21. SUMMARY AND CONCLUSIONS

"Some drill and bore
The solid earth, and from the strata there
Extract a register, by which we learn
That he who made it, and revealed its' date
To Moses, was mistaken in its' age."
William Cowper (1731-1800)
"The Task"

Glomar Challenger left Boston on 19 June, 1970 and arrived in Lisbon, Portugal, August 11. Along the route, thirteen holes were drilled at nine sites, recovering a total of 840.5 meters of sediment and hard rock cores. Drilling was conducted in four geographic regions in the North Atlantic: The Labrador Sea, the Reykjanes Ridge, the Rockall area and the Bay of Biscay (Figure 1). Between sites, a program of routine geophysical survey was carried on (Appendix III).

One objective of Leg 12 was to test the ability of *Glomar Challenger* to operate in the northern latitudes of the Atlantic where the weather could be expected to be considerably worse than on previous legs. It was found possible to carry on drilling under poorer conditions than was previously thought possible. Only one hole was terminated due to weather conditions when a swell of 5 meters across the wind direction made the ship roll over 15 degrees to either side, and heave by up to 6 meters. Out of 52 days at sea only half a days work was lost due to bad weather. However, the weather was relatively good for the area and season.

The principal results of drilling in each area are given below. Table 1 summarizes the basic statistics regarding each hole. Figure 2 summarizes the stratigraphic intervals recovered at each site.

SITE 111 (FIGURE 3)

Two holes were drilled at Site 111, which is situated in 1797 meters of water on top of an isolated knoll some 550 kilometers northeast of Newfoundland and 350 kilometers due north of Flemish Cap. The knoll is separated from the continental shelf by waters 2800 to 3400 meters deep and appears to be a piece of continent abandoned in the early stages of sea-floor spreading. It has been officially named Orphan Knoll. The principal objectives of drilling here centered on determining the history of the knoll and attempting to prove its continental nature by sampling the basement.

The sedimentary succession sampled can be divided into four main sections. Down to about 146 meters below the seabed, the sediments consist of glacial clays and deep-sea foraminiferal oozes of mid-Pliocene to Pleistocene age. The onset of glaciation began in mid-Pliocene at about 3 million years ago. This result has far reaching implications for paleogeographic and paleoclimatic reconstructions of the Late Cenozoic history of the North Atlantic. This is the first time we have an independent estimate for the initiation of glaciation in the North Atlantic region based on microfaunal evidence. This is also the first time, to our knowledge, that the contact between glacial and preglacial sediments has been cored in the deep sea. The presence of a rich subtropical microfauna and flora in Lower Pliocene sediments below (3 to 5 million years ago) suggests that a branch of the Gulf Stream flowed over Orphan Knoll prior to the onset of glaciation.

The upper Miocene and Pliocene sediments overlie disconformably upper and lower Eocene zeolitic clays which in turn lie unconformably upon soft chalks and nannoplankton marls of early Maestrichtian age. At a subbottom depth of 190 meters, the Maestrichtian chalks rest disconformably upon shallow water dolomitic calcarenites, carbonate sands and shelly limestones, mid-Cenomanian and Albian in age. The seismic profiler records show an angular unconformity at 248 meters separating these shallow water carbonates from graded sandstones and shales of Jurassic (Bathonian) age which were the deepest samples obtained. These graded sandstones contain fragments of coal and could be continental or at least nearshore deposits.

In summary, therefore, the hole has given direct evidence that Orphan Knoll is a continental fragment which foundered, without appreciable tilting, to oceanic depths during the Tertiary. Since this part of the North Atlantic is thought to have started to split apart in the Mesozoic, the knoll at first remained relatively closely tied to the Newfoundland shelf, and did not sink for 20 to 30 million years. If the knoll is in isostatic equilibrium some profound modification to the base of the crust under the knoll must have taken place to enable the vertical movement to have taken place.

SITE 112 (FIGURE 3)

Two holes were drilled at Site 112 in 3657 meters of water in the mid-Labrador Sea. The site is near the western edge of a thick sequence of acoustically transparent sediments occupying a broad region extending from the Site 112 region eastwards to the mid-Atlantic Ridge, northwards to the mid-Labrador Sea Ridge and passing southwards beneath thick sequences of turbidites probably derived from the continental margin north of Newfoundland. To the west the transparent sediments abut a basement high which isolates the region from the more typical, very thick Labrador Sea sediments. In the midst of the transparent sequence is a weak reflector. One of the

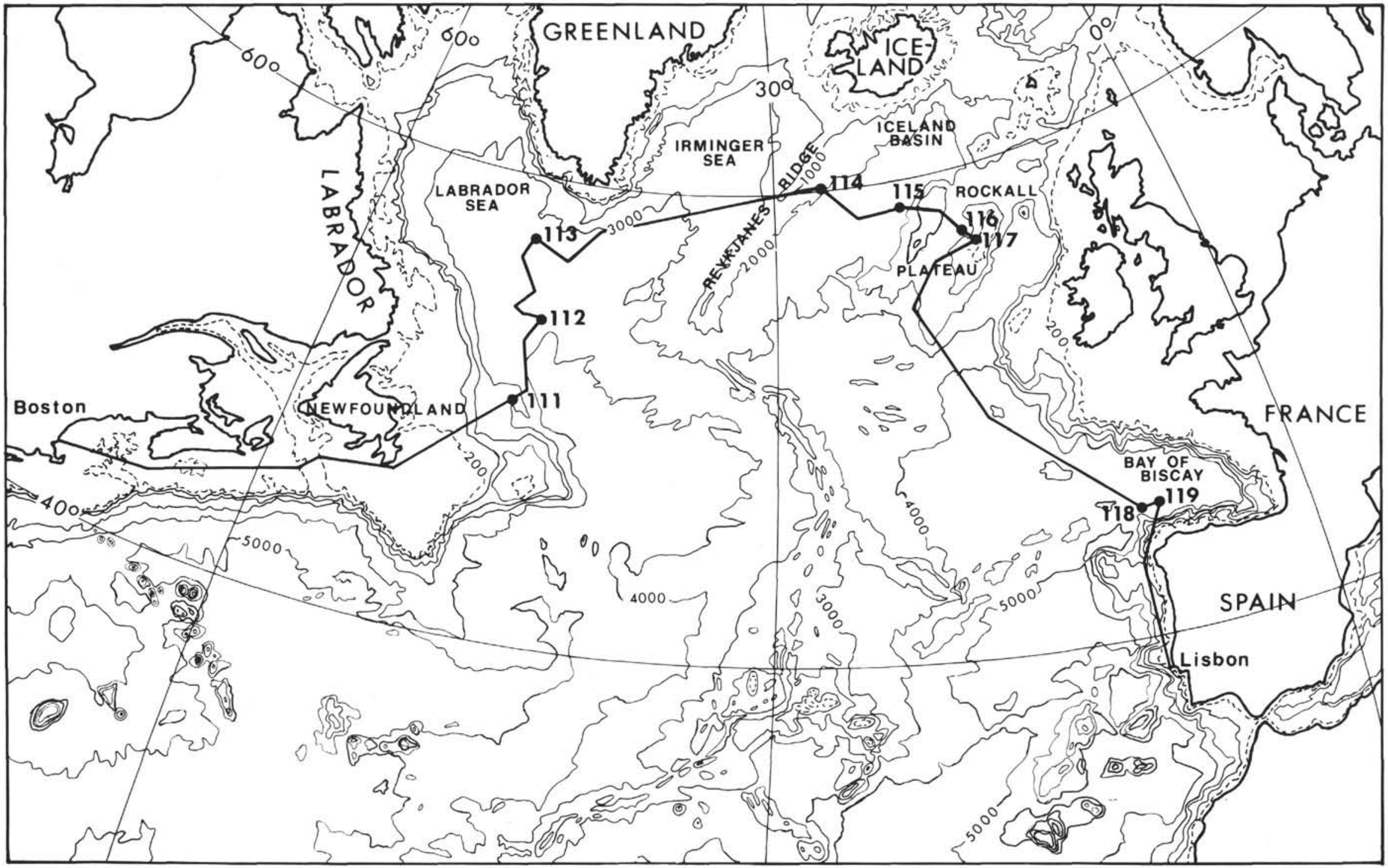

Figure 1. *Track Chart.*

TABLE 1
Summary of Holes Drilled on Leg 12

Hole	Position Latitude	Position Longitude	Dates of Drilling	Water Depth (m)	Penetration (m)	No. Cores Cut	Total Cored (m)	Total Recovered (m)
111	50° 25.57′N	46° 22.05′W	25-26 June	1797	250	7	48	15.0
111A	50° 25.57′N	46° 22.05′W	26-28 June	1797	199	12	94	59.2
112	54° 01.00′N	46° 36.24′W	29 June-2 July	3657	664	17	145	75.1
112A	54° 01.00′N	46° 36.24′W	2-3 July	3657	124	5	45	32.3
113	56° 47.40′N	48° 19.91′W	4-8 July	3619	923	12	76	30.5
114	59° 56′N	26° 48′W	11-13 July	1927	623	9	60	45.8
115	58° 54.4′N	21° 07.0′W	14-16 July	2883	227	8	55	11.3
116	57° 29.76′N	15° 55.46′W	17-20 July	1151	854	28	226	195.3
116A	57° 29.76′N	15° 55.46′W	21 July	1151	99	11	99	89.2
117	57° 20.17′N	15° 23.97′W	22 July	1038	156	3	20	8.5
117A	57° 20.17′N	15° 23.97′W	23-24 July	1038	313	11	66	34.3
118	45° 02.65′N	9° 00.63′W	29 July-2 August	4901	761	21	147	51.6
119	45° 01.90′N	7° 58.49′W	2-8 August	4447	711	40	368	192.4
Totals					5904	184	1449	840.5

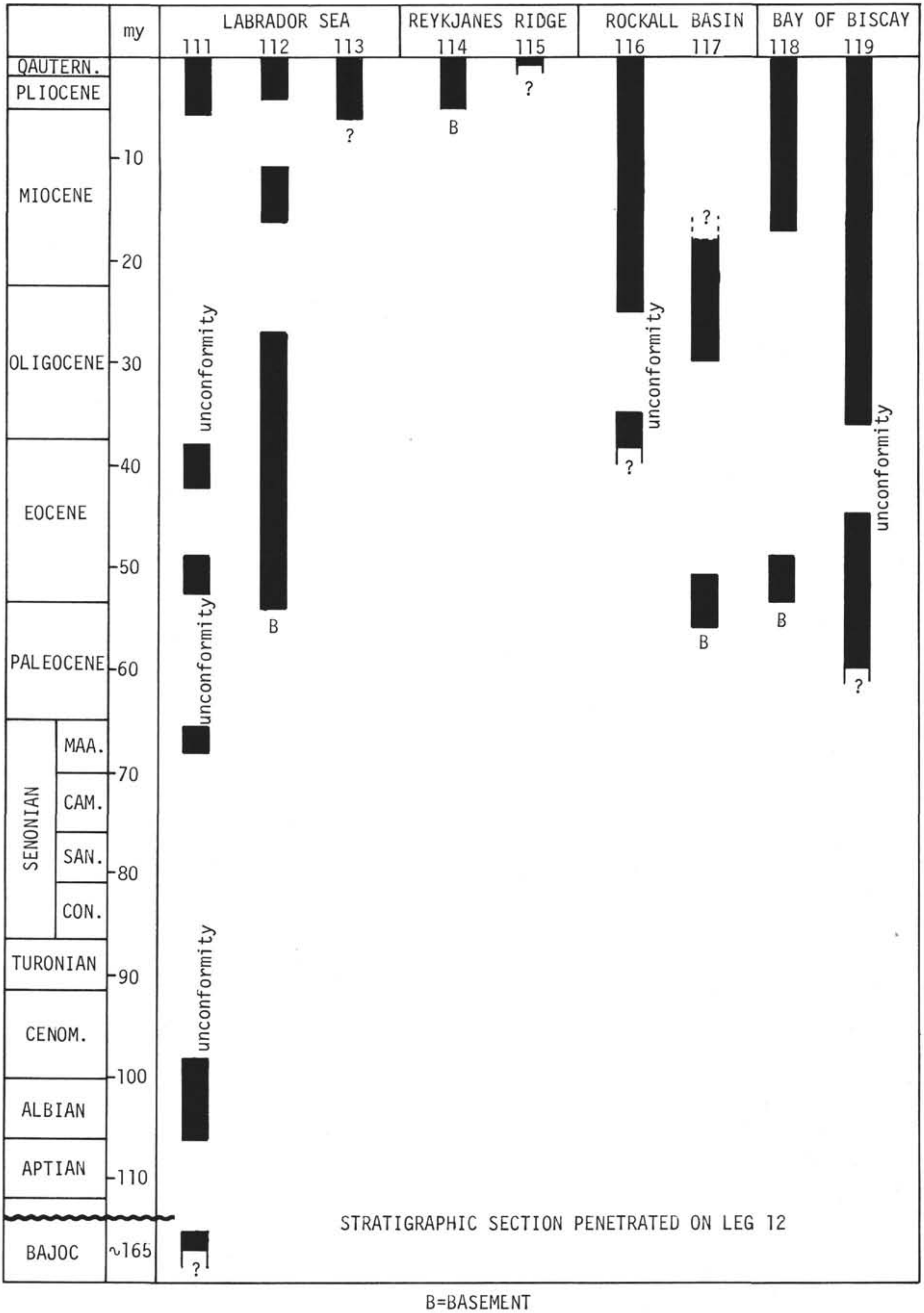

Figure 2. *Stratigraphic sections sampled (whole leg).*

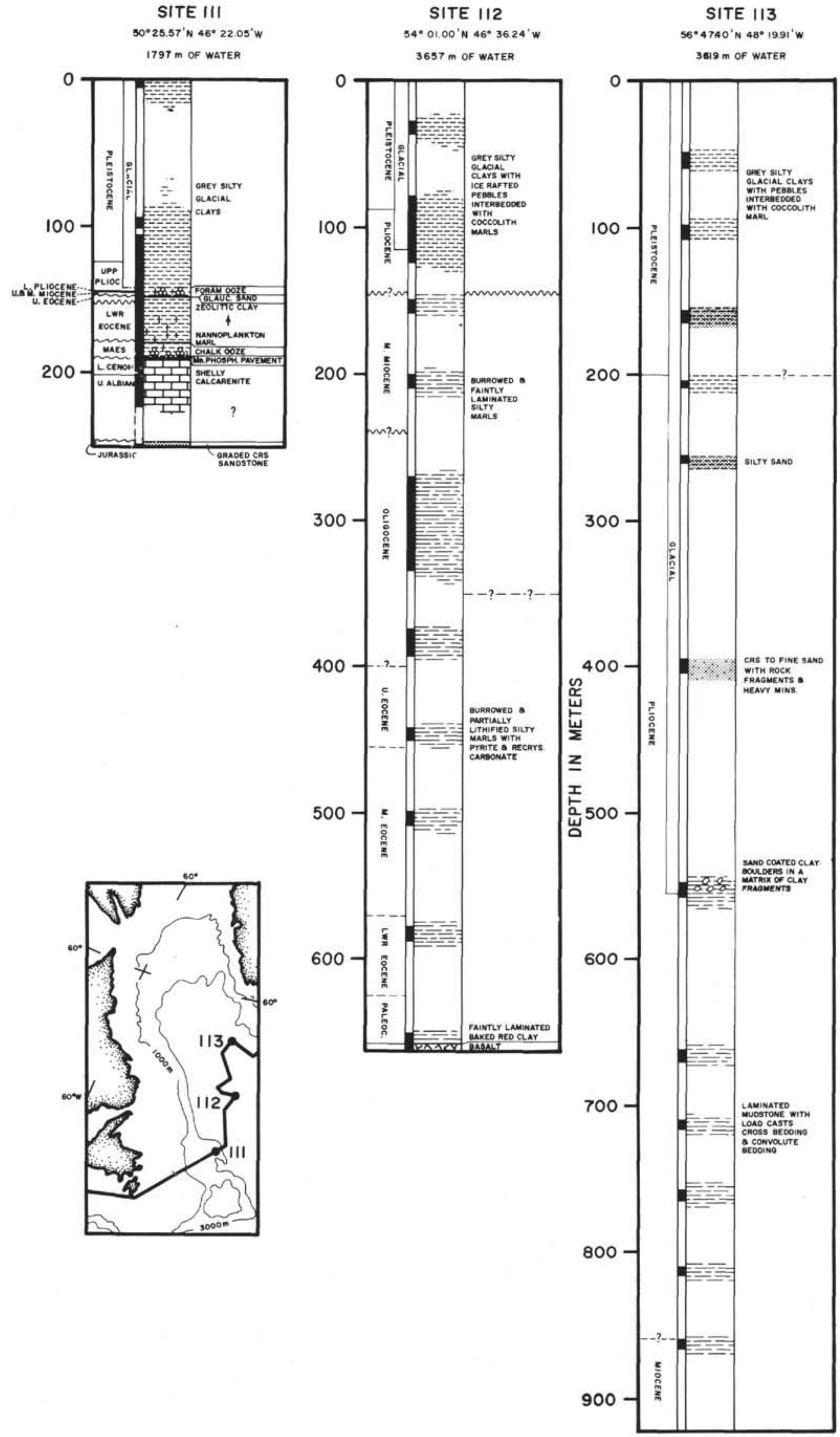

Figure 3. *Stratigraphy of Sites 111, 112 and 113 in the Labrador Sea.*

objectives of drilling Site 112 was to date the oldest sediments over the basement and to relate this to the magnetic anomaly pattern. Another objective was to identify and date the weak reflector.

Drilling and coring at Site 112 recovered a succession of about 115 meters of Pliocene-Pleistocene terrigenous clays and silts with glacial pebbles overlying faintly laminated and burrowed silty marls which range in age from Miocene back to Early Eocene and possibly Paleocene. At a depth of about 350 meters, these become partially lithified and probably give rise to the diffuse, weak reflections seen at 0.4 second on the profiler record. The topmost lithified sediments are Oligocene in age and show that the reflector can not be correlated with the mid-Eocene reflector A. Lithologically, the sediments are clearly not turbidites. However, the sedimentation rate is high (1.3 cm/1000 yrs) and this fact, together with the nature of the sediments and the shape of the sediment body as revealed in the seismic reflection profiles, leads to the conclusion that the bulk of the sediments have been brought into place by bottom currents which have wandered across the area within its topographic confines and resulted in periods of rapid deposition and periods of nondeposition.

Basement basalt was encountered at about 600 meters overlain by 10 meters or so of baked red clay. The oldest sediments found on top of the basement were unfossiliferous. By linear extrapolation of sedimentation rates downward, they would be about 54 million years old. However, the post-drilling seismic profile showed that the basement sample was on a topographic high 0.2 second above a basement valley to the northwest. There are, therefore, about 200 meters of sediment below the high, which contain on-lapping horizons parallel to the seabed. Extrapolating further the sedimentation rate of 1.5 cm/1000 yrs, the age of these deep sediments is 65 million years (Cretaceous-Tertiary boundary).

A compilation of magnetic data in the vicinity of Site 112 suggests that the ridge to the southwest of the site is an old spreading center prior to the development of a triple junction when Rockall split from Greenland. The age of the basement is consistent with the development of the triple junction 64 to 60 million years ago, as suggested by magnetic anomaly identifications.

SITE 113, (FIGURE 3)

Site 113 is situated in 3619 meters of water just south of the axis of the sediment buried mid–Labrador Sea Ridge. It was drilled in an attempt to date the oldest sediments immediately above basement and thus positively determine the age of the linear magnetic anomalies which have been variously identified as Anomalies 20 to 24 or 27 to 30. The last active phase of sea-floor spreading in the Labrador Sea can be dated if these anomalies can be identified unambiguously. The site selected was considered the most suitable on the basis of earlier seismic profiles available to us, although the *Glomar Challenger* profiler showed nothing which could be unambiguously recognized as basement. The basement was estimated to lie at about 850 meters below the sea floor.

Drilling at this site recovered a succession of Pliocene-Pleistocene terrigenous silty clays, some 390 meters thick, overlying Pliocene graded sands and alternating layers of Pliocene clay and a conglomerate of Eocene, Oligocene, and Pliocene clay clasts in a watery matrix. This part of the section extends down to 550 meters and is interpreted as consisting of turbidites related to glaciation. Beneath the turbidites is a succession of laminated mudstones with load casts, cross-bedding and convolute lamination of Pliocene and possibly Miocene age. These continued down to 923 meters. No significant changes in lithology or drilling breaks which could be related to reflectors in the seismic profiles were noted. At 923 meters the dynamic positioning system began to give trouble and, since time was running short and there was no certainty as to how deep basement might be, it was decided to abandon the hole. Abandonment of the hole before reaching basement, coupled with the virtual absence of microfauna in the sediments cored, did not permit an estimate of the age of the basement.

SITE 114 (FIGURE 4)

At magnetic Anomaly 5 (10 million years, Heirtzler's scale) near the crest of the Reykjanes Ridge, on the eastern flank of the ridge, there is an abrupt change in sediment thickness. West of Anomaly 5 the sediment thickness is less than half of what it is immediately to the east. Sites on either side of the discontinuity were therefore proposed in order to try to ascertain whether the sediment discontinuity was due to an interruption in sea-floor spreading or to an abnormally high sedimentation rate in the region to the east. The eastern site was drilled first (Site 114) on the grounds that if it showed the sediment discontinuity to be the result of a high sedimentation rate there would be no reason to drill the western site.

Drilling and coring at Site 114, in 1927 meters of water, recovered a succession consisting entirely of silty clays with sandier horizons in a few places. Basalt basement was cored in the bottom of the hole at 623 meters below the sea floor. The sediments range in age from Pleistocene back to ?Late Miocene. Both the nature of the sediments and the paleontological studies showed an abnormally high sedimentation rate (12 cm/1000 yrs), and the oldest sediments cored were considerably younger than the age predicted by the magnetic anomaly pattern. The results of drilling and the nature of the seismic reflection records lead to the hypothesis that the thick pile of sediments is due to deposition from bottom-contour currents, and the theory of a hiatus in sea-floor spreading need not be invoked. The western site, therefore, was not drilled.

SITE 115 (FIGURE 4)

Site 115 lies in 2883 meters of water in the deeper part of the Iceland Basin between the Reykjanes Ridge and the Rockall Plateau. The basin is asymmetrical, the deepest part being close to the scarp west of Hatton Bank, where the Maury mid-ocean canyon runs. The site lies between the canyon and the east side of the contour-current built Gardar Ridge in an area believed to be free of contour-current deposits. Site 115 was drilled in order to sample prominent reflectors and check the age of the basement which had been identified with magnetic Anomaly 22. An additional objective was to obtain a relatively complete Middle and Lower Tertiary section for this area of the North Atlantic.

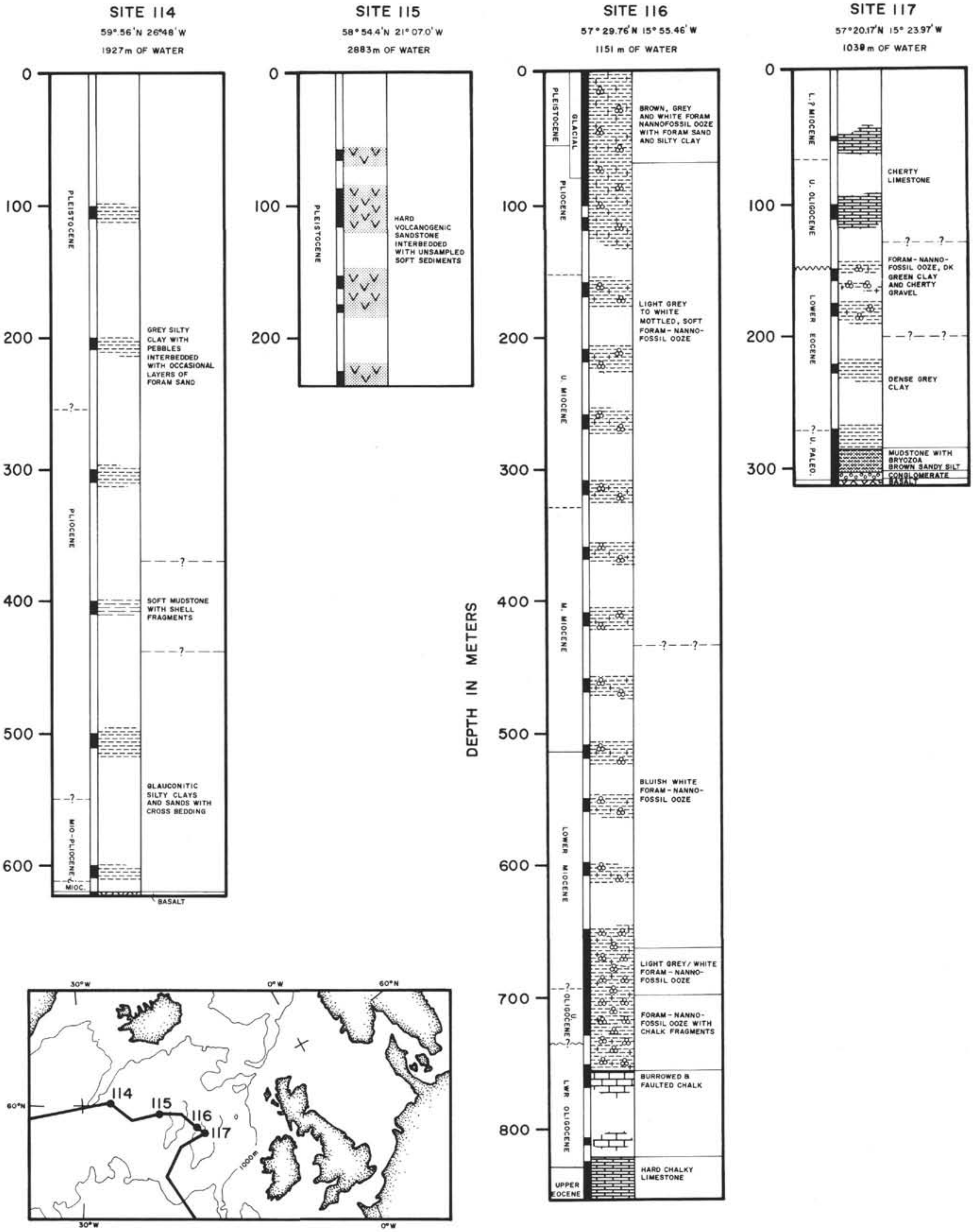

Figure 4. *Stratigraphy of Sites 114, 115, 116 and 117 on the Reykjanes Ridge, in the Iceland Basin and on Rockall Plateau.*

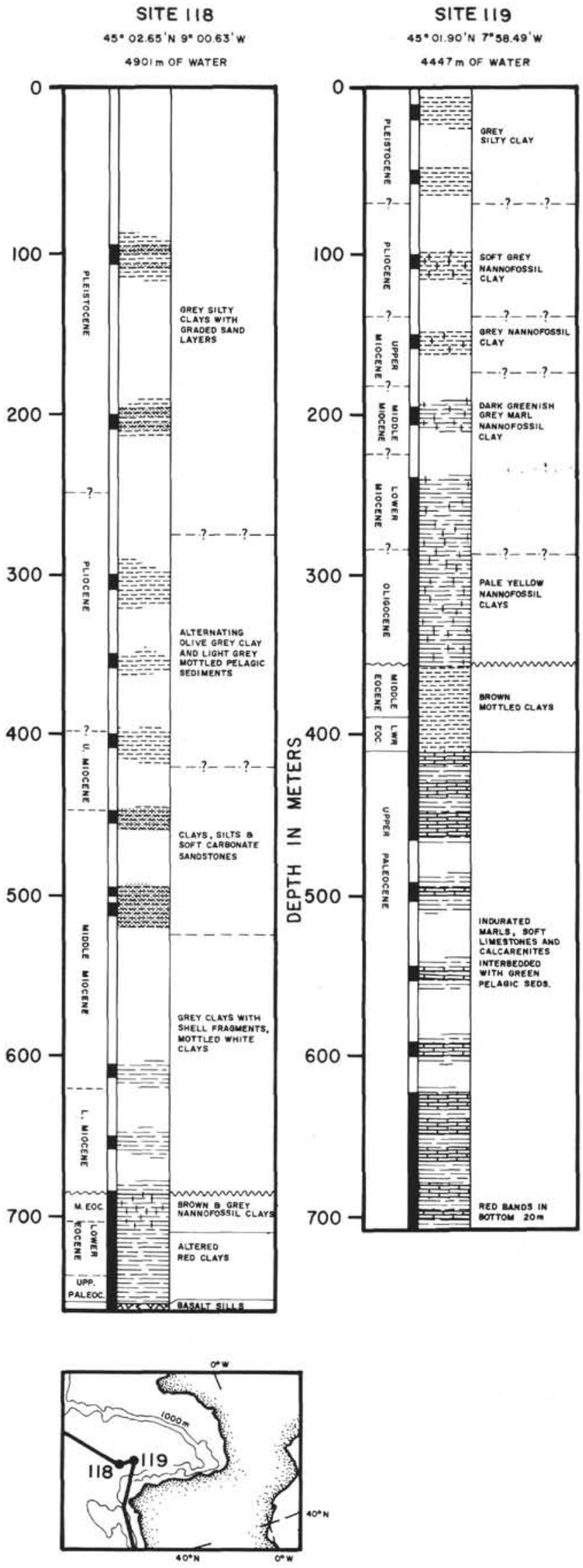

Figure 5. *Stratigraphy of Sites 118 and 119 on the Bay of Biscay.*

Unexpectedly, hard sandstones were encountered very soon after penetrating the bottom. Eight cores were taken at this site, all of which consisted of hard, graded volcanogenic sandstones, some more than 1 meter thick, before circulation became completely blocked at 228 meters subbottom, forcing us to withdraw from the hole. Attempts to sample the thin sediment layers between the sandstone layers failed as these were washed out by the high circulation required to cut the hard layers and keep the hole clear. The first sandstone layer was encountered at a depth of 58 meters, but the layers became thicker and more abundant at 87 meters, a depth which agrees well with the calculated depth to the very strong reflector observed on the seismic records. Drilling showed that the thick sandstones persist to a depth of at least 230 meters and it was decided that further attempts at drilling in this locality would be fruitless. The sandstones are turbidity current deposits of under-ice volcanic eruptions on Iceland.

SITES 116 AND 117 (FIGURE 4)

The Hatton-Rockall Basin is a part of the Rockall Plateau located midway between the Reykjanes Ridge and Ireland, which is believed to be a continental fragment isolated during spreading of the North Atlantic. The basin is situated between Hatton Bank to the west and Rockall Bank to the east. It is filled with a thick sedimentary sequence within which five prominent seismic reflectors can be recognized. Reflectors 1, 2 and 3 (numbered from the top down) form a comformable sequence that wedges out against the more steeply dipping reflector 4. Site 116 was drilled in 1151 meters of water in the center of the basin in order to sample the sedimentary section down to and including reflector 4 and, thus, to learn something about the history of subsidence and sedimentation on the Rockall Plateau.

The deeper layers of the Hatton-Rockall Basin were too deep to be sampled, but a site 32 kilometers ESE was chosen. In this region, the prominent reflector 4 emerges from beneath the cover of younger sediments, and the site was drilled in order to continue the stratigraphic section down into reflector 5 which forms the acoustic basement. Site 117 was drilled in 1038 meters of water on the western flank of Rockall Bank, near the margin of the Hatton-Rockall Basin.

Results of drilling showed that a relatively complete sequence of Cenozoic sediments is present in the Hatton-Rockall Basin. The gradual sinking of this basin to its present depth during the Cenozoic is reflected in the faunal record and the nature of the sediment: predominantly detrital in the lower part, with a gradually increasing proportion of pelagic material in the younger horizons. Two unconformities were recorded: at Site 116 between the Upper and Lower Oligocene–representing a time-interval of about 10 million years; and, at Site 117 between the Oligocene/Upper Eocene–representing about 20 million years.

Rockall Plateau has been shown from the shallow water sediments of Site 117, to have sunk at least 1400 meters. A history of vertical tectonic movements can be derived from a correlation of the depositional environment of sediments as a function of age, both indicated by the faunal assemblages.

The seismic reflection profiles across Rockall Plateau show that the sediment sequence sampled at 116 from the Miocene to Pleistocene can be traced over a large area (320 by 60 miles) between Hatton and Rockall Banks. The basin is nearly closed to the north and open to the south. Marginal channels and moats around basement highs, the wavy nature of the surface and sub-surface reflectors, and the sharp contacts between the basin and the areas of nondeposition on Rockall and Hatton Banks all suggest that the sediments were deposited under the control of near-bottom currents.

SITE 118 (FIGURE 5)

Site 118 was drilled in 4901 meters of water on the western margin of the Biscay Abyssal Plain. On the basis of available seismic records it is believed that the basement throughout the Bay of Biscay is mantled with a layer of sediment of varying thickness, referred to as "Layer 4". Lying horizontally and unconformably on Layer 4 and filling depressions in its surface are Layers R, 2 and 3, believed to be typical abyssal plain turbidite deposits. At the point chosen for Site 118, a basement high apparently brought Layer 4 relatively close to the seabed, within reach of the drill bit. The purposes for drilling were to sample the turbidite sequence—in order to obtain some knowledge of "typical" Bay of Biscay sediments—and to drill through, sample and date Layer 4 and the basement.

The sedimentary succession sampled can be divided into two main units. Down to about 675 meters below the seabed, the section consists of interbedded turbidites and pelagic sediment of Lower Miocene to Pleistocene age. The sand and silt layers in the Upper Miocene, Pliocene and Pleistocene turbidites contain an extensive suite of metamorphic detrital minerals indicating a source area on the shelf off Brittany, or perhaps northwestern Spain. Lying unconformably below the Miocene, from 675 to about 750 meters depth is a succession of Eocene and ?Paleocene clays. The upper 25 meters of these are typical gray and brown limonitic nannofossil clays, somewhat altered chemically. Below these, the succession consists of red limonitic and hemetitic clays with virtually no calcareous fossils; those present are extensively recrystallized. These 40 meters of red clay have probably been altered by the thermal and chemical effects of the basalt intrusion beneath.

Below 750 meters the hole entered basalt, drilling through one thin sill of weathered basalt into baked clay and then into another basalt layer where drilling stopped. This basalt is probably a sill also.

In the vicinity of this site, Layer 4 is not clearly recognizable on *Glomar Challenger* records and, therefore, we were unable to relate it to the stratigraphic sequence cored. If the sediments below the unconformity do represent Layer 4, then it is Late Paleocene in age.

SITE 119 (FIGURE 5)

Site 119 was drilled in 4447 meters of water on top of Cantabria Seamount, which is believed to represent an uplifted section of old ocean floor. The hole bottomed at 711 meters in indurated limestones of early Late Paleocene age.

A relatively complex sequence of Cenozoic sediments appears to be present on Cantabria Seamount. An unconformity which separates Lower Oligocene and Middle Eocene strata was encountered at about 360 meters. This hiatus represents a time-interval of about 10 million years. The uplift and tilting of Cantabria Seamount probably took place during Late Eocene.

The sequence of sedimentation appears to be reversed at Site 119 compared to Site 118. The upper 400 meters of sediment on Cantabria Seamount are primarily of pelagic origin. Below 400 meters a thick sequence of turbidites (approximately 300 meters) of Late Paleocene age was encountered.

The objective of the hole was to sample the Maestrichtian, previously cored and dredged on the north scarp. No Maestrichtian sediments were received down to 711 meters below seabed, well below where they were expected. Re-examination of the previously sampled sediments from Cantabria Seamount, thought to be Maestrichtian, showed them to be of Tertiary age.

ACKNOWLEDGMENTS

That part of this investigation done by one of us (WAB) was supported in part by Grant 6B16098 from the National Science Foundation (Submarine Geology and Geophysics Program, Oceanography Section). This is Woods Hole Oceanographic Contribution No. 2762.