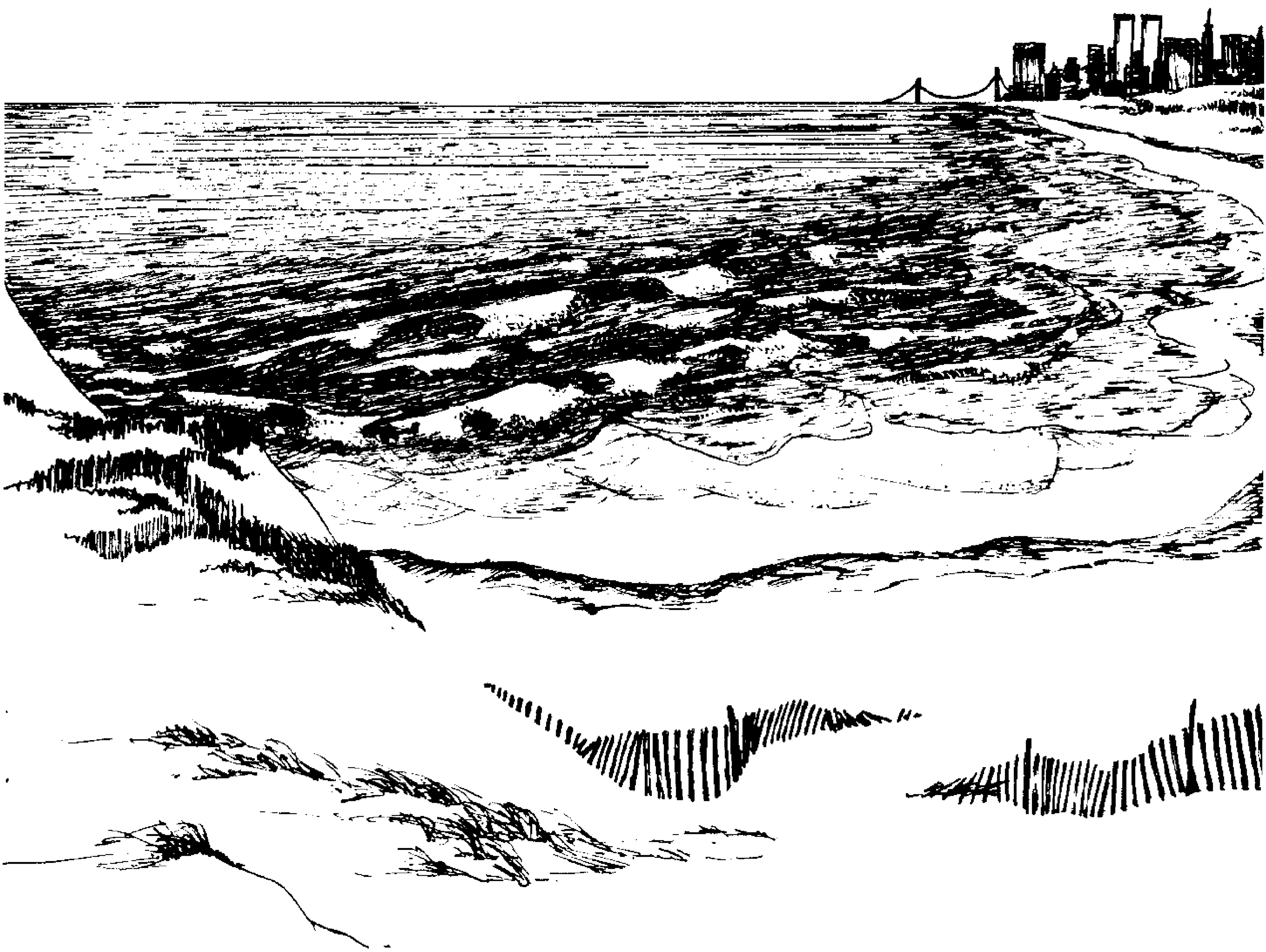
SUNY-T3-76-004 C. 2

Gravity, Magnetics, and Seismicity

James R. Cochran and Manik Talwani



MESA NEW YORK BIGHT ATLAS MONOGRAPH 9

The offshore water in the bend of the Atlantic coastline from Long Island on one side to New Jersey on the other is known as New York Bight. This 15,000 square miles of the Atlantic coastal ocean reaches seaward to the edge of the continental shelf, 80 to 120 miles offshore. It's the front doorstep of New York City, one of the world's most intensively used coastal areas – for recreation, shipping, fishing and shellfishing, and for dumping sewage sludge, construction rubble, and industrial wastes. Its potential is being closely eyed for resources like sand and gravel – and oil and gas.

This is one of a series of technical monographs on the Bight, summarizing what is known and identifying what is unknown. Those making critical management decisions affecting the Bight region are acutely aware that they need more data than are now available on the complex interplay among processes in the Bight, and about the human impact on those processes. The monographs provide a jumping-off place for further research.

The series is a cooperative effort between the National Oceanic and Atmospheric Administration (NOAA) and the New York Sea Grant Institute. NOAA's Marine EcoSystems Analysis (MESA) program is responsible for identifying and measuring the impact of man on the marine environment and its resources. The Sea Grant Institute (of State University of New York and Cornell University, and an affiliate of NOAA's Sea Grant program) conducts a variety of research and educational activities on the sea and Great Lakes. Together, Sea Grant and MESA are preparing an atlas of New York Bight that will supply urgently needed environmental information to policy-makers, industries, educational institutions, and to interested people. The monographs, listed inside the back cover, are being integrated into this *Environmental Atlas of New York Bight.*

MONOGRAPH 9 shows gravity and magnetic anomalies in New York Bight as broad bands reflecting major changes in the continental shelf's basement structure, dominated by the Appalachian Mountains and the transition from continent to ocean. Cochran and Talwani say that the evolution of continental margins like the US east coast is being intensively studied–knowing the environment in which shelf sediments were deposited helps determine, for example, the likelihood of petroleum deposits. The many small and moderate earthquakes in the Bight region indicate its evolution is still going on but the cause of these earthquakes is not clear.

Credits

Cynthia L. Williams monograph editor
April Shelford and Paula Krygowski drafting
Graphic Arts, SUNY Central Administration composition and pasteup
SUNY Print Shop printers
Mimi Kindlon cover and text design

Marine EcoSystems Analysis [MESA] Program
MESA New York Bight Project

Gravity, Magnetics, and Seismicity

James R. Cochran and Manik Talwani

MESA NEW YORK BIGHT ATLAS MONOGRAPH **9**

New York Sea Grant Institute
Albany, New York
May 1976

James R. Cochran, BS, is concluding work for his PhD in the Department of Geological Sciences at Columbia University. He has served as chief scientist on Lamont–Doherty Geological Observatory's research vessel *Vema* and has published several papers on interpreting gravity anomalies at continental margins and oceanic islands.

Manik Talwani, PhD, is director of Columbia University's Lamont–Doherty Geological Observatory in Palisades, NY, and is a professor of geology at the university's Department of Geological Sciences. He has been chief scientist on many cruises of Lamont–Doherty's research vessels and has served as cochief scientist on the drilling vessel *Glomar Challenger*. His current marine geological research concerns the Norwegian–Greenland Sea, the Barents Sea, and the Australian continental margin.

Contents

Maps

Figures

Tables

Acknowledgments

The data discussed in this report were collected through grants GA–550, GA–1415, GA–1434, GA–1615, GA–17761, GA–19030, GP–5392, GP–5536, and GA–27281 from the National Science Foundation and contracts Nonr 266(79), Nonr 266(48), and N00014-67-A-0108-0004 from the Office of Naval Research to Lamont–Doherty Geological Observatory. This monograph is Lamont–Doherty Geological Observatory contribution 2200.

Manuscript accepted April 1975.

Abstract

Free-air gravity and total-intensity magnetic anomalies in the New York Bight region, presented as profiles along ships' tracks, are dominated by prominent positive and negative bands. Those on the outer edge of the continental shelf and on the continental slope are associated with the transition from the North American continent to the Atlantic Ocean. Those on the inner shelf are associated with structures inherited from the region's geology prior to the formation of the present Atlantic Ocean. The Avalonian trends in the eastern part of the survey area extend to the shelf edge where they are truncated. The Appalachian trends in the western section are not truncated south of Long Island but swing west and continue under the coastal plain sediments in New Jersey.

Although the Bight region is not particularly active seismically, numerous small to moderate earthquakes have occurred. The earthquake activity is scattered, without any distinct trends, though epicenters have tended to cluster in a few areas--for example, Westchester–New York City. The cause of the seismic activity is not well understood.

Introduction

Geophysical methods extend geology to the third dimension by providing ways to determine subsurface structures. Of the diverse techniques developed, most are based on interpreting variations in parameters, which can be measured on the surface but depend on deeper structure. In this monograph we discuss two geophysical methods based on measuring small changes in the earth's gravity and magnetic fields. We first describe briefly how measurements are made, then present and interpret the available data for the New York Bight region.

Knowledge of deep structure is important in studying the geologic history and evolution of an area. The Bight is an "inactive" or Atlantic-type continental margin. At this time such margins are intensively studied to determine the nature of the transition from ocean to continent and the initiation and evolution of ocean basins. This topic is economically, as well as academically, valuable because knowing the evolution of the continental margin and the forces shaping it leads to a better understanding of how and where mineral deposits form. For example, the current interest in oil exploration on the outer continental shelf along portions of the US east coast, including the Bight, is based on geophysical exploration revealing a thick sequence of sediments within which concentration and retention of petroleum deposits could take place.

We also discuss the distribution of earthquakes in the Bight region. The area is geologically stable, but moderate earthquakes have occurred. With the increasing population pressure and development of previously rural areas, it is important for our safety to know where and what type of seismic activity is likely.

Gravity

One method of determining the subsurface structure of the earth arises from the fact that our planet's gravity field does not have a constant value at all points on the surface. The earth is not a perfect sphere; it has a distinct equatorial bulge, resulting in lower gravity at the equator than at the poles. The variation in absolute terms is not very great: from about 978 gal at the equator to 983 gal at the poles–or about 0.5%. The *gal*, named after Galileo, is a unit of acceleration with a value of 1 cm/sec^2 (0.39 in/sec^2).

In addition to this smooth, steady change, there are much smaller, irregular local changes in the force of gravity due to the distribution of mass in the earth's crust and upper mantle. These typically range from ten to a few hundred mgal (1 mgal or milligal = 0.001 gal). A *milligal* is about one part in a million of the earth's gravity field and is roughly equivalent to the gravity change experienced in going from the first to the second floor of a building.

The earth's shape has been determined with great precision, and mathematical expressions have been developed predicting what the value of the gravity field should be at any location, as a function of its latitude. The difference between the value measured at a particular place and the predicted value is referred to as a *gravity anomaly*.

Various forms of gravity anomalies can be defined, depending upon what corrections are applied to the measured gravity values. The simplest correction is for elevation. The force of gravity varies with the square of the distance from the center of the earth. The expected value of gravity therefore depends not only on the latitude but also on the elevation at a specific location. Usually a correction is added to the observed gravity value to account for the elevation of the observation station; this corrected value is compared to the theoretical sea-level value. The resulting anomaly is called a *free-air anomaly* because the gravitational effect of the masses between the observation station and sea level is not considered. For sea-level stations, no elevation correction is necessary.

Instrumentation

The gravity data in this report were collected on cruises of the Lamont–Doherty Geological Observatory vessels R/V *Vema* and R/V *Robert D. Conrad* between 1961 and 1973. The instruments and navigation used during these cruises are summarized in Table 1.

Graf–Askania Gss2 sea gravimeters (Figure 1) were used on all the cruises. These instruments measure changes in gravity by determining the deflections of a horizontal beam suspended by springs (Graf and Schulze 1961; Schulze 1962).

For measurements made on moving ships two special precautions are necessary. Because of the ship's roll and pitch, the gravimeter is mounted on a gyrostabilized horizontal platform. Because waves cause a large vertical acceleration in the ship, the gravimeter beam is damped strongly so that it does not respond to the ship's short-period vertical acceleration (that is, to the ship's bobbing up and down) but does respond to spatial changes in gravity as the ship travels.

Sources of error in gravity measurements are discussed below in some detail to show the errors with different measuring systems and to indicate how these errors were reduced as new equipment was developed.

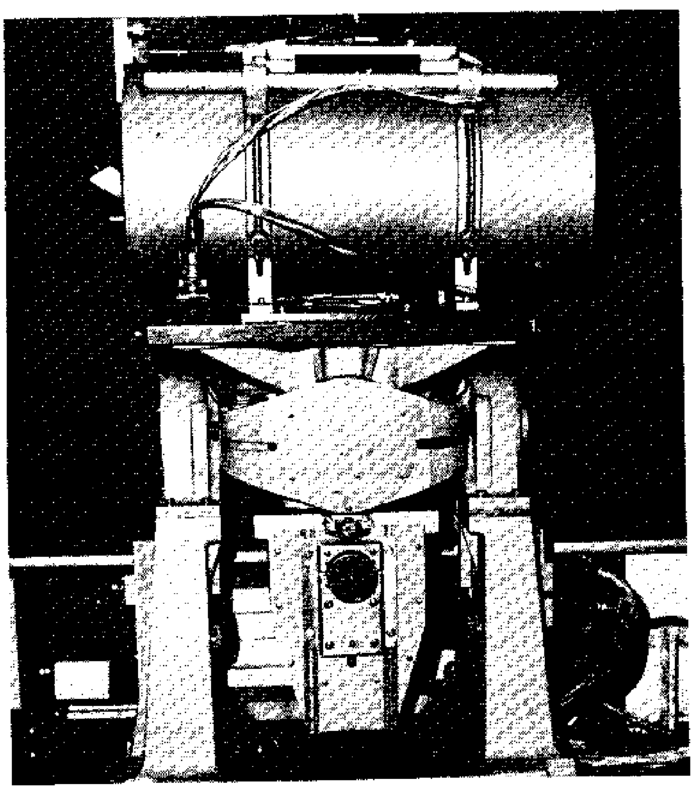


Figure 1. Graf-Askania Gss2 sea gravimeter mounted on Aeroflex gyrostabilized platform: gravimeter beam is within cylindrical drum; platform is designed to keep meter level to within 0.1

Table 1. Navigation and instrumentation

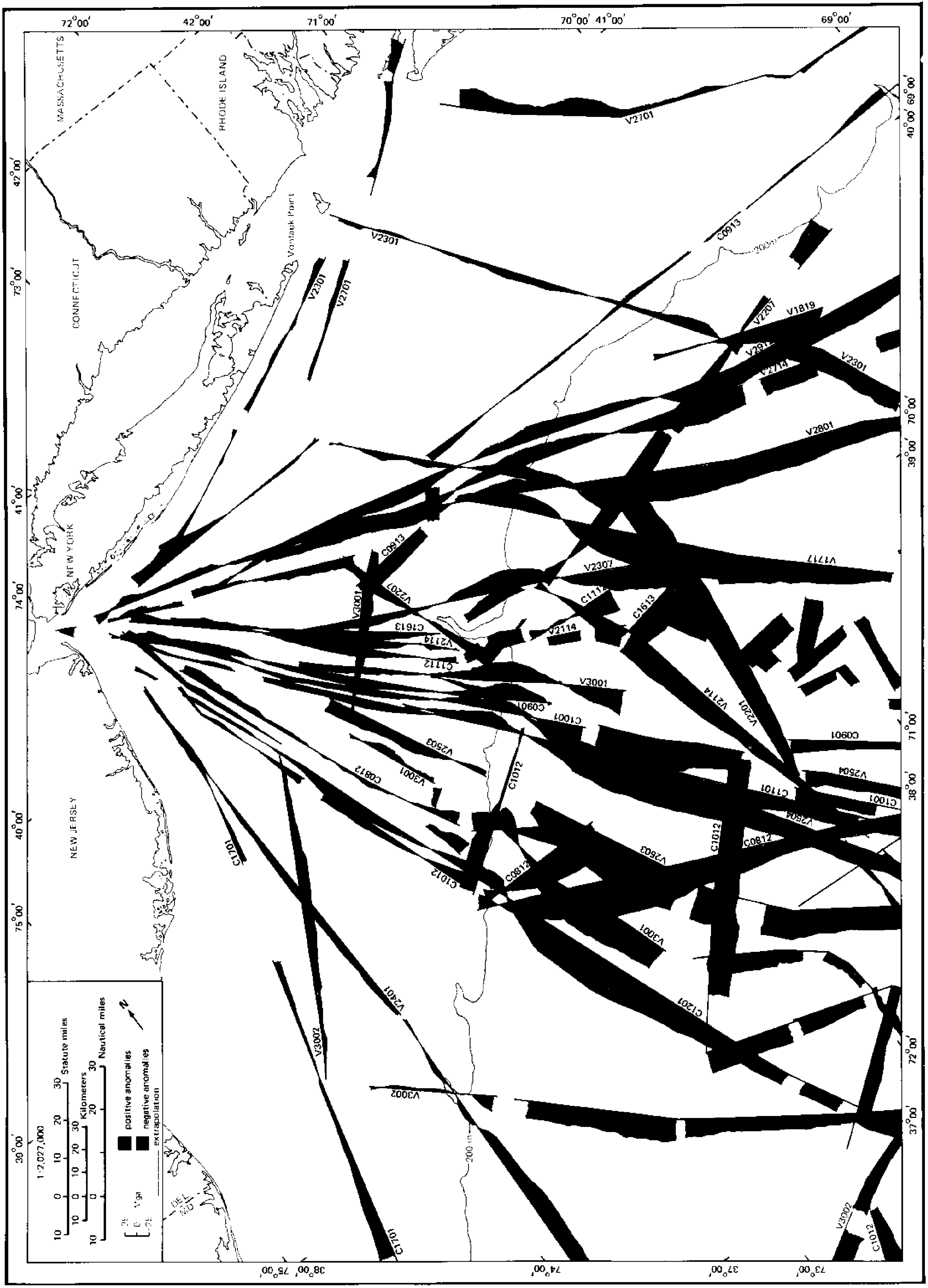
Cruise and Leg	Year	Type of Data Reported[a]	Gravimeter	Stable Platform	Cross-coupling Correction	Navigation
R/V *VEMA*						
17-17[b]	1961	G, M	Gss2–12	Alidade	no	celestial
18-01	1961	M				celestial
18-19	1962	G, M	Gss2–14	Alidade	no	celestial
19-13	1963	M				celestial
20-13	1964	M				celestial
21-01	1964	M				celestial
21-14	1965	G, M	Gss2–12	Alidade	no	celestial
22-01	1966	G, M	Gss2–12	Alidade	yes	celestial
22-07	1966	G, M	Gss2–12	Lamont	yes	celestial
23-01	1966	G, M	Gss2–12	Lamont	yes	celestial
23-07	1966	G, M	Gss2–12	Lamont	yes	satellite
24-01	1967	G, M	Gss2–12	Lamont	yes	satellite
25-03	1968	G, M	Gss2–12	Lamont	yes	satellite
25-04	1968	G, M	Gss2–12	Lamont	yes	satellite
26-01	1968	M				satellite
27-01	1969	G, M	Gss2–12	Aeroflex	yes	satellite
27-14	1970	G, M	Gss2–9	Anschutz electrically executed gyrotable	yes	satellite
28-01	1970	G, M	Gss2–12	Anschutz oil-erected gyrotable	yes	satellite
29-12	1972	G, M	Gss2–12	Aeroflex	yes	satellite
30-01	1972	G, M	Gss2–12	Aeroflex	yes	satellite
30-02	1972	G, M	Gss2–12	Aeroflex	yes	satellite
R/V *ROBERT D. CONRAD*						
08-12	1964	G, M	Gss2–6	Anschutz oil-erected gyrotable	no	celestial
09-01	1964	G, M	Gss2–6	Anschutz oil-erected gryotable	no	celestial
09-13	1965	G, M	Gss2–6	Anschutz oil-erected gyrotable	yes	satellite
10-01	1965	G, M	Gss2–6	Anschutz oil-erected gryotable	no	celestial
10-12	1966	G, M	Gss2–6	Anschutz oil-erected gryotable	no	satellite
11-01	1966	M				satellite
11-12	1967	G, M	Gss2–6	Anschutz oil-erected gryotable	yes	satellite
12-01	1968	G, M	Gss2–31	Anschutz electrically erected gryotable	no	satellite
16-13	1973	G, M	Gss2–31	Anschutz electrically erected gryotable	yes	satellite
17-01[c]	1973	G, M	Gss2–31	Anschutz electrically erected gryotable	yes	satellite

[a]G—gravity
M—magnetics

[b]Designated V1717 on Map 1

[c]Designated C1701 on Map 1

Map 1. Free-air gravity anomalies



Transverse Mercator Projection

Various stable platforms (Alidade, Lamont, Anschutz, and Aeroflex) have been used in making gravity measurements. Each platform employs a device known as the primary vertical reference, which always stays level; another mechanism ensures that the platform follows the primary vertical reference so that it too stays level as the ship rolls. The various platforms differ in the design of their primary vertical reference and in the mechanism used to level the platform. The *Alidade Table*, a gear-driven platform, has a pendulum in a highly viscous fluid as a vertical reference. The *Lamont stable platform* has torque motors instead of a gear train but uses the same vertical reference as the Alidade Table. The *Anschutz oil-erected gyrotable* (Hayes, Worzel, and Karnick 1964) uses a gear train to drive the table and a hydraulic system for the vertical reference. The main source of error with these platforms is the off-leveling effect from the influence of periodic horizontal accelerations (due to the ship's surging and swaying) on the primary vertical reference (LaCoste and Harrison 1961; Talwani 1971). The off-leveling error is, however, greatly reduced with the *Anschutz electrically erected gyrotable* and the *Aeroflex platform*, in which horizontal accelerometers supply the primary vertical reference.

Another major source of error in gravity measurements is the cross-coupling acceleration that occurs when the gravimeter beam is displaced from its null position by a vertical acceleration and is at the same time subjected to a horizontal acceleration. The beam need not have a zero average displacement if there is a coherent phase relationship between the beam motions caused by the vertical and horizontal accelerations, as often happens with ship motions (Bower 1966; Wall, Talwani, and Worzel 1966). A coherent phase relationship occurs, for example, when the ship heaves and surges at the same time. Under these conditions a spurious change in the gravity measurement—called the cross-coupling error—is recorded by the gravimeter. A correction can be applied to the data by continuously monitoring the gravimeter beam position and the horizontal accelerations with an instrument called an accelerometer and by employing an analog computer to determine the resulting error, which is then subtracted from the measured gravity. The corrections are generally small but can be as much as 30 mgal in very rough seas.

Reliable gravity data collection depends on accurate navigation for two reasons. First, only the precise latitude will give the proper latitude correction. At 45°N, an error of 1 nautical mile (nmi) in the north-south position will lead to an error of about 1.5 mgal in the gravity measurement. Second, when a body moves on the earth's surface, it experiences an extra vertical acceleration (*Eötvos acceleration*) due to the earth's rotation. A gravity measurement of this moving body includes both gravity and the Eötvos acceleration, which therefore must be known accurately so that the observed values can be correspondingly corrected. The magnitude of the Eötvos correction depends on the ship's speed, course, and latitude; to calculate it the ship's exact position must be known at all times. Accuracy in navigation was greatly increased in the late 1960s with the availability of the US Navy's satellite navigation system; fixes of the ship's location to within a few hundred yards can now be obtained at approximate two-hour intervals (Talwani 1970). Up to then, navigation in the open seas was limited to the traditional method of dead reckoning supplemented by star fixes and sun lines, when weather conditions allowed.

The accuracy of gravity measurements at sea is usually given at about ±5 mgal. Measurements employing cross-coupling corrections, satellite navigation, and the newer stable platforms have an accuracy of about ±2 mgal. The latter figure is obtained from the comparison of measurements at the crossings of different cruises. The internal relative accuracy for a ship line run along a constant course is usually good even when overall errors are present; these errors remain constant if sea conditions relative to the ship's course do not change appreciably.

Free-Air Gravity Anomalies

Free-air gravity in the New York Bight region is plotted on Map 1 as profiles along ships' tracks. Positive anomalies (gravity greater than predicted) are brown, and negative anomalies (gravity less than predicted) are blue; the ship's track serves as a zero line. The data are presented this way to emphasize trends and the character of the anomalies. Cruise and leg numbers refer to Table 1.

The free-air anomaly map (Map 1) is characterized by distinct bands of anomalies. The most prominent trend is a band of positive anomalies with a magnitude of 25 to 35 mgal along the edge of the continental shelf. This high can partly be accounted for by the so-called isostatic edge effect. Most continental margins are nearly in isostatic balance (Worzel 1968)—that is, the total mass in a deep vertical column remains almost constant as one proceeds from land to sea. The mass deficit caused by the water is balanced by a thin crust in the oceanic area; thus, the high-density mantle is found at a shallower depth beneath the ocean than beneath the continent. The gravitational effect of this distribution of masses associated with a continental margin leads to the *isostatic edge effect*—a gravity high at the continental shelf edge and a broad gravity low seaward of it.

Even if a correction is made for the isostatic edge effect (this correction is not made for Map 1, which shows observed anomalies), a residual shelf edge high is still evident in the gravity anomalies. The residual shelf edge high is subject to different interpretations. One is that the model of local compensation (that is, that every vertical column has exactly the same mass) assumed in computing the isostatic anomalies does not completely hold. Several authors (Gunn 1944; Walcott 1972) have suggested that great outbuildings of sedimentary wedges are accommodated by a gentle sagging of the crust over a fairly wide region. Under this regional assumption the compensation is spread over a wide area, producing a positive gravity anomaly over the section of thickest sediments. The gravity high is flanked by shallow lows, due to the distributed compensation. While the regional model of isostatic compensation is certainly more realistic than the model of local compensation in areas such as river deltas where there is an unusually large accumulation of sediments, we do not believe it can completely account for the observed anomalies in the Bight region.

Another explanation for the residual shelf edge anomaly is that it is due, in part, to basement structures near the shelf edge. Drake, Ewing, and Sutton (1959) interpreted seismic refraction data on the continental margin as indicating the presence of a buried basement ridge near the shelf edge. This ridge separates a deep sedimentary basin under the continental shelf—named the Baltimore Canyon Trough (Map 2)—from deepwater sediments deposited on the slope and rise.

The seismic structure observed by Drake and his associates might not represent a basement ridge but might be due to a facies change to a carbonate reef under the outer shelf; such a reef has been observed during drilling on the Nova Scotia continental shelf. Either a basement ridge or a carbonate reef structure would have a positive density contrast with the surrounding sediments and thus could contribute to the shelf edge high.

In summary, there are three possible explanations for the shelf edge gravity high:

1. there is a sedimentary wedge that is thickest at the edge of the shelf;
2. a thickening sedimentary wedge exists but there is also a facies change, with the denser sediments at the edge of the shelf; or a reef structure exists at the edge of the shelf; or
3. a basement ridge exists at the edge of the shelf.

These explanations are not necessarily mutually exclusive. For example, a reef structure could be built up on a preexisting ridge.

Deciding the nature of the subbottom structure at the shelf edge becomes very important when we consider the band of negative anomalies landward of the shelf edge high (the blue band above 200 m in Map 1), with magnitudes of -15 to -25 mgal and a width of about 70 km (44 mi). This negative band appears to correlate with the position of the Baltimore Canyon Trough (Map 2) in which as much as 9

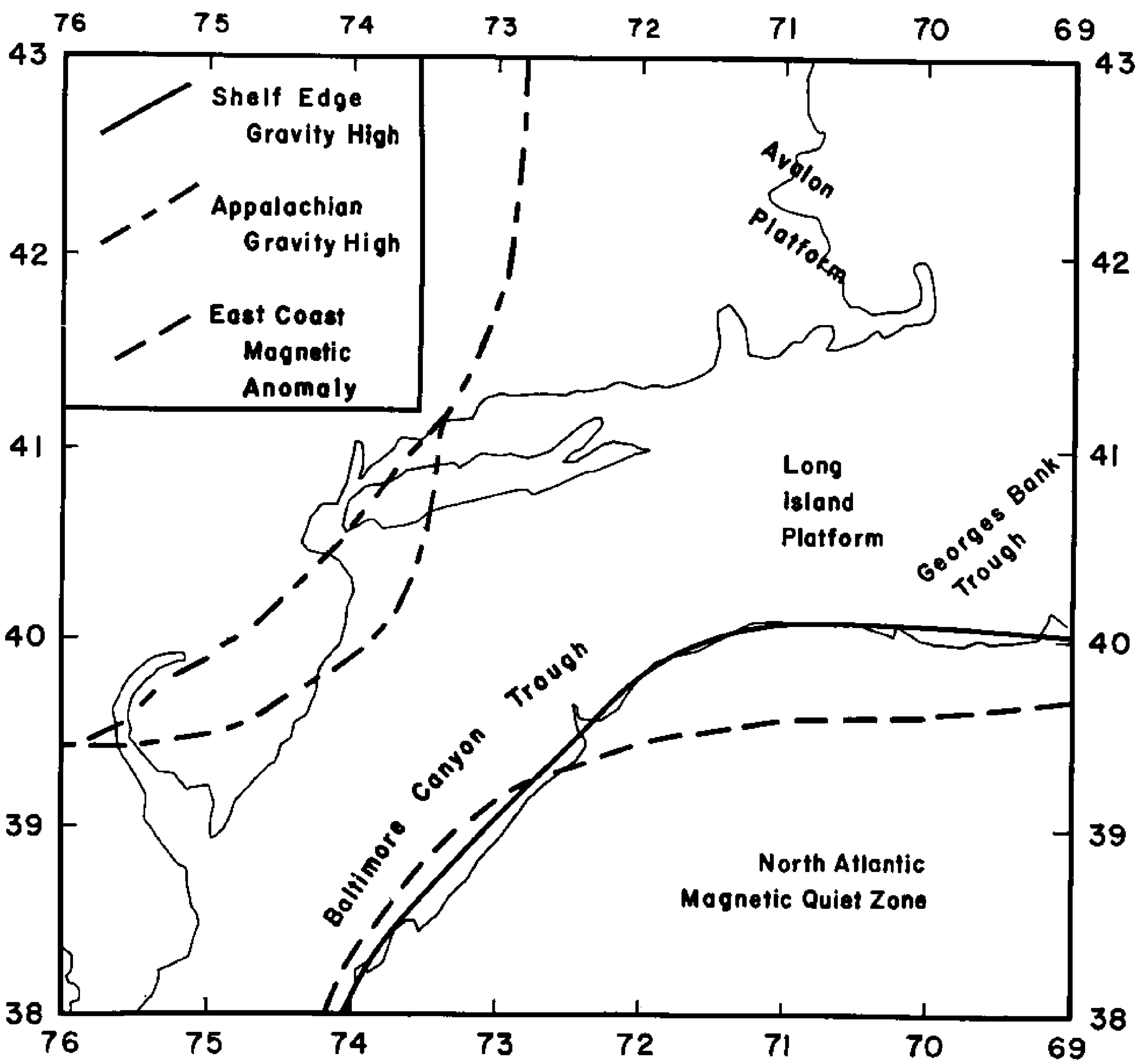
Table 3. Major stratigraphic and time divisions in use by the US Geological Survey

Erathem or Era	System or Period	Series or Epoch	Estimated ages of time boundaries in millions of years
Cenozoic	Quaternary	Holocene	
		Pleistocene	2-3
	Tertiary	Pliocene	12
		Miocene	26
		Oligocene	37-38
		Eocene	53-54
		Paleocene	65
Mesozoic	Cretaceous	Upper (Late) Lower (Early)	136
	Jurassic	Upper (Late) Middle (Middle) Lower (Early)	190-195
	Triassic	Upper (Late) Middle (Middle) Lower (Early)	225
Paleozoic	Permian	Upper (Late) Lower (Early)	280
	Carboniferous Systems: Pennsylvanian	Upper (Late) Middle (Middle) Lower (Early)	
	Carboniferous Systems: Mississippian	Upper (Late) Lower (Early)	345
	Devonian	Upper (Late) Middle (Middle) Lower (Early)	395
	Silurian	Upper (Late) Middle (Middle) Lower (Early)	430-440
	Ordovician	Upper (Late) Middle (Middle) Lower (Early)	500
	Cambrian	Upper (Late) Middle (Middle) Lower (Early)	570
Precambrian		Informal subdivisions such as upper, middle, and lower, or upper and lower, or younger and older may be used locally.	3,600+

Source: *Strategraphic nomenclature in reports of the US Geological Survey* by G.V. Cohee, 1970 (Internal USGS document) km (6 mi) of sediment, mostly Cretaceous and Jurassic (see Table 2) may be present. Whether the Baltimore Canyon Trough is actually a trough depends on which of the above interpretations is correct. With a marginal ridge, there is differential subsidence behind the ridge, and a closed basin is implied. If there is no structure (ridge or reef) at the shelf edge, then the sediments thicken continuously seaward, and the probability of large petroleum concentrations is much less. What actually has taken place is important not only in unraveling the evolutionary history of the continental margin but also in estimating the total thickness and nature of shelf sediments—and their petroleum potential.

The landward band of negative anomalies is considerably reduced to the east of about 72°W. An area of slightly positive anomalies has been shown to extend from the southeastern Massachusetts coast to the shelf edge (Emery et al 1970). This area is also a structural high, referred to as the *Long Island Platform* (Map 2), which separates the Baltimore Canyon Trough from the Georges Bank Trough to the east. The area of positive gravity anomalies extends inland across eastern Massachusetts, along the coast of Maine, and into New Brunswick. There it is over late Precambrian rocks of the *Avalon Platform* (Map 2), the continental landmass thought to have collided with the North American craton (the stable interior

Map 2. General locator



of the continent), causing the Acadian phase of mountain building during Devonian time (see Table 2). It thus appears that the Avalon Platform extends to the shelf edge and might form a structural high separating areas of subsidence on either side of it.

Another prominent belt of positive anomalies, shown on Map 1 between Long Island and New Jersey, continues north through Long Island and Long Island Sound into Connecticut. Southward it curves west across New Jersey. This band of anomalies follows the trend of the Appalachian mountain range and is a portion of the main Appalachian gravity high running from Canada to the Carolinas.

Seaward of the shelf edge, on the continental slope, large negative gravity anomalies with values of about -50 to -60 mgal exist; they gradually decrease southeastward to values to -20 to -30 mgal, typical of those found in the western basin of the North Atlantic. The large negative values on the slope are at least partly caused by the isostatic edge effect described earlier.

Magnetics

Magnetic anomalies are also valuable in studying the geology of particular regions: they help in identifying changes in the magnetic properties of rocks and in mapping areas differing in magnetic character. This in turn can give information on subsurface geologic structures such as faults and on changes in rock composition.

The main part of the earth's magnetic field probably originates from electrical currents in the molten iron-nickel core of our planet. Outside the core the magnetic field is nearly dipolar (similar to the field caused by a bar magnet). The nondipole part, however, introduces great complexity into a mathematical description of the magnetic field; in general, an empirical reference field is used to remove the long wavelength variations and reveal the short wavelength magnetic anomalies due to shallow sources. The magnetic field at the earth's surface is about 0.5 oersteds. Magnetic anomalies are usually measured in gammas (1 gamma = 10^{-5} oersted) and range up to a few thousand gammas, although they are ordinarily a few hundred gammas.

Mapping magnetic anomalies is complicated by the fact that the magnetic field is not stationary in time. There are secular variations (long-term) in which major features of the field appear to drift slowly. Local changes in the field due to secular variation may be more than 100 gammas/yr, but these drifts are approximately allowed for by time-dependent terms in the empirical reference field. There are also daily (diurnal) variations and large variations caused by magnetic storms.

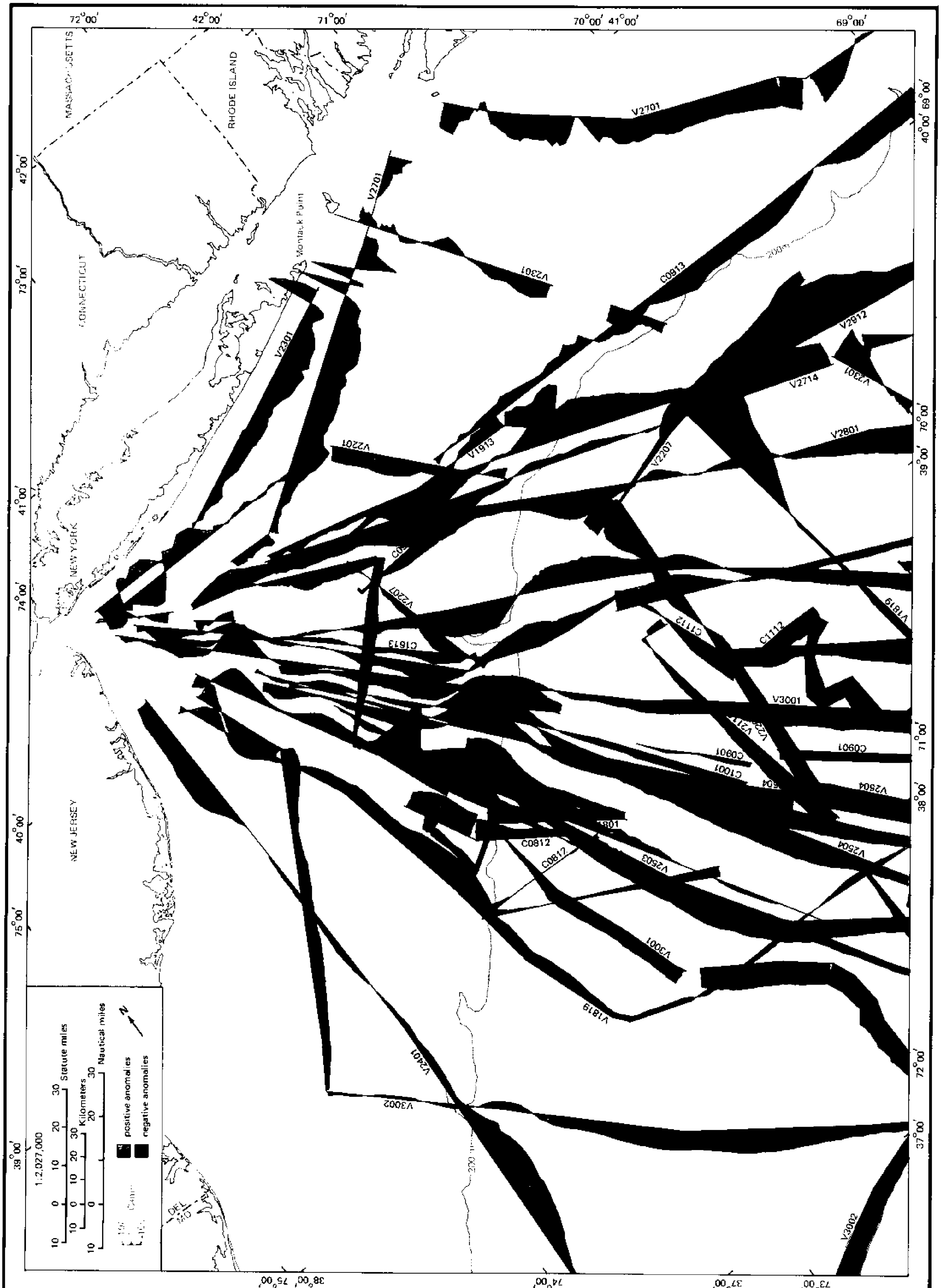
Instrumentation

The magnetic data in this monograph were all collected with proton precession magnetometers towed approximately 183 m (200 yd) behind ships. Proton precession instruments use nuclear magnetic resonance to measure the earth's magnetic field. A strong magnetic field is applied to water in a bottle by passing a current through a coil wound around it, aligning the protons of the water molecules along the applied field. When the magnetic field is removed the protons momentarily precess about the earth's magnetic field (in the same manner that a spinning top can precess about the vertical), inducing a small voltage in the coil. The frequency of the voltage, which can be determined, is proportional to the earth's magnetic field. These magnetometers measure the total intensity of the earth's field rather than its components. The resulting total-intensity magnetic anomalies represent the difference in magnitude between the actual field and the reference field, with no measure of the difference in direction of the two vectors. Proton precession magnetometers are simple, accurate, and relatively inexpensive.

Total-Intensity Magnetic Anomalies

Map 3, showing total-intensity magnetic anomalies, bears a marked resemblance to the free-air gravity map (Map 1). Bands of anomalies appear in basically the same areas and are again dominated by a large

Map 3. Total-intensity magnetic anomalies



Transverse Mercator Projection

positive anomaly near the edge of the continental shelf. Examination of the magnetic high near the shelf edge shows, however, that it does not follow the bathymetric contours but cuts across them, appearing on the shelf in the west and on the lower continental slope in the east. This anomaly has been traced for almost the entire length of the eastern margin of the United States (Taylor, Zietz, and Dennis 1968; Emery et al 1970) and has been given the name *East Coast Magnetic Anomaly* (Map 2). The anomaly bears no systematic relationship to surficial topographic features; it is found at all locations from the continental shelf to depths exceeding 3,500 m (12,000 ft) on the continental rise.

The source of the East Coast Magnetic Anomaly has been the subject of much speculation (Keller, Menschke, and Alldredge 1954; Drake et al 1959; King, Zietz, and Dempsey 1961; Drake, Heirtzler, and Hirshman 1963; Watkins and Geddes 1965; Taylor et al 1968; Keen 1969; Emery et al 1970; Zietz 1971; Luyendyk and Bunce 1973; Rabinowitz 1974). The two most popular explanations are that it is: (1) a magnetic edge effect anomaly involved with the transition from oceanic to continental structure, or (2) an intrusive body, presumably associated with the initial stages of the rifting that separated Africa and North America.

Seaward of the East Coast Magnetic Anomaly is the *North Atlantic Quiet Zone* (Map 2), an area of subdued, long wavelength magnetic anomalies separating the continental margin from high-amplitude seafloor spreading anomalies found farther out to sea and associated with oceanic crust. Quiet zones are a common feature of seismically inactive Atlantic-type continental margins. A good deal of guessing about their origin has been published, without reaching consensus (King et al 1961; Heirtzler and Hayes 1967; Luyendyk and Melson 1967; Drake, Ewing, and Stockard 1968; Taylor et al 1968; Emery et al 1970; Vogt et al 1970; Rona 1970; Mascle and Phillips 1972; Poehls, Luyendyk, and Heirtzler 1973; Luyendyk and Bunce 1973; Rabinowitz 1974). It is clear, however, that shallow extrusive igneous basement with alternating normally and reversely magnetized stripes—such as is found in most oceanic regions—does not exist in the North Atlantic Quiet Zone.

A broad area of generally negative anomalies lies landward of the East Coast Magnetic Anomaly in the vicinity of the Baltimore Canyon Trough. With the exception of the very high-amplitude positive anomaly near 73°W, 39°N, the anomalies are uniformly of low amplitude and long wavelength, reflecting the great depth of basement rock here. The negative band swings around to the north and appears to continue into eastern Long Island. These negative anomalies are bounded on the east by a north-south trending positive band starting at the shelf edge and passing east of Long Island. This anomaly lies along the western edge of the Long Island Platform.

The magnetic anomalies south of Long Island consist of alternate positive and negative bands, probably caused by compositional differences within the basement rocks. Like the free-air gravity anomalies here, the magnetic anomalies appear to emerge from Long Island and curve toward New Jersey.

Several isolated anomalies are also evident on Map 3. The most apparent is the 800 gamma positive anomaly close to the edge of the shelf near 73°W, 39°N. There is also a 15 mgal gravity anomaly (cruise V3001 on Map 1) at the same location. This large magnetic anomaly was first mapped and described by Drake et al (1963). Seismic reflecton data indicate that the anomaly is associated with a very large intrusive body that pierces up through the sediments, deforming them.

Two other prominent local anomalies are apparent in the northern part of the survey area. One is the sharp, double-peaked magnetic anomaly just south of Montauk Point (cruise V2701 and also cruise V2301 on Map 3); the other is an anomaly near 70°W (cruise V2701 to far right in Map 3). These are associated with positive gravity anomalies and presumably are due to intrusions of dense, highly magnetized rocks into basement rock or into the sediments.

In summary, the free-air gravity and total-intensity magnetic anomaly maps are dominated by prominent bands of anomalies. The anomalies on the outer edge of the shelf and upper continental slope are associated with the transition from the North American continent to the Atlantic Ocean. The anomalies on the inner shelf are associated with structures inherited from the geology of the region prior to the formation of the present Atlantic Ocean. The Avalonian trends in the eastern part of the survey area continue to the shelf edge, where they are truncated. The Appalachian trends in the west are not truncated south of Long Island but swing to the west and continue under the coastal plain sediments in New Jersey.

The New York Bight area is not particularly active seismically. Although areas in the northeastern United States, specifically north of Boston and in the St. Lawrence Valley, are subject to large earthquakes, the Bight region has been given the second lowest rating (minor) on the seismic risk map published by NOAA's Environmental Research Laboratories (Coffman and van Hake 1973).

There have been numerous moderate earthquakes in the Bight region, however. Those earthquakes that have been recorded are plotted on Map 4. Each earthquake's year and intensity on the Modified Mercalli Scale (Table 3) are also shown. The plotted locations should be considered approximate, especially for the older earthquakes because observations were not evenly distributed then. It is important to note that *intensity* (on Mercalli or any other scale) is not a measure of the earthquake's size but of the degree to which it was observed and did damage. *Magnitude* scales, such as the Richter Scale, based on the measurement of ground motion amplitudes, give more precise measurements of an earthquake's size.

Earthquake activity is scattered throughout the region without any distinct trends. Epicenters have tended to cluster in a few areas. One such cluster is southeast of Hartford, CT, near the town of East Haddom where two large (for this region) earthquakes have occurred. The 1791 earthquake was felt in Boston and New York and was of sufficient force to throw down chimneys and stone walls near the epicenter.

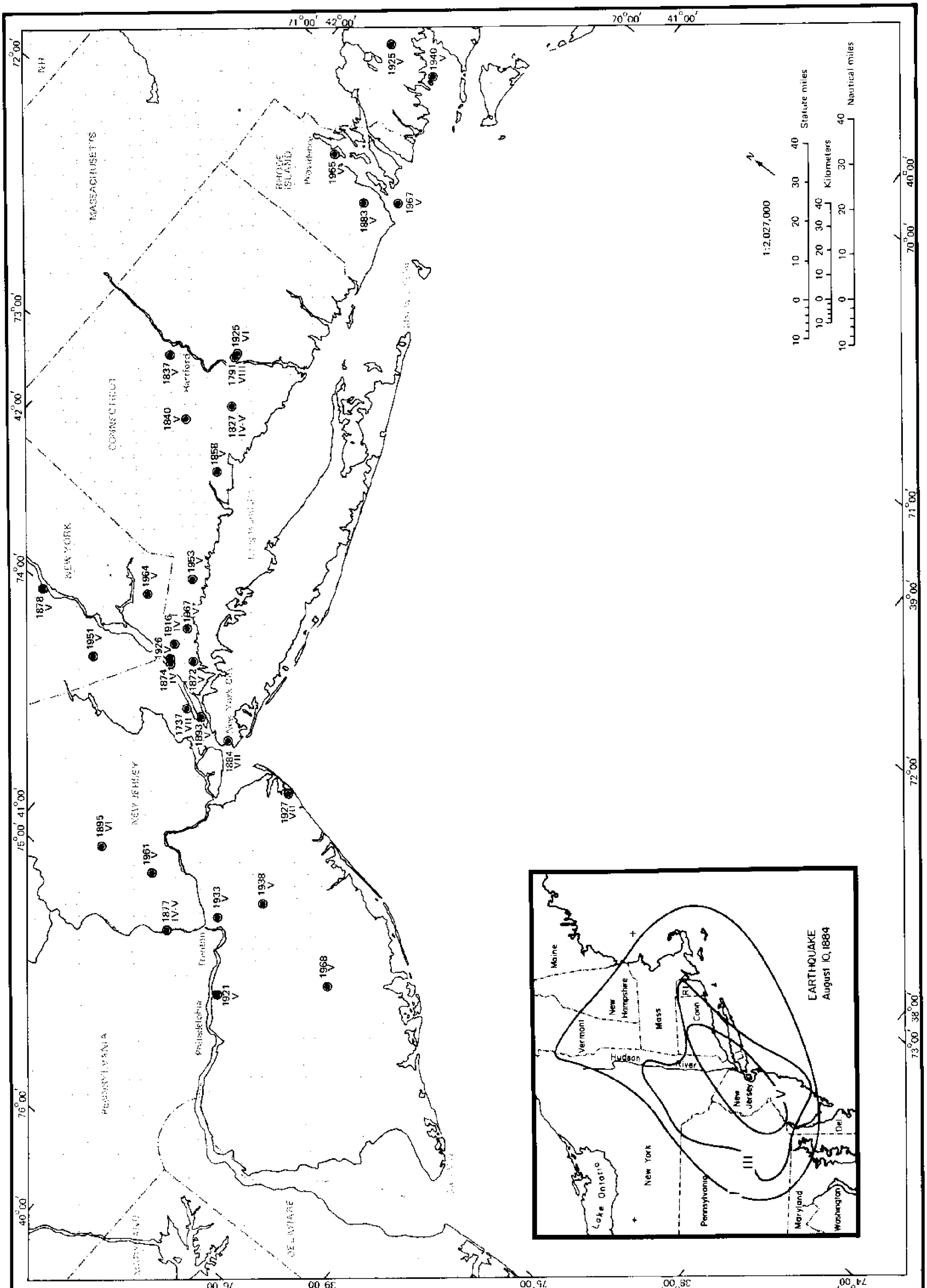
Several earthquakes have also occurred in the Westchester County–New York City region. The 1893 earthquake in Manhattan was centered somewhere between 10th and 18th streets and appears to have been relatively minor. Accounts of the earthquake record that billard games were disturbed and zoo animals were frightened. Two significant earthquakes have occurred in the New York City area. The 1737 earthquake was large enough to topple chimneys. The 1884 earthquake (Map 4 inset), apparently centered near Jamaica or Amityville, cracked plaster in buildings from Hartford, CT, to West Chester, PA, and was felt from Portsmouth, NH, to Baltimore, MD (Rockwood 1885). *Isoseismals* (lines of equal intensity) from Rockwood (1885) are shown for the 1884 earthquake in the Map 4 inset.

Table 3. Modified Mercalli intensity scale (abridged)

I:	Not felt except by a very few under especially favorable circumstances.
II:	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III:	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck.
IV:	Felt indoors by many during the day, outdoors by few. At night some awakened. Dishes, windows and doors disturbed. Walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably.
V:	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI:	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII:	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motor cars.
VIII:	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Chimneys, factory stacks, columns, monuments, walls fall. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX:	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X:	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI:	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and landslips in soft ground. Rails bent greatly.
XII:	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Wood and Newmann 1931

Map 4. Historical earthquakes



Transverse Mercator Projection

The isoseismals are greatly elongated along the Appalachian structures. Thus a moderate earthquake is felt for a considerable distance to the northeast or southwest but not nearly as far to the northwest. Comparison of these isoseismals with those from earthquakes elsewhere indicates that an earthquake in northeastern United States is felt over a greater area than is an earthquake of similar magnitude located, for example, in California.

The cause of the earthquakes in the New York Bight region is not well understood. Coffman and van Hake (1973) suggest that they are due to readjustment of the crust following the withdrawal of glacial ice. Another possibility is that they are related to the slow sagging of the continental margin as sediments accumulate offshore.

Summary

The gravity and magnetic anomalies in New York Bight reflect the geologic structure of the region. The great depth to the anomalies' sources on the continental shelf has smoothed out local variations so that the anomalies appear as broad bands reflecting major changes in basement structure. This structure is dominated by the Appalachian Mountains and the transition from continent to ocean. The interaction of these two features has shaped the structural evolution of the continental margin.

The evolution of the US east coast and other continental margins has been intensively studied by geophysicists attempting to comprehend the processes by which continents are pulled apart to form the great ocean basins. Their growing knowledge has brought a better understanding of the environment in which the continental shelf sediments were deposited and of likely mineral deposits within them. Early in the 1970s interest began to focus on possible petroleum deposits beneath the outer continental shelf along the US east coast, particularly in the Bight. Geophysical measurements cannot determine whether such deposits exist but can aid in locating structures that could trap and concentrate any petroleum in the sediments.

The numerous small to moderate earthquakes indicate that, although the Bight region is geologically stable, its evolution continues into the present. Seismicity is widely scattered and its cause is not well understood. Although the chance of a major earthquake is extremely remote, some care should be taken in placing sensitive structures. Local geology should be studied because small earthquakes, such as are found in the Bight region, generally occur along already existing faults.

References

Bower, D.R. 1966. The determination of cross-coupling errors in the measurement of gravity at sea. *J. Geophys. Res.* 71:487-93.

Coffman, J.L. and van Hake, C.A. 1973. *Earthquake history of the United States.* Revised ed. US Dep. Comm., NOAA pub. 41/1.

Drake, C.L., Ewing, J.I., and Stockard, H. 1968. The continental margin of the eastern United States. *Canadian J. Earth Sci.* 5:993-1010.

Drake, C.L., Ewing, M., and Sutton, G.H. 1959. Continental margins and geosynclines: the east coast of North America, north of Cape Hatteras. *Physics and Geochemistry of the Earth,* vol. 3, pp. 113-98. New York: Pergammon Press.

Drake, C.L., Heirtzler, J., and Hirshman, J. 1963. Magnetic anomalies off eastern North America. *J. Geophys. Res.* 68:5259-75.

Emery, K.O., Uchupi, E., Phillips, J.D., Bowin, C.O., Bunce, E.T., and Knott, S.T. 1970. Continental rise off eastern North America. *Bull. Amer. Assn. Petrol. Geol.* 54:44-108.

Graf, A., and Schulze, R. 1961. Improvements on the sea gravimeter Gss2. *J. Geophys. Res.* 66:1813-21.

Gunn, R. 1944. A quantative study of the lithosphere and gravity anomalies along the Atlantic coast. *Franklin Inst. J.* 237:139-54.

Hayes, D.E., Worzel, J.L., and Karnick, H. 1964. Tests on the 1962 model of the Anschutz gyro table. *J. Geophys. Res.* 69:749-57.

Heirtzler, J.R., and Hayes, D.E. 1967. Magnetic boundaries in the North Atlantic Ocean. *Science* 157:185-87.

Keen, M.J. 1969. Possible edge effect to explain magnetic anomalies off the eastern seaboard of the US. *Nature* 222:72-74.

Keller, F., Menschke, J.L., and Alldredge, L.R. 1954. Aeromagnetic surveys in the Aleutian, Marshall and Bermuda Islands. *Trans. Amer. Geophys. Un.* 35:558-72.

King, E.R., Zietz, I., and Dempsey, W.J. 1961. *The significance of a group of aeromagnetic profiles off the eastern coast of North America.* US Geol. Surv. Prof. Paper 424/D:D299-D303.

LaCoste, L.J.B., and Harrison, J.C. 1961. Some theoretical considerations in the measurement of gravity at sea. *Geophys. J. Royal astronom. Soc.* 5:89-103.

Luyendyk, B.P., and Bunce, E.T. 1973. Geophysical study of the northwest African margin off Morocco. *Deep-Sea Res.* 20:537-49.

Luyendyk, B.P., and Melson, W.G. 1967. Magnetic properties and petrology of rocks near the crest of the Mid-Atlantic Ridge. *Nature* 215:147-49.

Mascle, J., and Phillips, J. 1972. Smooth zones in the South Atlantic. *Nature* 240:80-84.

Poehls, K.A., Luyendyk, B.P., and Heirtzler, J.R. 1973. Magnetic smooth zones in the world's oceans. *J. Geophys. Res.* 78:6985-97.

Rabinowitz, P.D. 1974. The boundary between oceanic and continental basement in the western North Atlantic Ocean. *Geology of Continental Margins,* eds. C. Burk and C.L. Drake, pp. 67-84. New York: Springer–Verlag.

Rockwood, C.G. 1885. American earthquakes. *Amer. J. Sci.* 3rd series, vol. 29.

Rona, P.A. 1970. Comparison of continental margins of eastern North America at Cape Hatteras and northwestern Africa at Cape Blanc. *Amer. Assn. Petrol. Geol. Bull.* 54:129-57.

Schulze, R. 1962. Automation of the sea gravimeter Gss2. *J. Geophys. Res.* 67:3397-401.

Talwani, M. 1970. Developments in navigation and measurement of gravity at sea. *Geoexploration* 8:151-83.

______. 1971. Gravity. *The Sea,* ed. A. Maxwell, vol. 4, pt. 1, pp. 251-97. New York: Wiley–Interscience.

Taylor, P.E., Zietz, I., and Dennis, L.S. 1968. Geologic implications of aeromagnetic data for the eastern continental margin of the United States. *Geophysics* 33:755-80.

Vogt, P.R., Anderson, C.N., Bracey, D.R., and Schneider, E.D. 1970. North Atlantic magnetic smooth zones. *J. Geophys. Res.* 75:2955-68.

Walcott, R.I. 1972. Gravity, flexure and the growth of sedimentary basins at a continental edge. *Geol. Soc. Amer. Bull.* 83:1845-48.

Wall, R.E., Talwani, M., and Worzel, J.L. 1966. Cross-coupling and off-leveling errors in gravity measurements at sea. *J. Geophys. Res.* 71:465-85.

Watkins, J.S., and Geddes, W.H. 1965. Magnetic anomaly and possible orogenic significance of geologic structure of the Atlantic shelf. *J. Geophys. Res.* 70:1357-61.

Wood, H.O., and Newmann, F. 1931. Modified Mercalli intensity scale of 1931. *Bull. Seis. Soc. Amer.* 21:277-83.

Worzel, J.L. 1968. Advances in marine geophysical research of continental margins. *Canadian J. Earth Sci.* 5:963-83.

Zietz, I. 1971. Eastern continental margin of the United States, part 1: a magnetic study. *The Sea,* ed. A. Maxwell, vol. 4, pt. 2, pp. 293-310. New York: Wiley–Interscience.

The Atlas Monograph Series

1 **Hydrographic Properties** Malcolm J. Bowman, with cartographic assistance by Lewis D. Wunderlich, Marine Sciences Research Center, SUNY

2 **Chemical Properties** James and Elizabeth Alexander, Institute of Oceanography, SUS Florida

3 **Circulation** Donald Hansen, Atlantic Oceanographic and Meteorological Laboratories

4 **Tides** R.L. Swanson, MESA New York Bight Project

5 **Wave Conditions** Willard J. Pierson, University Institute of Oceanography, CUNY

6 **Storm Surge** N. Arthur Pore and Celso S. Barrientos, National Weather Service

7 **Marine Climatology** Bernhard Lettau, Atmospheric Sciences Research Center, SUNY, William A. Brower, Jr. and Robert G. Quayle, National Climatic Center

8 **Regional Geology** John E. Sanders, Columbia University

9 **Gravity, Magnetics, and Seismicity** James R. Cochran and Manik Talwani, Lamont–Doherty Geological Observatory

10 **Surficial Sediments** George Freeland and Donald J.P. Swift, Atlantic Oceanographic and Meteorological Laboratories

11 **Beach Forms and Coastal Processes** Warren E. Yasso, Columbia University, and Elliott M. Hartman, Jr., Westchester Community College

12 **Plankton Production** Charles S. Yentsch, Bigalow Laboratory for Ocean Sciences

13 **Plankton Systematics and Distribution** Thomas C. Malone, City University of New York

14 **Benthic Fauna** John B. Pearce and David Radosh, National Marine Fisheries Service

15 **Fish Distribution** Marvin D. Grosslein and Thomas Azarovitz, National Marine Fisheries Service

16 **Fisheries** J.L. McHugh, Marine Sciences Research Center, SUNY, and Jay J.C. Ginter, NY Sea Grant Institute

17 **Aquaculture** Orville W. Terry, Marine Sciences Research Center, SUNY

18 **Artificial Fishing Reefs** Albert C. Jensen, NYS Dept. of Environmental Conservation

19 **Recreation** E. Glen Carls, University of Waterloo, Canada

20 **Port Facilities and Commerce** Alfred Hammon, The Port Authority of New York and New Jersey

21 **Sand and Gravel** John S. Schlee, US Geological Survey, with a section by Peter T. Sanko, NY Sea Grant Advisory Service

22 **Governmental Jurisdictions** Paul Marr, SUNY at Albany

23 **Demographic Patterns** Charles Koebel and Donald Krueckeberg, Rutgers University

24 **Transportation** Richard K. Brail and James W. Hughes, Rutgers University

25 **Electricity Generation and Oil Refining** H.G. Mike Jones, Harold Bronheim, and Philip F. Palmedo, Brookhaven National Laboratory

26 **Waste Disposal** M. Grant Gross, Chesapeake Bay Institute, Johns Hopkins University

27 **Water Quality** Donald J. O'Connor, Robert V. Thomann, and John P. St. Clair, Hydroscience, Inc.

28 **Air Quality** Volker A. Mohnen, Atmospheric Sciences Research Center, SUNY

29 **The Lower Bay Complex** Iver Duedall, Harold O'Connors, and Robert Wilson, Marine Sciences Research Center, SUNY

30 **Industrial Wastes** James A. Mueller and Andrew R. Anderson, Manhattan College

31 **Marine and Coastal Birds** Marshall A. Howe, Roger B. Clapp, and John S. Weske, US Fish and Wildlife Service

32 **Environmental Health** Joseph M. O'Connor, Chun Chi Lee, and Merril Eisenbud, Institute of Environmental Medicine, NYU Medical Center

New York Sea Grant Institute
State University of New York
99 Washington Avenue
Albany, New York 12210

Printed in USA

NYSSGP-AM-76-006

$4.00