left little doubt that Georges Bank is much more productive than the deeper parts of the Gulf of Maine.
>
> Most of Georges Bank was productive enough for effective use of the now almost obsolete light and dark bottle method for measuring photosynthetic oxygen production. Maximum spring flowering values were about 2 mgO_2/liter/day [from] surface samples incubated in a tub of water on deck. . . . Assumptions based on other experimental work were used to extrapolate surface values to estimates of total production . . . combined into a smoothed seasonal curve. The data set obviously was minimal for the purpose . . . but the total annual carbon

fixation by photosynthesis was estimated to be about 500 gC/m^3 in water of 60 m depth or less and about 350 gC in the range of 61–100 m.

The time of inception of the spring flowering was analyzed (Riley, 1942) in terms of the average amount of light received by the phytoplankton in a turbulent mixed layer. Another paper (Riley, 1943) examined some physiological aspects of phytoplankton growth during spring flowering.

The onset of the war brought a halt to data analysis, and some of it was never worked up in detail. This included the zooplankton collections, although Clarke, Pierce, and Bumpus (1943) discussed the relationship of Sagittae and the hydrography of the bank, and after the war there were papers on phytoplankton-zooplankton relationships (Riley and Bumpus, 1946) and the large crustaceans taken in the "chariot" (Whiteley, 1948).

Clarke (1946) integrated much of what was known about the biology of Georges Bank in an examination of inter-relationships among the processes of production, consumption and decomposition at various trophic levels. Riley (1946) combined field observations and laboratory experimental data in the development of a mathematical model of the seasonal cycle of phytoplankton on Georges Bank. Although it was a crude first modeling attempt, it appeared to be a more logical way of analyzing dynamic inter-relationships than the correlation techniques that had been previously used. For example, the model showed, among other things, that the spring flowering was terminated by a combination of grazing, nutrient depletion and, to a lesser extent, self shading. This was in contrast to the British view that in their waters grazing was the only important factor. The phytoplankton study was followed by an analogous model of the seasonal cycle of zooplankton (Riley, 1947).

During the 1930s Iselin studied the Gulf Stream and the hydrography of the western North Atlantic Ocean, relating his physical findings to the coastal fisheries (Iselin, 1939). He discussed the fundamentally estuarine nature of the continental shelf, the causes of large-scale offshore movements of shelf water (including what are now called warm-core rings, pinched off from the Gulf Stream), and the efficacy of upwelling and winter mixing for resupplying biologic nutrients. He questioned whether annual catch variations could be explained by "purely physical mechanisms."

In 1931 and 1932 the Fisheries conducted haddock surveys on Georges Bank, and Walford (1938) reported the results in a discussion of survival of haddock eggs and larvae in relation to water density and nontidal flow as determined by drift bottles. As the 1930s progressed, fisheries funding diminished to the point that the Woods Hole laboratory was threatened with closing. However, collection of fishing statistics continued, and some analyses were made on the abundance of year classes, rates of growth and mortality, and fish migration (Galtsoff, 1962).

Modern Investigations: 1948 to the Present

In recent times the pace of research on Georges Bank has accelerated. There has been a prodigious concentration of funds and scientific attention on studies of the region, results of which will be found throughout this volume. In large part, this reflects a renewed interest of federal agencies: Fisheries, the U.S. Geological Survey, and lately the Bureau of Land Management. There has also been strong international involvement, first through the International Commission for Northwest Atlantic Fisheries (ICNAF), and subsequently through ICES.

This renaissance of research began with the Bureau of Commercial Fisheries, which responded to fishermen's complaints after World War II that groundfish resources of the offshore banks were becoming depleted. Equipped for the first time in years with a capable offshore vessel, *Albatross III*, in 1948 Fisheries could embark on a varied program of trawling, plankton collection, dredging, gear testing, and hydrography, most of it related to the offshore cod, haddock, and flounder fisheries. Colton (1955) found that the distribution of haddock on Georges Bank varied markedly with location, depth, season, and bottom type. In the early 1950s Schroeder organized the first deepwater exploratory fishing to be done off the New England coast since the days of the *Fish Hawk* 70 years earlier. Otter trawl hauls were made at about 130 stations in water between 70 and 500 fathoms. Among the discoveries were new and prolific lobster grounds offshore, which gave rise to a new lobster fishery. The biology of deepwater red crabs was investigated with an eye to the crab's commercial potential (Schroeder, 1955). In August 1957 *Albatross III* crisscrossed Georges Bank collecting sediment samples and benthic organisms. In two 1961 papers Wigley mapped the distribution and abundance of benthic animals, relating these to the distribution of sediment type.

With the commissioning in 1963 of *Albatross IV*, a new vessel built for research, Fisheries began regular fall groundfish surveys on the continental shelf from Nova Scotia to southern New England; in 1968 a spring survey was added. These surveys (Grosslein, 1969, 1974) monitor fluctuations in structure and size of the groundfish population as an independent measure of fishing effect. They also serve other, related purposes: assessing fish production potential; finding the determinants of fish distribution and abundance; and providing data on such factors as growth rates and food habits. Over the years the groundfish cruises have had the highest priority among all Fisheries projects, and the resulting information has been the backbone of the agency's data bank on which most of its projections and recommendations are based.

In a first attempt to predict Georges Bank fish-stock size on the basis of a simple environmental index, Chase (1955) related brood strength of haddock to winter air temperatures and wind data. He found generally good agreement with actual haddock data from 1928 to 1951, and his index held up pretty well into the 1960s, when overfishing eclipsed natural fluctuations. Trends in air and sea-surface temperatures and changes in the distribution of key fish and invertebrate species were examined for New England by Taylor, Bigelow, and Graham (1957). They found a warming trend of 1–5°C throughout the water column in comparison with temperatures measured between 1912 and 1926. This was accompanied by a

Figure 1.6
The "chariot," a plankton net equipped with wheels for sampling just over the bottom, being taken aboard the research vessel *Atlantis* on a 1935 cruise. [O. E. Sette Collection, National Marine Fisheries Service]

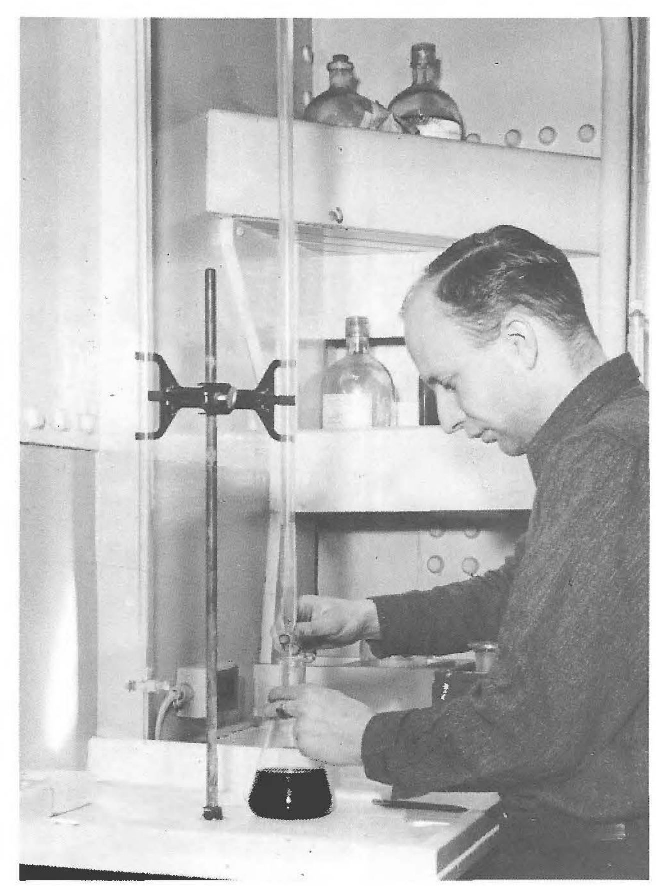

Figure 1.7
Gordon Arthur Riley in the lower lab of the research vessel *Atlantis* about 1940, the year he made cruises to Georges Bank in January, April, May, and June. [Courtesy G. A. Riley]

northward shift in abundance of fauna, but there was no major alteration in the region's faunal characteristics.

Bumpus and Day began to fill in Bigelow's picture of water circulation using physical data taken by lightships and Fisheries vessels along the coast, and the results of drift-bottle studies (Bumpus and Day, 1957, summarized in Bumpus, 1973; Day, 1958). They deduced that the Gulf of Maine and Georges Bank gyres became stronger and better defined in the summer as a result of stratification and that the flow was readily disrupted by winds. In 1957 the first attempt was made to measure currents on Georges Bank with radio-equipped drogues (Bumpus, 1976). Too few drogues were released for conclusive results, but the trajectories were similar to those followed two decades later by satellite-tracked drifters (Butman et al., 1982).

A valuable set of physical data was gathered in a series of eight cruises taken at 3-month intervals between 1964 and 1966 (Colton et al., 1968). Temperature, salinity, and dissolved oxygen were measured each time at the same stations; this series provided the most thorough coverage of Georges Bank up to that time and was not surpassed until the more detailed work of the late 1970s.

The first major study of Georges Bank geology since Stetson's was started in the fall of 1962 by the USGS and WHOI. This was part of a comprehensive survey of the Atlantic continental shelf and slope from the Canadian border to the southern tip of Florida. The work was funded by USGS and directed by K. O. Emery of WHOI with scientists from both institutions participating; both the Fisheries and the USC&GS cooperated as well.

The program included detailed topographic studies, seismic profiling, and occasional measurements of bottom currents and other factors. Samples of sediments, rocks, and benthic fauna were also collected (Emery and Schlee, 1963; Emery and Uchupi, 1972). The basic description of the collection was published in a series of Geological Survey Professional Papers between 1966 and 1981, but several hundred other publications resulted as well (USC&GS, Woods Hole, has a bibliography). Among the most useful was a topographic map (Uchupi, 1965) that showed the entire eastern seaboard from Florida to Nova Scotia on three large sheets at a scale of 1 : 1,000,000.

A new dimension in benthic studies on Georges Bank came with the development of manned submersibles in the late 1960s. The first dive on the bank was made with WHOI's *Alvin* in Oceanographer Canyon on 15 October 1966 (Trumbull and McCamus, 1967). Large talus blocks were found littering the flat canyon floor, as well as scour marks and ripples suggesting intermittent down-canyon currents. Other early dives were made in Corsair Canyon in 1967 (Ross, 1968; Dillon and Zimmerman, 1970) and in the Gulf of Maine (Ballard, 1974). To date there have been more than 200 dives in the region, providing a wealth of information about geology, benthic animal communities, the effects of currents, and the influence of animal activity on the substrate. Warme, Slater, and Cooper (1978) credit divers with demonstrating that "animals are the major eroders of most present submarine canyon walls."

Other important contributions from the postwar period include the first systematic survey of the New England seamount chain, which runs southeast from Georges Bank (Zeigler, 1955); a seismic survey of the Georges Bank canyons (Roberson, 1964); and a detailed study of the slope and rise off the Northeast Channel, made in the course of a search for the submarine *Thresher*, which sank in early 1963 (Hurley, 1964). Four years later *Alvin* was used for an even more detailed bathymetric survey on the lower slope south of the Great South Channel (Emery and Uchupi, 1972); this revealed unexpected low ridges on the bottom, about 200 m wide and at least 1.5 km long.

Global expansion of fishing in the postwar period, and consequent pressure on fish stocks along the northeast coast of North America, led to the founding in 1950 of the International Council for the Northwest Atlantic Fisheries (ICNAF). ICNAF was created to promote cooperative fishery research and to develop measures to conserve resources; ultimately 18 nations joined. ICNAF concerned itself with more than 2 million square miles of ocean, within which lay Georges Bank. Much research and survey work on Georges was accomplished under ICNAF auspices; most of it was related to the assessment and prediction of stock abundance and the development of regulations to reduce the effects of overfishing. There was a regular series of groundfish investigations, which involved vessels from several ICNAF member nations. A series of larval-herring surveys—fall and winter plankton cruises on Georges Bank and in the Gulf of Maine—was carried out from 1971 to 1978; vessels from the United States, the Soviet Union, Germany, France, and Poland participated. Hydrographic data were collected, along with a wealth of information on various plankton species. Eventually, more than 400 ICNAF research papers were produced on the Georges Bank/Gulf of Maine region.

Despite measures taken, serious overfishing persisted and stock abundance fell precipitously; dissatisfaction among U.S. fishermen grew in proportion. This led the U.S. Congress in 1976 to pass the Fisheries Conservation and Management Act, which extended U.S. jurisdiction over most fish resources to 200 miles from the coast; Canada followed suit (see chapters 41 and 45). Both countries withdrew from ICNAF, which was replaced in 1979 by a new body, the Northwest Atlantic Fisheries Organization (NAFO); statistical series begun under ICNAF are continued by NAFO.

Recent Developments

The recent flowering of research on Georges Bank celebrated by this volume can be dated from 1973, when the United States decided to lease sites off the Atlantic coast for oil and gas development. The next year, the USGS expanded its Branch of Atlantic and Gulf of Mexico Geology to emphasize environmental and resource studies; headquarters were established in Woods Hole.

Figure 1.8
William C. Schroeder with specimens of the chimaera *Harriotta raleighana*, on the fishing vessel *Cap'n Bill II* in 1952. [Photograph by Jan Hahn]

Figure 1.9
Dean Bumpus pipetting New Year's rum, a decade or so after his work on Georges Bank with Clarke, Riley, and Woodcock. [Photograph by David M. Owen, courtesy Woods Hole Oceanographic Institution]

The principal objectives of the USGS program (Folger and Needell, 1983) are (1) to provide publicly available oil and gas resource data in support of the OCS leasing program; (2) to determine areas with significant petroleum potential for future OCS sales; (3) to provide data to the public and to state and federal governments for long-term planning; and (4) to characterize the nature of offshore hazards to oil exploration and development. Resource assessment based on identification of sedimentary basins and the thickness, type, and age of sediments has been a major objective. So has environmental research, which has focused on surficial sediment dynamics, composition and chemistry of sediments, gas content, heavy-hydrocarbons geochemistry, and bottom stability. In the summer of 1976 seven holes were drilled in the Georges Bank area to investigate the bottom structure as part of the Atlantic Margin Coring Program.

At NEFC environmental influences on distribution and survival of fish stocks have been given increased attention. The Atlantic Environmental Group, in Narragansett, Rhode Island, has developed time series of data on such factors as wind stress, the position of fronts, and the warm-core Gulf Stream rings. An NEFC program of current measurement began with a 2-year installation to monitor deep flow through the Northeast Channel. There have been cooperative progams; one was carried out with the Bedford Institute in a small region on northern Georges Bank; another, done jointly with WHOI, USC&GS, and the University of New Hampshire, was designed to measure flow along the shelf south of Nantucket Shoals. The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program of NEFC (Sherman, 1980) was intensified in 1977 to six annual plankton and hydrograph surveys at some 200 stations between Cape Hatteras and Nova Scotia.

At WHOI interest in the coastal margin began to quicken in the 1970s. Techniques and ideas that had been developed for deepwater investigations were applied to the slope and shelf. It was not until 1976, however, that substantial ship time was devoted to coastal studies; initially most of that time was spent in the Middle Atlantic Bight rather than on Georges Bank. In the 1970s other east-coast laboratories became interested in Georges Bank: Lamont-Doherty Geological Observatory, Bigelow Laboratory for Ocean Sciences, and the universities of Rhode Island and New Hampshire. An increasing commitment of funds by BLM and other government agencies led to corporate research by Raytheon, EG&G, and others. By late 1976, when national attention was focused on the area by the *Argo Merchant* oil spill, a tremendous store of information had already been assembled, and a growing number of scientists from many disciplines were committed to research there.

Acknowledgments

Many helpful suggestions were provided by the reviewers, notably G. Riley, G. Clarke, and D. Bumpus, who were among the Georges Bank pioneers in the 1930s. Riley's comments captured the essence of the research during that period so well that he has been quoted at length.

Other major resources were the WHOI Archives and the Library of the Northeast Fisheries Center (NEFC) in Woods Hole; I am indebted to William Dunkle, WHOI archivist, for helping me to make good use of the wealth of material in his custody, and to NEFC librarians Judy Brownlow and Susan Rockwell for their knowledgeable assistance. Preparation of this chapter was supported by a grant from the Woods Hole Oceanographic Institution.

Reviewed by Dean F. Bumpus, George L. Clarke, John B. Colton, Jr., Gordon A. Riley, and John S. Schlee

Notes

1. Both of these agencies have been reorganized and renamed a number of times. The United States Coast Survey (part of the U.S. Navy, 1818–1832 and 1834–1836) became known as the United States Coast and Geodetic Survey (USC&GS) in 1878, and the National Ocean Survey (NOS) in 1970. For convenience, it will be referred to as the Coast Survey.

The United States Fish Commission, founded as an independent agency of government in 1871, was incorporated in 1903 in the Department of Commerce and Labor as the Bureau of Fisheries. In 1940 it was transferred to the Department of the Interior and redesignated the Fish and Wildlife Service (FWS). In 1956 many functions of the FWS were split off and placed within a new Bureau of Commercial Fisheries (BCF). Next, in 1970, BCF was reorganized as the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce. In 1975 the Northeast Fisheries Center (NEFC) in Woods Hole, Massachusetts, was established as headquarters for NMFS operations off the northeast coast of the United States. For convenience, it will be referred to as the Fisheries.

2. Riley remembers Bigelow as "skeptical but permissive" with regard to the kind of quantitative work done on these cruises. According to Riley, Bigelow's characteristically blunt words were, "Anybody who thinks he can predict more than 10 percent of plankton variations is a damn fool, but good luck!"

3. gC stands for grams of carbon.

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2

Cartographic History, 1524–1850

Barbara B. McCorkle

The modern chart of Georges Bank is the result of more than 450 years of harsh experience and hard survey. It developed from maps so primitive in their depiction that they merely gave suggestive guidance, and during much of the period under review, there was very little information on the location, size, or shape of the bank. I shall try here to show the steps by which maps of Georges Bank gradually approached an accurate representation.

News of the form and dimensions of the New World reached the Old from two directions. From the south, Columbus and those who followed him explored the shores of the Caribbean, discovered the main outlines of the islands, and drew the great curve of the Gulf of Mexico with the peninsulas of Yucatan and Florida. From the north, the Corte-Reals and the unnamed fishermen who sailed from English, French, and Iberian ports confirmed the existence of Labrador, Newfoundland, and the Grand Banks. But in those first decades of exploration, the middle latitudes were ignored. Cabot may have sailed through the Gulf of Maine as he skirted the continent on his voyage of 1498, but it was not until the voyage of Giovanni da Verrazzano in 1524 (Wroth, 1970) that there was any account of the region wherein lies Georges Bank.

Verrazzano's expressed purpose was to find a route to Cathay. He must have read many accounts of America and undoubtedly had access to the most current maps, both published and manuscript, when he began to plan his voyage in 1523. An unknown coast stretched from Florida to Newfoundland. Verrazzano proposed to King Francis I that he sail to this blank part of the map and find the westward passage for France.

Verrazzano made landfall in the vicinity of Cape Fear. Coasting north along North Carolina's Outer Banks, he looked across the narrow strip of sand to Pamlico Sound and concluded that it was the great Eastern Ocean itself. (His error was perpetuated on maps for over a century as the Sea of Verrazzano.) Sailing on, Verrazzano discovered New York Harbor, passed along the southern shore of Long Island, and entered Narragansett Bay, where he rested for 15 days in a fair land that he called Refugio. Then Verrazzano continued east, crossing the great shoal that includes Georges Bank on his way home. The first recorded mention of the bank is in a letter that Verrazzano sent to King Francis I after his return to France. He wrote, "We found sandbanks which stretch from the continent 50 leagues out to sea. Over them the water was never less than three feet deep: thus there is danger in sailing there. We crossed them with difficulty and called them 'Armellini' " (Wroth, 1970, p. 140).

Estevão Gomes, a Portuguese serving Spain, also sought a westward passage to the riches of the East. Sailing to the New World only a few months after Verrazzano had returned to France, Gomes made a careful examination of the New England coast and was the first to mark the existence of Cape Cod (Cumming, Skelton, and Quinn, 1972, p. 74).

The results of the voyages of Verrazzano and Gomes were soon reflected in maps, and the dangerous New England shoals first received expression in the Salviati map, a manuscript prepared circa 1525 (Cumming, Skelton, and Quinn, 1972, p. 74; figure 2.1). The cartographer, about whom nothing is known, apparently based his map on news from the Gomes voyage because the Sea of Verrazzano is not shown. Two other manuscript maps followed shortly, one by Vesconte de Maggiolo (1527), the other by Verrazzano's brother Girolamo (1529). Both maps show a flattened oval Armelline Shoals swinging out to sea from an unnamed headland that is Cape Cod (figure 2.2).

On a manuscript map (circa 1537) attributed to Gaspar Viegas (Cortesão, 1960, p. 115), the shoals have been reworked, now stretching like a boomerang from 36 to 42° north latitude, being broadest just east of a north-jutting Cape Cod (figure 2.3). The Viegas interpretation of the Verrazzano and Gomes information was copied on many manuscripts and printed maps over the next 30 years, even by Mercator on his monumental and momentous world chart of 1569.

As the voyages of Verrazzano and Gomes had failed to find a midlatitude passage to the Orient, the New England coast was largely ignored until the time was ripe for colonization early in the seventeenth century. Then came the explorations of Gosnold, Pring, Champlain, and Waymouth, at least partly inspired by the search for Verrazzano's Refugio. After them came the ships sent by stock companies organized to colonize. One of the last—the Virginia Company—is credited with a map, prepared circa 1608 (Stokes, 1916, p. 134, plate 21a), that marks a new trend in the delineation of the Gulf of Maine shoals. On this map an unnamed shoal lies in the Gulf of Maine, one end pointed toward Cape Cod, the other toward Cape Sable. Viegas had freed the Armelline Shoals from anchor at Cape Cod; the unknown cartographer of the Virginia Company map took the original oval shape used by Verrazzano and Maggiolo and set it adrift in the middle of the Gulf of Maine, where with varying orientations, it would remain for many years.

The shape of the bank on the Velasco map of 1611, on which the name "S. Georges Banck" makes its first appearance, is similar to that on the Virginia Company map. The bank lies south of Penobscot Bay, but with a WNW/ESE orientation, and shows what seems to be a cluster of four small islands at its southern edge (figure 2.4). Although the Velasco map lay hidden in a Spanish archive for 270 years, the original from which it was copied was undoubtedly known, and probably influenced those maps on which Georges Bank lies north of Cape Cod. Its maker apparently had access to not only information from the Gorges/Popham settlement attempt at the mouth of the Kennebec (see the vignette "How the Bank Got Its Name" by McCorkle) but also reports of other early seventeenth-century explorations, for the map incorporates information from John Smith's voyage to Virginia and the surveys of Pring, Gosnold, and Argall along the New England coast.

Another first in the cartographic history of Georges Bank occurs on the "Carta particolare della nuova Belgia e parte della nuova Anglia" in Robert Dudley's *Dell'Arcano del Mare*, Florence, 1646/1647 (figure 2.5). On this chart soundings have been added. Depths range from 3 fathoms at the southern end to 12 fathoms at the northern end of the bank. In preparing his atlas Dudley drew upon many maps and charts, including Dutch and English ones. His large collection has long been dispersed, however, making it impossible to do more than conjecture about his sources (Stokes, 1916, pp. 145–148). Whatever the origins of the Velasco and Dudley maps, their representations of Georges Bank share an important characteristic. They show an awareness of both the Northeast and Great South channels, an improvement not always followed by copiers.

Jan Jansson, one of the great Dutch cartographers who dominated mapping in the seventeenth century, first devised the next shape to be considered (figure 2.6). In their sea atlases the Dutch had developed a style of depicting shoals and banks that was marked by sweeping curves, graceful ellipses, and crisply pointed cusps. Such features are very evident on Dutch charts of the Grand Banks, and Jansson devised a highly specialized form for the shoals and banks in the Gulf of Maine. Not enough research has been done to enable us to know upon what sources this configuration was based, but it does seem to indicate an increased knowledge of the hazards of the Gulf of Maine. Instead of one great shoal we find several lesser ones—a bladder-shaped shoal would seem to be Georges Bank, a southward bulge obviously indicates Nantucket Shoals, while several "barbs" may indicate Cashes Ledge or Jeffreys Ledge. Although there is no clear Great South Channel through these shallows, a channel is shown to the northeast. This elegant, if somewhat fanciful, treatment of the banks in the Gulf of Maine seems to have been limited to the Dutch and those who copied them. It is characteristic of the entire series of 28 maps known as the Jansson/Visscher New England series, which kept this odd shape in circulation from 1650 to 1750 (Campbell, 1965, plates 1–7, 10, 11, 14–17).

Maps by the Englishman John Senex, the German Johann Baptist Homann, the Frenchman Guillaume De L'Isle, and the Dutchman Pieter van der Aa—a nice spectrum of leading European cartographers—employ a variation of the peculiar Dutch shape (figure 2.7). However, as this version merged all the shoal areas into one amorphous mass stretching east from Cape Cod almost to Cape Sable, the shape is regressive and does not seem based on new information. It was popular, however, and was copied by many map makers.

One Dutch publishing firm noted for the accuracy of its charts was that founded by Johannes Van Keulen. His "Pas-kaart Vande Zee Kusten inde Boght van Nieuw Engeland" (figure 2.8), first published in 1684 and appearing in his atlases until 1734, was more accurate in several respects than any of the maps so far discussed. Soundings on the north/south-oriented, pear-shaped bank

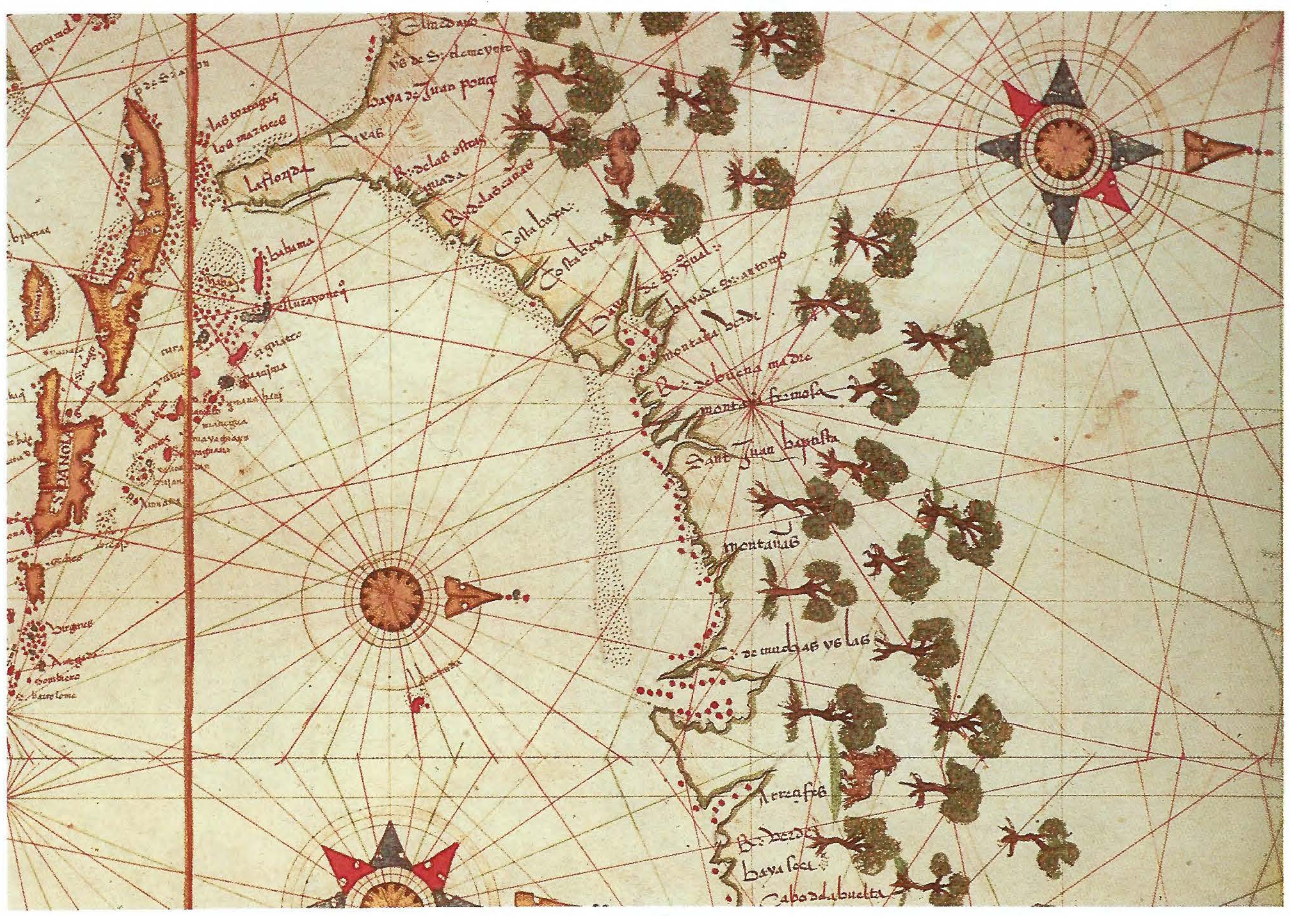


Figure 2.1
"Salviati Mappemonde," anonymous world chart, circa 1525, 93 cm × 209 cm, manuscript on parchment (detail). The map, which was made by an unknown chart maker for the powerful Florentine family Salviati, whose arms are twice emblazoned upon it, reflects information brought back from the voyage of Estevão Gomes, who returned to Spain in August 1525. Gomes discovered Cape Cod and reported the existence of shoals along the eastern seaboard and out across the Gulf of Maine. [Biblioteca Mediceo-Laurenziana, Florence]

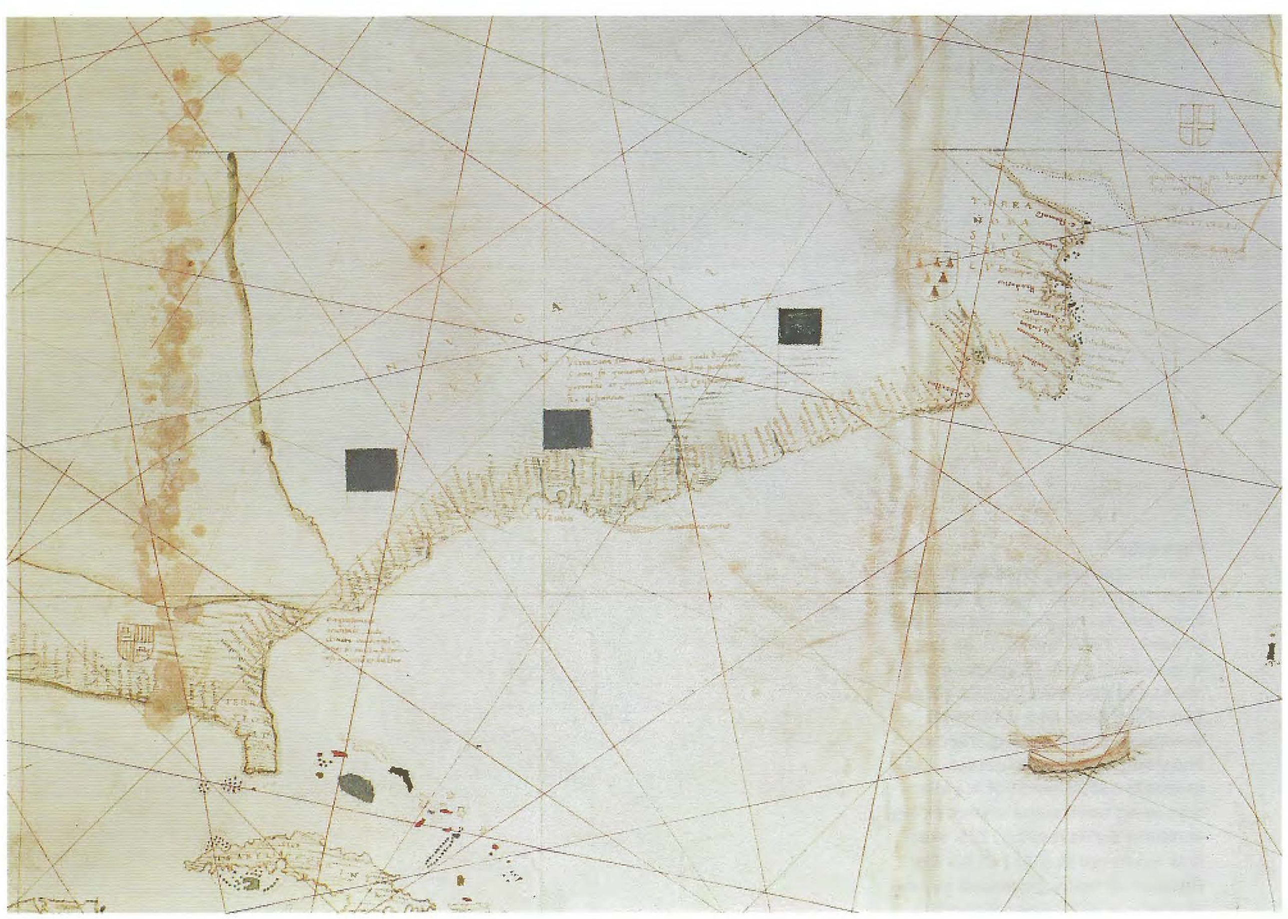


Figure 2.2
Girolamo da Verrazzano, "Mappemonde," 1529, 130 cm × 260 cm, manuscript on parchment (detail). This manuscript map was drawn at least partly to show the New World discoveries of the cartographer's brother, Giovanni. The detail shows the Armelline Shoals off Cape Cod. Verrazzano's report did not note the existence of the cape, which is represented here by an indistinct headland.

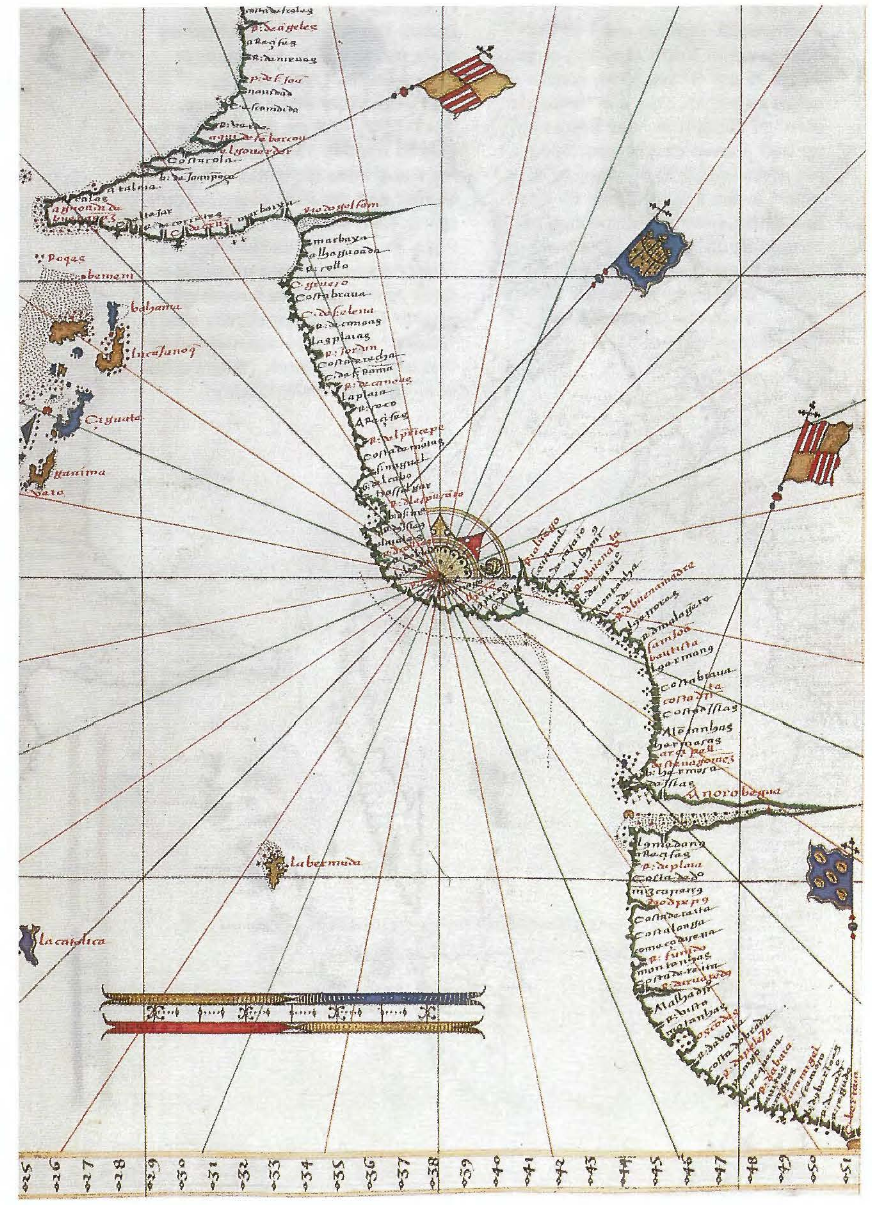
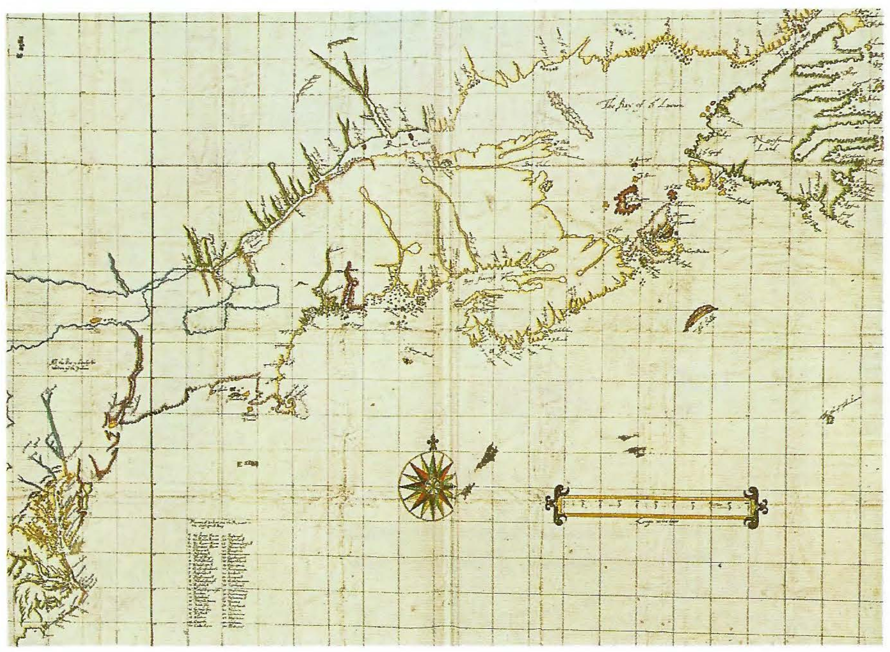
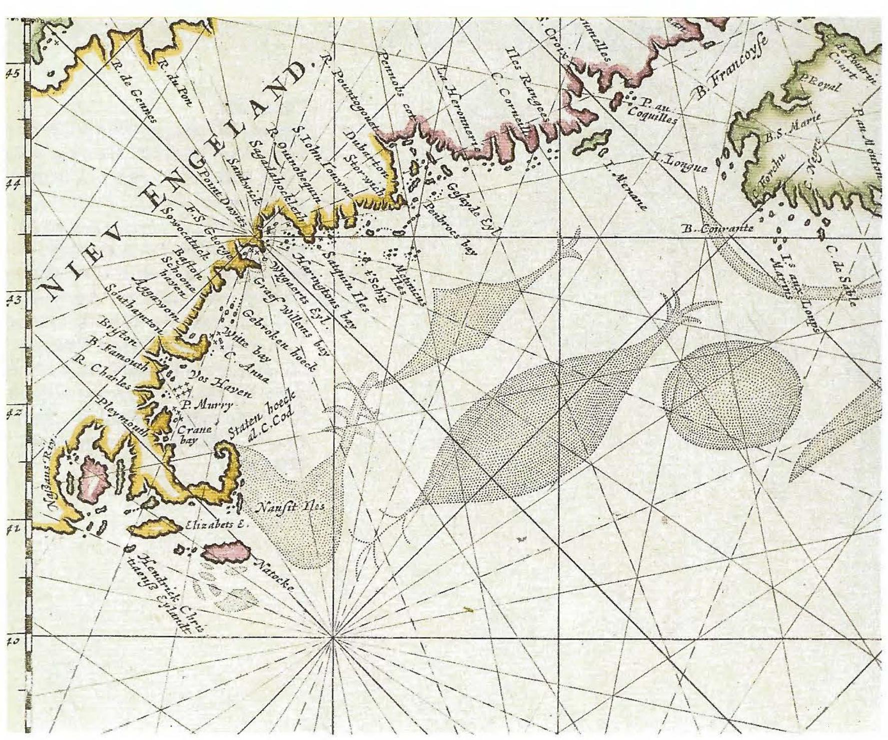


Figure 2.3
Gaspar Viegas, untitled chart of the east coast of North America, circa 1537, 28.5 cm × 39.5 cm, manuscript on parchment, chart No. 19 in unsigned, undated atlas of 26 sheets (detail). From its style, nomenclature, league scales, and ornamentation, Armando Cortesão has attributed the chart to Viegas. This detail shows Cape Cod (unnamed) and its neighboring shoals. Note the cross marks opposite the tip of the cape, indicating a special hazard. [Biblioteca Riccardianai, Florence]

Figure 2.4
Anonymous. Untitled chart of the east coast of North America, circa 1610, 78 cm × 108.5 cm, manuscript on paper. This, the "Velasco Map" is thought to have been sent by Don Alonso de Velasco, Spanish ambassador to England, in a report to the king of Spain on English discoveries and colonizing efforts in North America. The map marks the first appearance of the name "St. George's Banck." [Archivo General de Simancas, Estado, Simancas]

Figure 2.5
Robert Dudley, "Carta particolare della nuova Belgia e parte della nuova Anglia," from Dudley's *Dell'Arcano del Mare*, Florence, 1647/1647, 47.5 cm × 38.5 cm, engraved (detail). The charts in Dudley's sea atlas are noted for their beauty and the fine, flourished lettering. Like the other charts in the atlas, this one of the New England coast has been drawn on the Mercator projection. Five soundings appear on the schematically oval "Banca" in an area approximating that of Georges Bank. [Map Collection, Yale University Library]





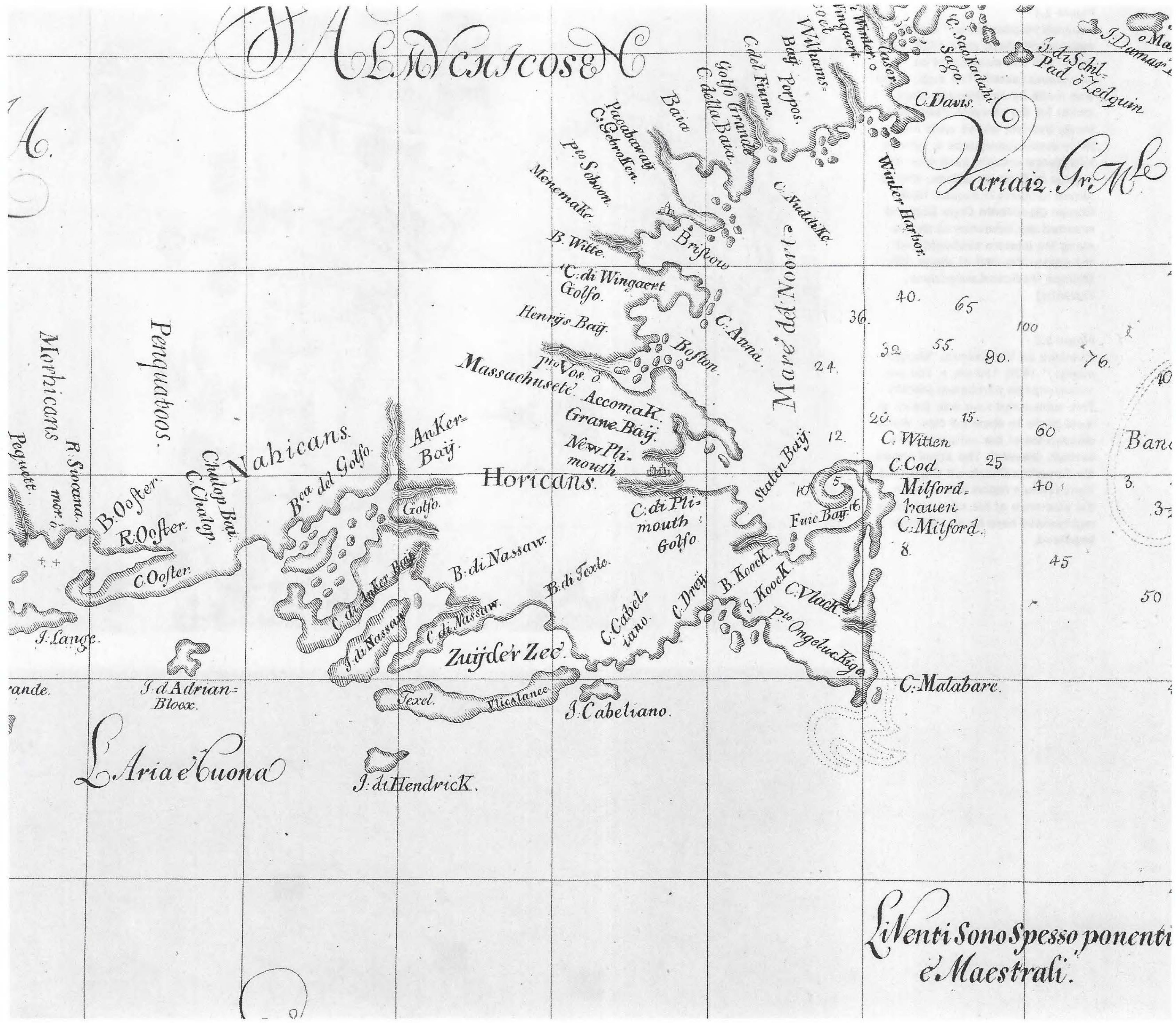


Figure 2.6
Arent Roggeveen, "Pascaerte van Terra Nova, Nova Francia, Nieuw Engeland En de Groote Revier van Canada," 1675, 44 cm × 54 cm, engraved (detail). Roggeveen had access to the hydrographic collection of the East and West India Company at Middelburg, then an important commercial center, and probably based much of his information on manuscript charts in the company's possession. The chart first appeared in part I of his *Het Brandende Veen*, published in Amsterdam in 1675. [Map Collection, Yale University Library]

Figure 2.7
Guillaume De L'Isle, "Carte du Canada ou de la Nouvelle France et des Découvertes qui y on été faites Dressée sur plusieurs Observations et sur un grand nombre de relations imprimées ou manuscrites Par Guillaume de l'Isle Geographe de l'Academie Royale des sciences. A Amsterdam chez Iean Covens et Corneille Mortier," [1730], 49 cm × 57 cm, engraved (detail). De L'Isle's popular and much copied map went through numerous editions after its initial publication in 1703. This version, a very close copy of the original, appeared in an edition of De L'Isle's *Atlas Nouveau*, published by Covens and Mortier in Amsterdam, 1730. [Map Collection, Yale University Library]

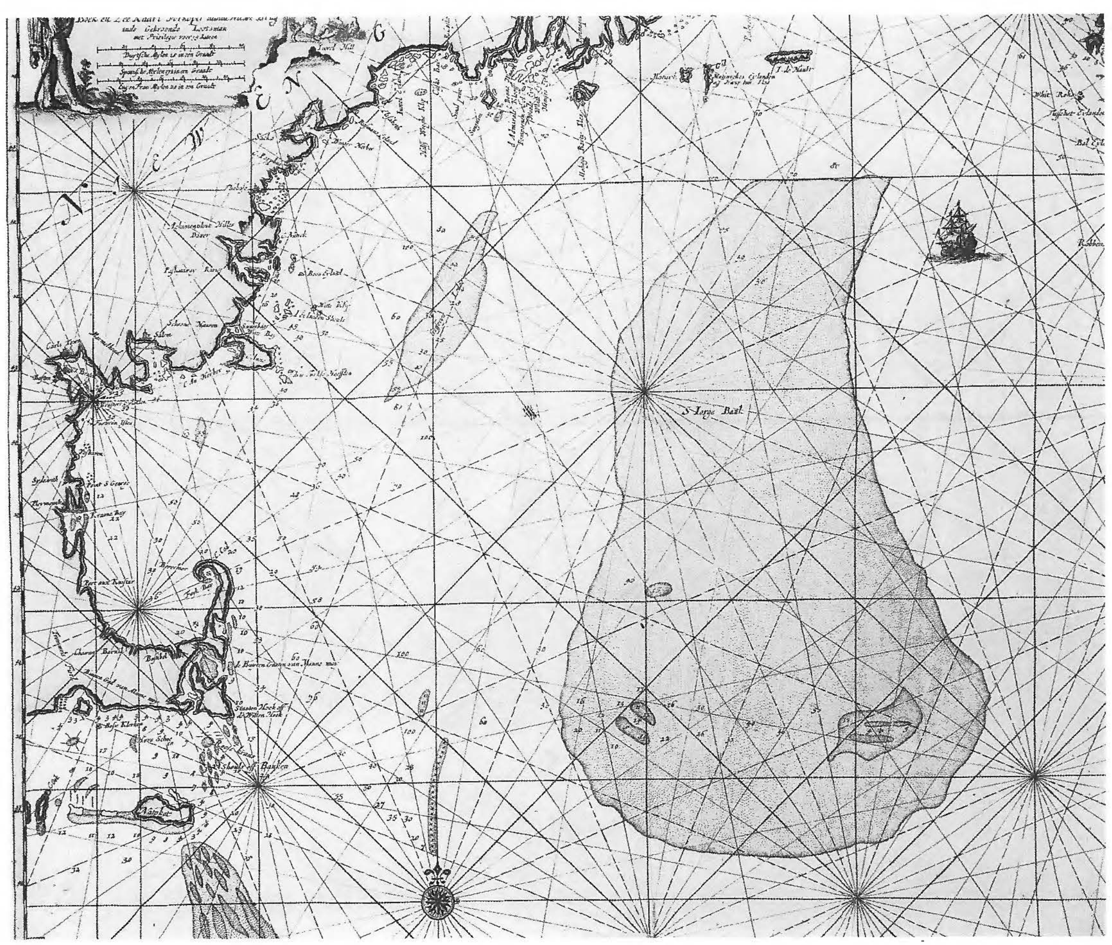


Figure 2.8
Johannes Van Keulen, "Pas-kaart Vande Zee Kusten inde Boght van Niew Engeland Tusschen de Staaten Hoek en C. de Sable Door Vooght Geometra T'Amsterdam by Johannes van Keulen Boek en Zeekaart verkoper aande Niewe Brug inde Gekroonde Lootsman," [1695], 50 cm × 58.5 cm, engraved (detail). This map originally appeared in the great sea atlas *De Nieuwe Groote Lightende Zee-Fakkel*, published in Amsterdam in 1684, and was reissued in various editions of Keulen's sea atlases until 1734. The copy shown, with its curious rendition of Georges Bank, is an early state before additional shoals and soundings were added. [Map Collection, Yale University Library]

delineate four separate shallow areas—perhaps an early attempt to show Cultivator and Georges shoals. Curiously, this shape was not copied and thus had no influence on later charts.

On John Thornton's "New Mapp of the North Part of America" (London, 1673), Georges Bank assumes an entirely new form, which, though erroneous, was copied by many cartographers during the next 75 years. Thornton's bank was long and club shaped, nearly touching Cape Sable at its narrow northeastern end and stretching southwest toward Cape Cod. In *The English Pilot, The Fourth Book*, the standard mariners' atlas for the coasts of America, charts following Thornton's pattern were used in editions from 1689 to 1784, perpetuating this erroneous form long after more accurate information was available (figure 2.9) (*The English Pilot*, 1967, pp. xix–xx). While all maps of this type are inaccurate in their depiction of a long, narrow bank and in virtually eliminating the Northeast Channel, they do open out the Great South Channel, which henceforward never disappears from maps. Furthermore, Jeffreys Ledge and a small Cashes Ledge have appeared. We have no records of the observations from which these charts were drawn, but they must have been made infrequently, as some of the charts were used without changes for many years.

For the most part, maps produced late in the seventeenth and early in the eighteenth centuries were copies or adaptations of earlier ones. The first radically new map after Thornton's of 1673 was Captain Cyprian Southack's "New Chart of the English Empire in North America," published in 1717. In a move that influenced maps and charts until the end of the century, Southack separated Georges Bank from Browns Bank, indicating a 100-fathom channel between the two, the first such representation of the Northeast Channel. On his chart Southack claimed, "As far as the Prick't Line runs I have been cruising in the Service of the *Crown of Great Britain* from the Year 1690 to the Year 1712." The pricked line mentioned traces several routes through the Gulf of Maine, an area Southack knew well from his experience as a mariner, including 15 years, 1697–1712, as master of the *Province Galley*, the Massachusetts coast-guard vessel (Hitchings, 1980, p. 51).

Southack enlarged and improved the chart for his *New England Coasting Pilot* (London, 1720?, 1734?), and thereafter it became the model for leading map and chart makers (figure 2.10). The enlarged chart, the first to come close to the actual shape of the bank, had 50 soundings on Georges Bank, 11 on Browns Bank, and numerous soundings beyond to the south and east. Additionally, it gave information about the bottom: for example, "Brown sand," "Rocky Ground Good fishing in April and May," and "Coarse Sand."

Southack had his detractors, one stating that "it does not appear . . . that . . . he employed any instruments excepting the Log and Compass . . . [and] undertook to make a chart . . . without ever taking a single latitude" (Mead, 1755, p. 5). Another was even harsher, calling the

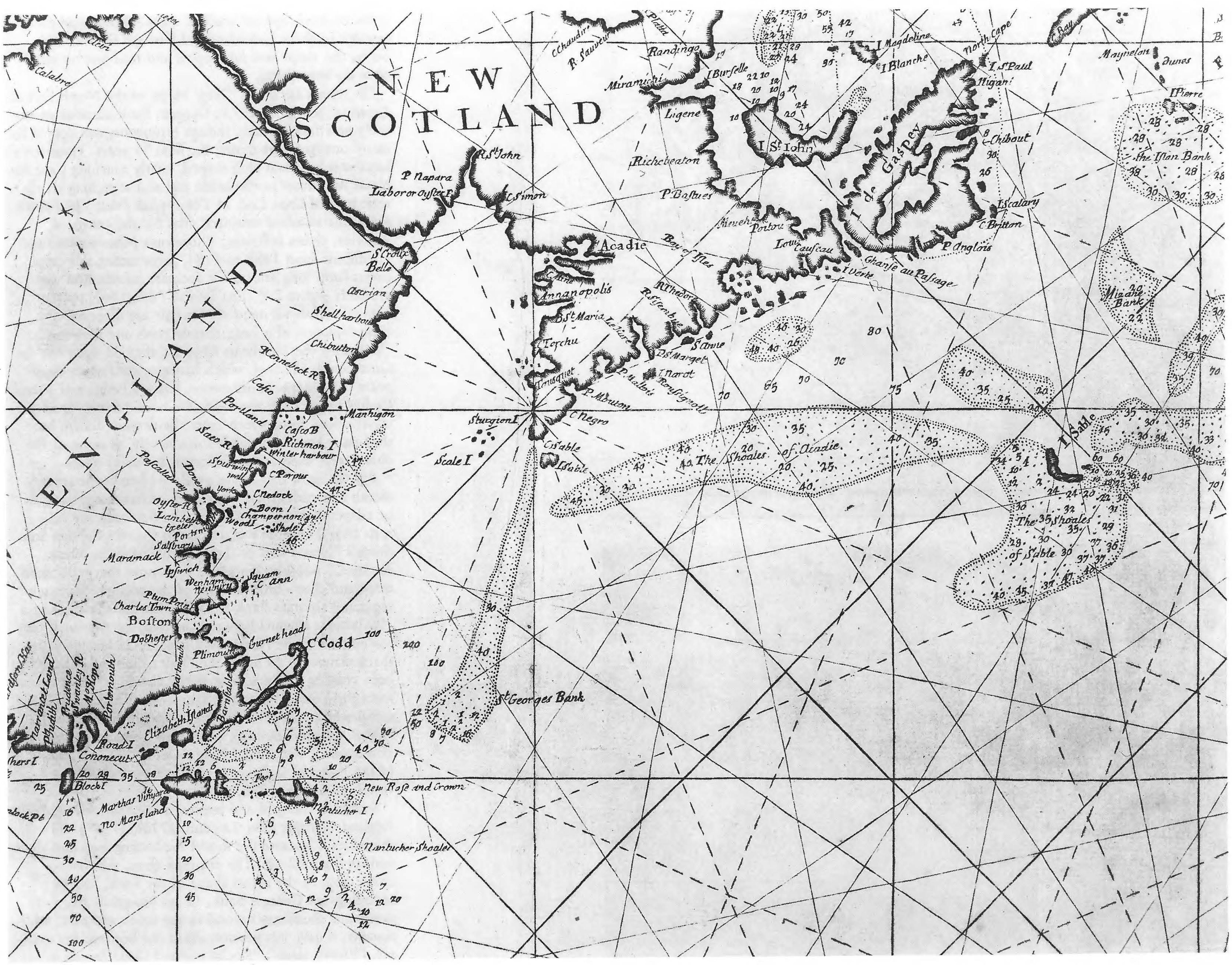
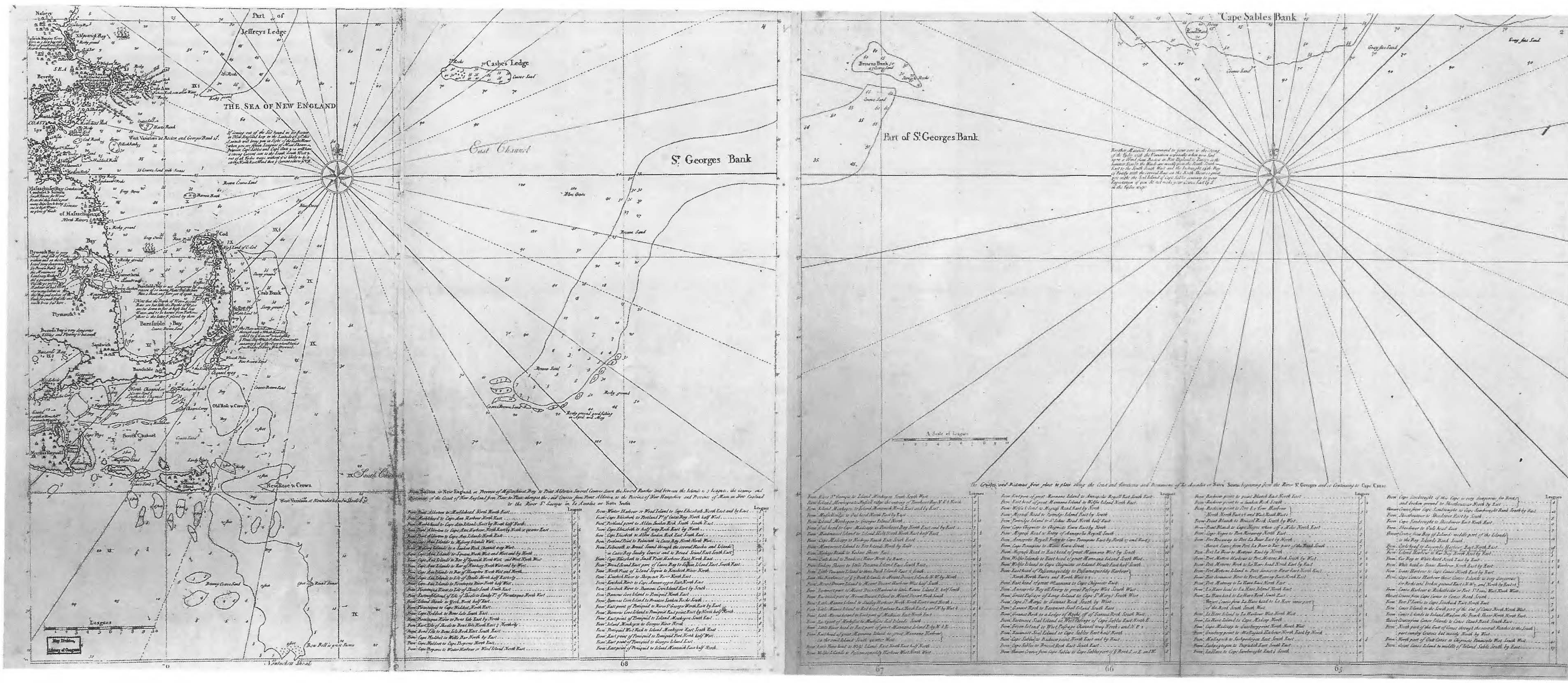


Figure 2.9
"A Chart of the Sea Coast of New Found Land, New Scotland, New England, New York, New Jersey with Virginia and Maryland. Sold by Willm. Mount & Tho. Page at the Postern on Great Tower hille London," [1689], 45.5 cm × 57 cm, engraved (detail). The chart, with configurations based on John Thornton's chart of 1673, was included in all editions of *The English Pilot. The Fourth Book*, 1689–1706, and can be found in some copies of later editions until 1770, although its information had long been superseded. [Map Collection, Yale University Library]

Figure 2.10
Cyprian Southack, "The New England Coasting Pilot. From Sandy Point of New York, unto Cape Canso in Nova Scotia, and part of Island Breton," [1720?, 1734?], 107 cm × 252 cm, engraved (detail). Two sheets, of eight, are here shown joined to depict a radically new shape for Georges Bank. Southack's *New England Coasting Pilot* is exceedingly rare in its original edition, possibly published in London in 1720. However, the map was quickly copied, and with its fringing shoals, curved shape, and numerous soundings, it became the prototype of maps of the area for the next 50 years. [Library of Congress]


Part of Jeffreys Ledge
THE SEA OF NEW ENGLAND
Cashes Ledge
St. Georges Bank
Part of St. Georges Bank
Cape Sables Bank
Plymouth
Barnstable Bay

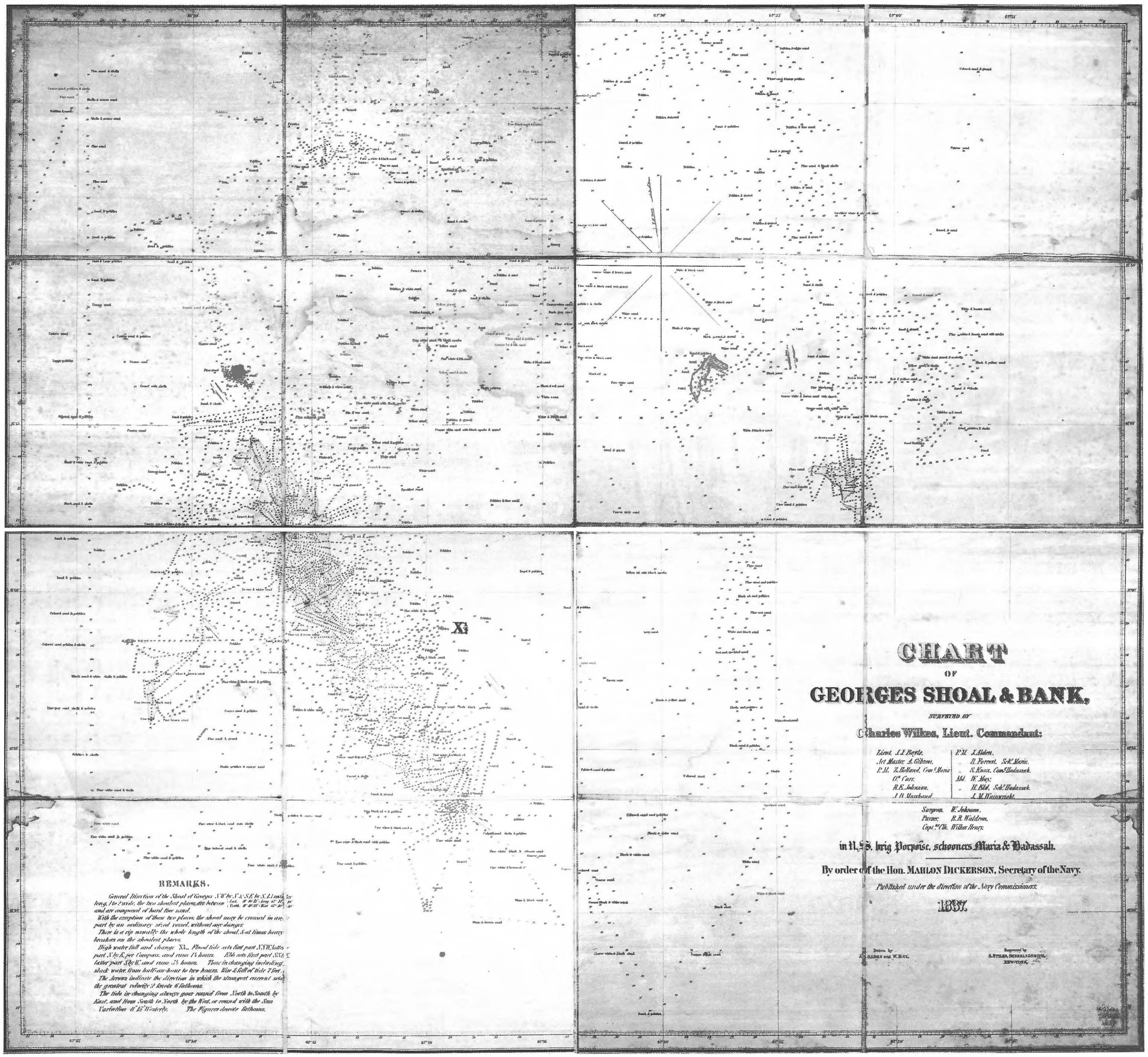


Figure 2.11
Charles Wilkes, "Chart of Georges Shoals & Bank, surveyed by Charles Wilkes, Lieut. Commandant . . . in U.S. brig Porpoise, schooners Maria & Hadassah, by order of the Hon. Mahlon Dickerson Secretary of the Navy, Published under the direction of the Navy Commissioners. 1837. Drawn by J. Alden and W. May. Engraved S. Stiles, Shennan & Smith, New-York," 99 cm × 111 cm, engraved (detail). Wilkes's 1837 map was the first bathymetric chart published by the U.S. Navy Hydrographic Office. Although its coverage was limited to the shallowest part of Georges Bank (around Georges Shoal), a better survey was not undertaken until 1930–1932. [Map Collection, Yale University Library]

chart "one continued error . . . [and] ought to be publickly advertised as such and destroy'd wherever it is found" (Douglass, 1749, vol. 1, p. 362). Nonetheless, the shape Southack had given to Georges Bank persisted. Charts based on it, with soundings unchanged from the original, were used in editions of *The English Pilot, The Fourth Book* (along with charts using the old Thornton shape) from 1737 to 1794. Its distinctive curved form was found on French and German, as well as English, maps. John Mitchell copied it on "A Map of the British and French Dominions in North America" (London, 1755), often called the most important map in the history of American cartography, and the map used to draw the boundaries of the United States at the Treaty of Paris, 1783. Since Mitchell had access to official British sources in compiling the material for his map, we can assume that the Southack data were considered accurate (Berkeley and Berkeley, 1974, pp. 175–213).

Lawrence Wroth, for many years librarian of the John Carter Brown Library and a preeminent bibliographer and historian, put our debt to Southack concisely: "If one may use sentiment, as has sometimes been done, to bridge the breaks in a line of descent, it is not difficult to think of Southack as the ancestor of the United States Coast Survey, which today carries on a continuous charting and recharting of our waters" (Wroth, 1947, p. 87).

Political events in the second half of the eighteenth century prompted the English to concentrate on producing accurate maps and charts of the American coast. Joseph Frederick Wallet Des Barres, an army engineer of Swiss origin, was commissioned to make the first scientific survey of the coasts of Nova Scotia, New Brunswick, and Sable Island (Evans, 1969, p. 12). Samuel Holland, surveyor general of the Northern District of North America, was to survey those of New England and the St. Lawrence River and Gulf. Des Barres published the charts in *The Atlantic Neptune*, one of the most magnificent collections of nautical charts and views ever produced. One of the charts, "The Coast of New England" (1781), contains the first recognizably modern depiction of Georges Bank. The chart has no attribution, but was undoubtedly drawn by Holland. The eastern edge of the bank lies beyond the map's border, but the western edge slopes south, then curves north, as on a modern chart, to indicate the Great South Channel. Although neither Cultivator Shoal nor Georges Shoal is named on the chart, two groups of shallow soundings appear in their approximate locations. This new information quickly replaced the old on nautical charts, although maps following the old Southack shape continued to appear for another 20 years.

By the end of the eighteenth century, charts made by Americans, published in America, and frequently based on original observations by American navigators, began to replace English ones. The first such collection was published by Matthew Clark in Boston in 1790. One of the nine large charts is a "Chart of the Coast of America from George's Bank to Rhode Island Including Nantucket Shoals etc. . . ." No study of the basis for this chart has been made (Wroth, 1947, p. 103). However, as the chart is certified by Osgood Carleton, Boston surveyor, mathematician, and map maker, as being true and accurate compared "with Des Barres & other good authorities," Des Barres's chart may have been its source. A new feature on the Clark chart is a "Shoal Ground of St. George's Bank," located at approximately the correct latitude for Georges Shoal, but too far west—a common error.

The second American chart to show Georges Bank was produced in the following year, when John Norman brought out *The American Pilot* (Boston, 1791). A slightly more ambitious work than Clark's, it had 11 charts and a brief list of sailing directions. A "Chart from New York to Timber Island Including Nantucket Shoals" also included Georges Bank, with the same configuration and soundings on the shoal areas as the Clark chart of 1790.

It was now the turn of the American map makers to be copied. On "A New and Correct Chart of the Coast of New England and New York . . . by Captain Holland," published in London in 1794, the "Shoal Ground of St. George's Bank" is taken directly from the Clark/Norman charts, including all soundings.

Edmund Blunt, an important figure in American nautical publishing, brought out the first separate chart of Georges Bank in 1797—"A Chart of George's Bank, Including Cape Cod, Nantucket and the Shoals lying on their east . . . Surveyed by Capt. Paul Pinkham." Like Pinkham's "A Chart of Nantucket Shoals," which had been prepared earlier for *The American Pilot* (Wroth, 1947, p. 104), his chart of Georges Bank was clearly an original work and differs in several respects from the charts of Des Barres and Norman. In a lengthy note on his chart, Pinkham wrote, "As there has never been a correct chart of George's Bank published I have attempted to perfect such a work and submit it to the inspection of the public." While his chart has many errors, particularly of longitude, Pinkham made explicit what was implicit on Des Barres's chart—that Georges Bank is only a part of a larger shoal complex.

In 1828 Blunt brought out a new, large-scale chart, "The North Eastern Coast of North America from New York to Cape Canso including Sable Island," to supplement the printed sailing directions in the newest edition of his popular *Atlantic Coast Pilot.* Over 100 soundings are given on Georges Bank, with several dozen notes on bottom conditions. It was by far the most accurate and detailed chart of the bank yet to appear.

Charles Wilkes, one of the first important American naval explorers, showed an early interest in both sea and science. A lieutenant in the United States Navy, he studied nautical surveying under Ferdinand Hassler, superintendent of the U.S. Coast Survey. Wilkes surveyed Georges Bank in 1837, and his "Chart of Georges Shoal & Bank" was published the same year (figure 2.11). The large chart, measuring 39 inches × 44 inches, at the scale of an inch to the mile, gives over 1,000 soundings and dozens of notes on bottom conditions. Wilkes describes in a note on the chart the "two shoalest places," both of which are on Georges Shoal.

Here, at the midpoint of the nineteenth century, the end of our inquiry into the cartographic history of Georges Bank, the Wilkes chart had become the basis for all charts of the bank, both official and commercial, American and foreign. It was the culmination of 300 years of mapping Georges Bank and distinctly modern in its accuracy and wealth of detail.

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