7. SITE 115

The Shipboard Scientific Party[1]
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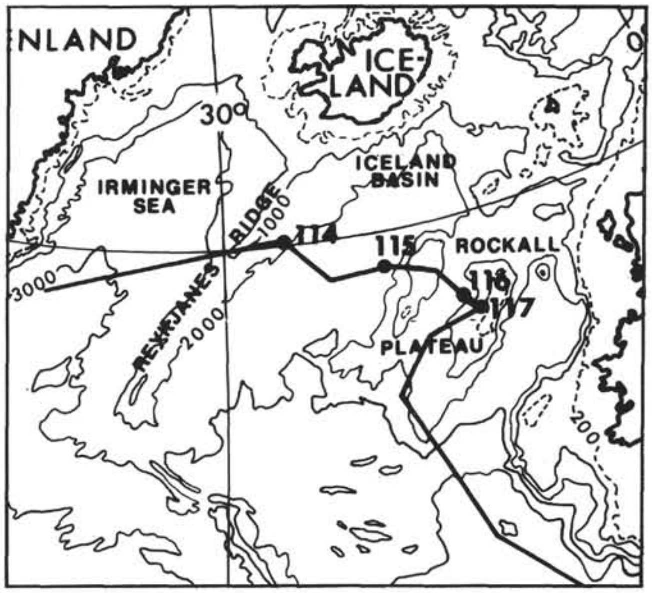
Location: Basin east of Reykjanes Ridge at Anomaly 22.

Position: 58° 54.4′N, 21° 07.0′W; (celestial navigation).

Depth of water: 2883 meters (corrected).

Total penetration: 228 meters.



SITE BACKGROUND AND OBJECTIVES

The principal aim of drilling at this site was to obtain a more or less complete Tertiary sequence of sediments which would reveal a biostratigraphy typical of high latitudes. This objective was thwarted, however, when drilling encountered indurated volcanogenic sandstones deposited by turbidity currents. The site lay in the deeper part of the Iceland Basin (Ulrich, 1962) between the crest of the Reykjanes Ridge and Rockall Plateau, 65 kilometers from the foot of the scarp west of Hatton Bank (Figure 1). The basin is asymetrical (Figure 1), the deepest point being on the east side where the Maury mid-ocean canyon runs from the northeast to the southwest (Johnson, Vogt and Schneider, 1971). The drill site was chosen, on the basis of *Discovery*-29 seismic profile, between the canyon and the east side of the contour current built Gardar Ridge (Johnson and Schneider, 1969). It was hoped that the site would be clear of sediments deposited by this mechanism, which appears to operate in the whole of the western side of the basin and has given rise to other sediment ridges, such as that sampled at Site 114.

The *Discovery*-29 seismic profile (Scrutton and Roberts, 1971) showed two prominent reflectors at 0.3 and 0.8 seconds lying above a very irregular and rather indistinct basement at 1.0 second (Figure 2). The reflector at 0.8 second is shown more clearly on a section of *Discovery*-29 profile near Site 115 which has been processed and filtered with a time variable filter. The upper high reflecting beds do not extend more than 0.4 second below seabed. The upper reflector occurs only on the eastern side of the basin (to a distance of 100 kilometers from the eastern edge of the basin) where it stops abruptly and is replaced to the west by a deeper reflector at 0.7 second. The lower reflector at 0.8 second appears to be continuous across the basin just above basement as far as 22°30′W at Anomaly 20 (49 million years). The site lay at Anomaly 22 (56 million years), and the oldest sediments were therefore expected to be Late Paleocene.

In summary the objectives were:

(a) To obtain a middle and lower Tertiary sequence of high latitude sediments, in particular to sample the Eocene-Paleocene boundary.

(b) To identify the prominent reflecting horizons.

(c) To date the basement by the oldest sediments and hence to check the identification of Anomaly 22.

(d) To detect and date the onset of glaciation.

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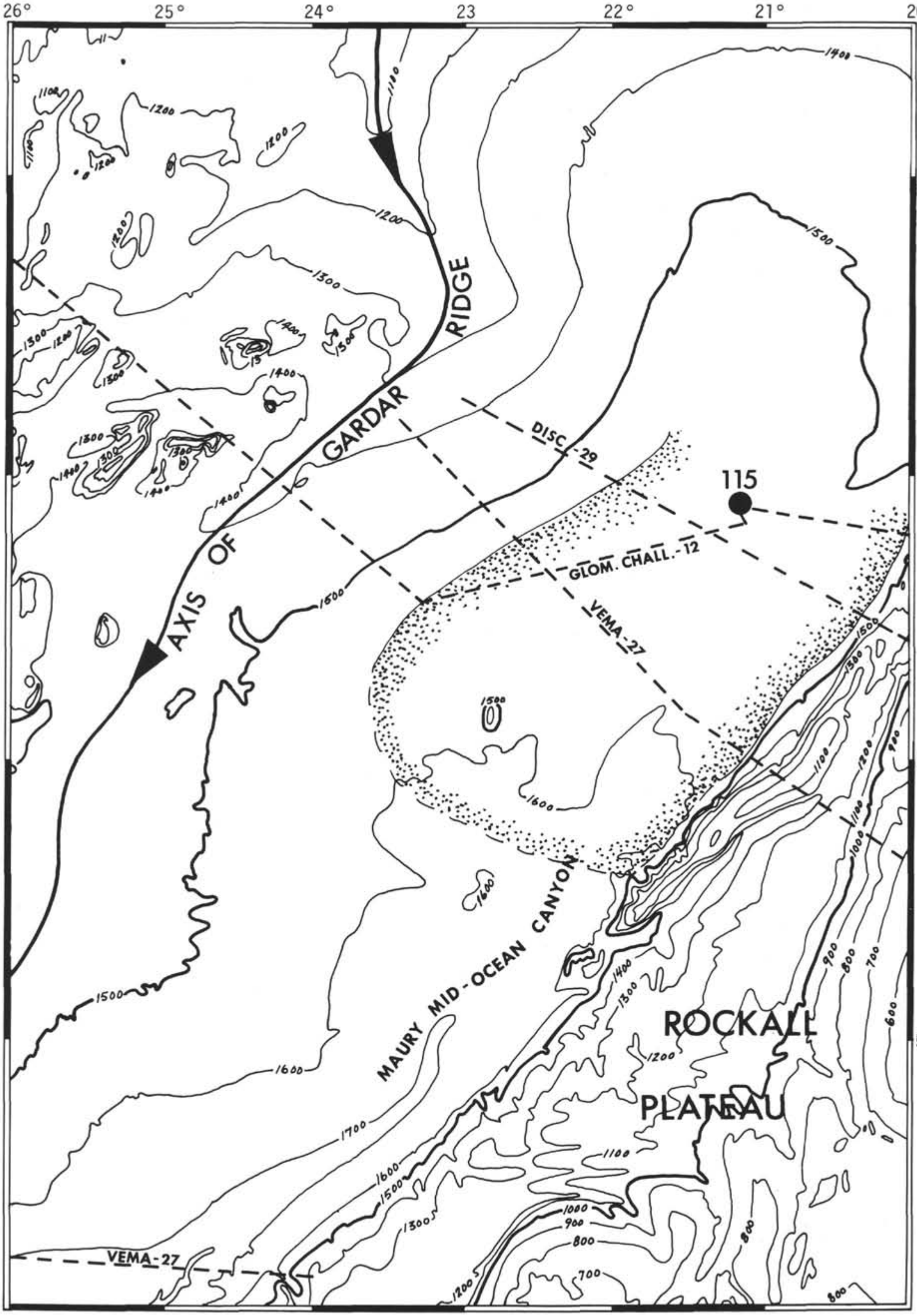

Figure 1. *Bathymetric chart of basin west of Rockall Plateau showing position of* Glomar Challenger *track, and positions of* Discovery*-29 and* Vema*-27 profiles illustrated in Figures 3, 10 and 11. (Bathymetry from Johnson, Vogt and Schneider, 1971.) Area of ponded volcanogenic sandstones is enclosed by line with dots.*

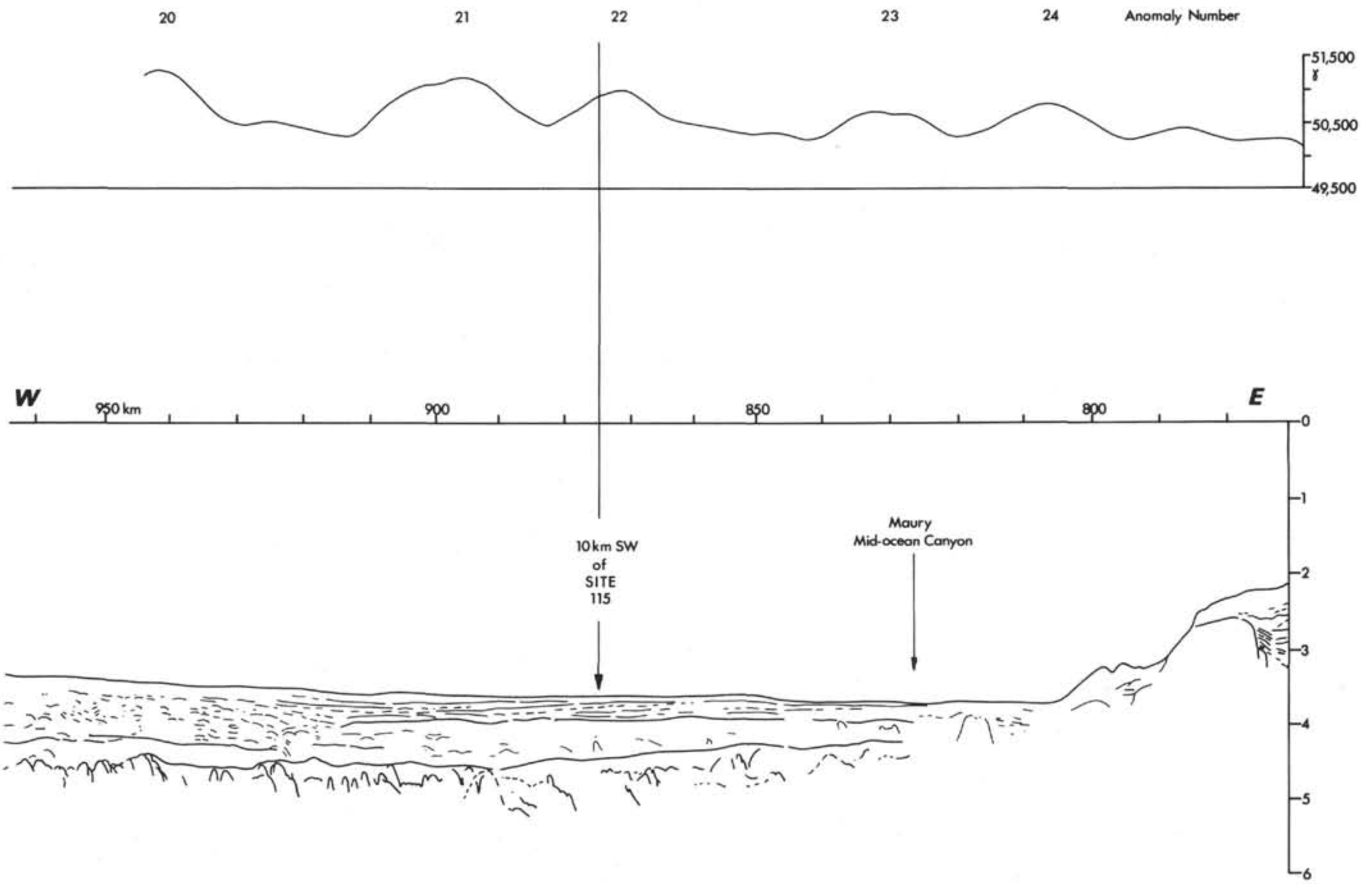

Figure 2. *Line drawing of seismic reflection profile from* Discovery-*29 (after Scrutton and Roberts, 1971).*

SURVEY DATA

The approach track to Site 115 was from WSW owing to a navigational error on leaving Site 114. Without satellite navigation, the approach was by dead reckoning. Ten miles west of the nominal site position, the ship slowed to 6 knots in order to improve the seismic profile record. Penetration was very poor and the only reflector visible was a very strong one at about 0.1 second (Figure 3). The reflectivity of this layer was higher than that of the seabed itself and gave rise to a number of internal multiples within the upper sediment layer. The drilling results showed the reflector to be indurated sandstone.

A check on the position of the ship was obtained by the crossing of the magnetic Anomaly number 22 which was readily recognized. It appeared that we were to the east of the D. R. position, so the course was altered to the northwest until we were on the crest of Anomaly 22, when the gear was recovered and the beacon dropped.

On leaving the site, we steamed eastward toward Rockall Plateau. The strong reflector persisted at a constant depth below sea level although the sediment cover at first increased somewhat and then reduced in thickness down to zero in the axis of the Maury mid-ocean canyon (Figure 4). This traverse, made at 8 knots, then crossed the shallowest part of Hatton Bank and one aim was to discover whether there was a volcanic feature here that could possibly account for the volcanogenic sandstones of Site 115. The seismic profile showed Hatton Bank here to be smooth topped, with basement rising from below the sediments of the basin to the west, and dipping below Hatton-Rockall Basin to the east. The magnetic profile is devoid of sharp, narrow magnetic anomalies which would indicate surface volcanic activity, although there are two anomalies of 800 and 400 gamma which might arise from deeper bodies.

No seismic record was made over the beacon after leaving the site, so the nearest records were about 2 kilometers away during both approach and departure. The approach run shows the beds west of 21°W to be essentially horizontal, so no appreciable error is made by extrapolating to the site. East of 21°W, some irregularity can be seen in the reflector (partially obscured by 60 Hz noise on the system). At 0950 hours, (Figure 4) two distinct reflecting horizons can be seen which probably correspond to those sampled at about 60 and 90 meters.

The major reflecting horizon from the low frequency (40 to 80 Hz) record at 0.11 second gives a depth of 88 meters at 1.6 km/sec. The high frequency record (160 to 320 Hz) showed a strong reflector to be at 0.06 second equivalent to 48 meters at 1.6 km/sec. During drilling the sediment hardened at 51 meters, and the first sandstone bed was encountered at 58 meters.

An intermediate frequency (80 to 160 Hz) gave a reflector at 0.11 second equivalent to 88 meters corresponding approximately to the top of the major group of sandstone beds found below 87 meters. Apparently the

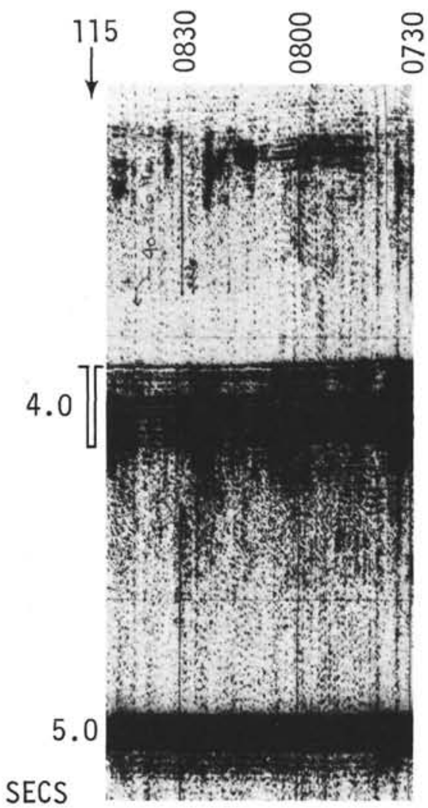

Figure 3. *Seismic reflection profile on approaching site (40-80 Hz).*

layers at 50 to 60 meters are too thin to give reflections at frequencies lower than 160 Hz (wavelength = 10 meters at 1.6 km/sec). A velocity of 1.6 km/sec for the upper sediments fits the data well, but the thicknesses are too small to measure the velocity accurately.

DRILLING OPERATIONS

A beacon was lowered at 0900 hours on July 14th in 2883 meters of water. The bottom hole assembly consisted of a Smith 3-Cone tungsten carbide insert bit below 10 drill collars, and 3 bumper-subs.

The first core was planned to be at 85 meters in order to start coring continuously past the reflector at about 110 meters. At first the drilling was fast, but at 50 meters it started to stiffen up, and at 58 meters it came against a very hard layer. With so little pipe in the hole it was difficult to apply much weight on the bit. We cored this layer with some difficulty, punching through hard layers into soft. The hard layers turned out to be lithified sandstones. After the few hard layers at 60 to 70 meters, drilling (with a center bit) was fast until 87 meters when another hard layer was hit. A series of continuous cores between 87 and 115 meters were cut. An attempt was made to sample the soft layers between the hard sandstone beds, but the water circulation required to cut the hard beds washed away all the softer material. Recovery was therefore relatively low, the highest being 3.25 meters out of 7 meters cut.

Having determined the nature of the strong reflector, we planned to drill ahead until we came to a consistently softer

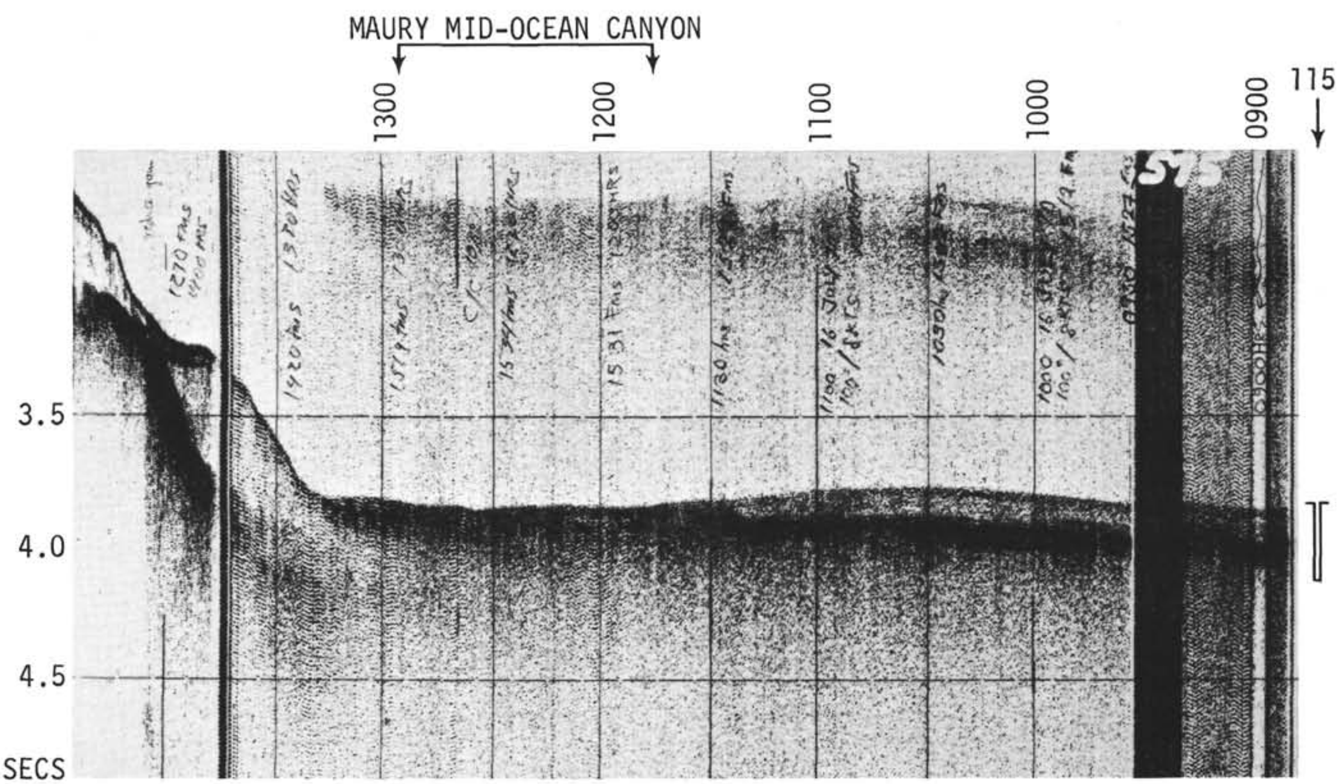

Figure 4. *Seismic reflection profile after leaving site (80-160 Hz).*

layer. Between 115 and 153 meters, several hard layers were encountered but drilled through without much difficulty using a center bit. On recovery the center bit gave several bucketfuls of sandstone cuttings of a few millimeters diameter. A core of 153 meters showed that we were still drilling through hard sandstone layers.

Again we drilled on to find the base of the sandstone zone. At 175 meters it appeared to be drilling more uniformly and softer so the center bit was withdrawn (yielding more hard cuttings) and a core cut. Again, there was only hard sandstone and no soft sediment.

Another 43 meters were drilled encountering a hard zone between 191 and 199 meters; otherwise, drilling was easier but firm. At 223 meters a core was cut which started firm but steady, minimum circulation being used. At 228 meters it became hard again so coring was stopped and the overshot sent down to engage the core barrel. However it failed to do this; moreover circulation became blocked and the overall weight of the drill string appeared to have decreased. It was at first thought that the bottom hole assembly had been lost, but later it was realized that hard cuttings had flowed back into the bottom hole assembly during reduced circulation and had filled the drill collar above the core barrel, preventing the overshot engaging. With circulation blocked there was danger of the hole collapsing on the drill string, so the decision was made at 2300 hours on July 16th to withdraw from the hole.

The bottom hole assembly was brought on board at about 0730 hours and it was found that there were several feet of cuttings above the core barrel which was jammed tight in the drill collar. A core was however recovered from the core barrel showing the hard sandstone beds to extend at least down to 228 meters. Some soft clay samples were recovered from the drill bit.

Departure from the site was at 0800 hours July 16th; 9 meters of core being recovered from a total of 55 meters cored (16 per cent).

TABLE 1
Cores Cut at Site 115

Hole	Core	Cored Interval (m, Subbottom)	Core Recovered (m)
115	1	58-67	1.50
115	2	87-96	1.75
115	3	96-100	0.20
115	4	100-107	3.25
115	5	107-115	2.30
115	6	153-162	0.30
115	7	175-180	0.90
115	8	223-228	1.37

LITHOLOGY

Introduction

At Site 115, eight cores of Pleistocene greenish gray hyaloclastic volcanic sandstone[2] partly grading into silty sand and clay, were recovered from various depths between 58 and 228 meters downhole. Though cores were recovered only from the sandstone, it was learned from the drilling characteristics, a few center bit and core catcher samples and from reworked mud pellets within the sandstone, that the hard sandstone is interbedded with soft clayey sediments. The clay from Sample 115-1-1 consists of kaolinite and other clay minerals, together with a varying amount of feldspar, pyroxene, glass, palagonite, chlorite and zeolite, nannofossils and planktonic foraminifera.

Petrology of the Volcanic Hyaloclastic Sandstone

G. P. L. Walker, Imperial College, London, in cooperation with the Shipboard Scientists

Structure and Texture

The cores consist of a number of graded units. At least fifteen units, or parts of them, can be distinguished. Each has a relatively coarse-grained and very homogenous unbedded basal and middle part (Plate 1), and a laminated and sometimes cross-laminated, largely fine-grained, upper part (Plate 2). The base of one unit succeeds the top of the underlying unit with a very abrupt, sharp, generally horizontal, contact.

In one case (115-4-2, Samples 11 and 12),[3] the contact is irregular and steeply dipping (Plate 3). The fine-grained sediment underneath the contact is evidently disturbed and contaminated with coarse grains from the base of the overlying 1.8-meter thick graded unit, the thickest one observed from all cores. Well-rounded dark gray shale pebbles, up to 12 millimeters across, are at the base of this unit. The contact must be considered erosional. Less indurated clay pellets, up to 16 millimeters across, can be observed at the base of graded units from other cores, as for instance, in Cores 2 and 5. In some cases the laminated part, close to the contact with the next graded unit, has been burrowed by marine organisms. Burrows at the top of a graded sediment unit are usually taken for a good proof that the unit has been rapidly deposited, and that there has been enough time between deposition of one unit and another to allow the inhabitation of the sediment surface by burrowing organisms. Consequently, the burrowed horizons in the second, more or less homogeneous coarse-graded unit of Core 5, Section 2 suggest that this unit is multiple.

The maximum grain-size is generally in the range 0.2 to 2.0 millimeters, and the estimated median diameter in the range 0.05 to 0.3 millimeter (phi 4.3 to 1.7). In view of the fact that disaggregation of the material does not seem practicable without creating a large quantity of dust from the secondary minerals interstitial to the clasts, the samples

[2]This term is used following the definition in the *Glossary of Geological and Related Sciences,* A.G.I. (1966). The adjective of "hyaloclastic" is added to point out that contrary to the A.G.I. definition, the volcanic components are thought to be not pyroclastic but hyaloclastic in nature, ie. they are the result of quenching of basaltic magma under ice or water.

[3]Due to the indurated and fractured nature of the sediments rock samples were numbered consecutively downwards from the top of each section (Figure 5).

have not been sieved, but from a comparison of the thin sections with volcaniclastic rocks which have been sieved it is estimated that $\sigma\phi$ (Inman, 1952) is of the order of 1.0 or less. For volcaniclastic rocks they are well sorted.

Secondary structural features in many sections of the cores (especially Core 4) include subhorizontal massive or imbricate veins (up to 1 centimeter thick) and clusters of zeolite (thaumasite, according to X-ray diffraction identification by J. C. Hathaway, W.H.O.I.) indicated in Figure 5 (as mineral veins) and illustrated in Plate 2.

Petrographic Description of Volcanic Constituents

The principal clasts, constituting between them some 90 per cent of the total in most samples examined, are volcanic. They are:

1. Sideromelane: clear basaltic glass. It is pale yellow or yellow-brown in thin section and is marginally altered to palagonite (entirely altered in the finer-grained rocks). Phenocrysts of plagioclase and pyroxene are generally present. Sometimes vesicular.
2. Tachylite: basaltic glass which is darker and more crystalline than sideromelane. It contains feathery growths and microlites of pyroxene, plagioclase feldspar and opaques. It is often variolitic, and sometimes vesicular.
3. Basalt: moderately coarse-grained plagioclase/clinopyroxene rocks with some opaques and probable olivine. Probably tholeitic in composition. The basalt is nonvesicular and is always very fresh, with no sign of alteration.
4. Crystals, almost invariably broken fragments, of plagioclase feldspar, augite, some olivine and opaques. No trace of alteration is seen, apart from the rare partial replacement of the feldspar by zeolite.

The volcanic clasts are mostly angular to subangular in form. Those of sideromelane are often bounded by concave curved fracture surfaces.

The above-mentioned volcanic clasts are all of basaltic composition or provenance. There are in addition occasional pieces of intermediate to acid pumice or glass shards. One specimen 115-5-2, Sample 1) gave a refractive index of 1.533, indicating an intermediate composition. An iron-rich clinopyroxene (ferroaugite or aegirine-augite) in 115-5-1, Sample 1 could be a phenocryst mineral from an acid volcanic. The X-ray diffraction investigation of a sample from Core 4 reveals 42 per cent plagioclase feldspar and 47 per cent augite.

More than half of the volcanic clasts and all of those made of crystalline basalt are nonvesicular. In most of the others, vesicles make up less than 50 per cent of their volume. Clasts in which vesicles make up as much as 50 per cent of the volume are generally a very minor constituent (though not in 115-8-1, Sample 6, in which they are moderately common). The vesicles are mostly small, measuring 0.02 to 0.1 millimeter in diameter. The nonvesicular clasts are bounded by fracture surfaces which, although often curved, are clearly not vesicle walls.

The refractive index of the sideromelane (determinations of five samples) is 1.600 to 1.613, which are typical values for sideromelane. One sample (115-4-2, Sample 6), gave a refractive index between 1.57 and 1.58 which is rather low for sideromelane. Becke lines seen in thin section within the sideromelane clasts indicate refractive index differences, probably due to variable amounts of contained water.

Palagonite is widespread and may constitute around 50 per cent of the total bulk of the rocks. Some of it is isotropic and forms a rim around (just inside the boundary of) the sideromelane clasts. This rim is generally 20 to 50 microns thick and in the finer-grained rocks, where the diameter of the clasts is of this order, the sideromelane is entirely palagonitized. Most of the palagonite in the rocks, that which occurs interstitially and cements the clasts, is fibrous and anisotropic. In some samples it is associated with, or its place taken, by a green chloritic mineral.

Zeolites occur in some of the samples, in interstices between the clasts, occupying the body chamber of foraminifera, occasionally replacing clasts (of glass ?), or partially replacing plagioclase feldspar. The zeolites are believed to include chabazite, analcite and phillipsite, though no detailed study has been made of them. Thaumasite ($Ca_3H_2[CO_3,SO_4,SiO_2] \cdot 13\ H_2O$), hexagonal acicular or fibruous zeolite (Troeger, 1969), has been proved to be the vein mineral from Core 4, according to X-ray diffraction investigation by J. C. Hathaway (W.H.O.I.). It is known as an amygdale mineral in the Antrim Basalts (Walker unpublished data) and occurs associated with sulphates in the Triassic basalts of New Jersey (Mason, 1960). Thaumasite was also tentatively described, cementing "tuffaceous biocalcarenite" and "basalt and tuff breccia" from Josephine Seamount in the eastern North Atlantic by Schulze and von Rad (1971).

An attempt was made to detect significant petrographic differences between the above described graded units, but it was not successful. No systematic difference was found between one graded unit and another. The lower refractive index α', of cleavage flakes of plagioclase feldspar was determined on eleven samples, for example, and was found to be nearly constant, lying almost entirely in the range 1.571 to 1.573 (indicating bytownite, An 80 to 85), though occasionally dropping as low as 1.560 (labradorite, An 60), probably in zoned crystals.

The Nonvolcanic Constituents

Grains of nonvolcanic material are minor constituents, making up, it is estimated, not more than 10 per cent and in most samples probably less than 5 per cent of the rock. These are mainly calcareous and silicious fossils and some fish debris. They were found throughout all cores, even in the hardest portions, as well as in center bit samples. The fossil assemblage is a mixed one from both deep and shallow water environments, although mainly representative of a deep water environment: Coccoliths, planktonic and benthonic (arenaceous and calcareous) foraminifera, radiolarians, siliceous sponge spicules and some shark teeth of the genus *Scyliorhinus.* The shallow water environment is indicated by *Elphidium, Nucula,* and shell fragments of *?Cyprinia, Cardium,* and brachiopods.

The nonvolcanic material also includes quartz, some of it angular and some in well-rounded grains. Other grains include a variety of metamorphic and igeneous rocks and minerals: microcline, graphic granite (microcline/quartz intergrowth), quartz-epidote rock, phyllite (quartz/sericite rock, with strained quartz), chlorite (both as isolated flakes

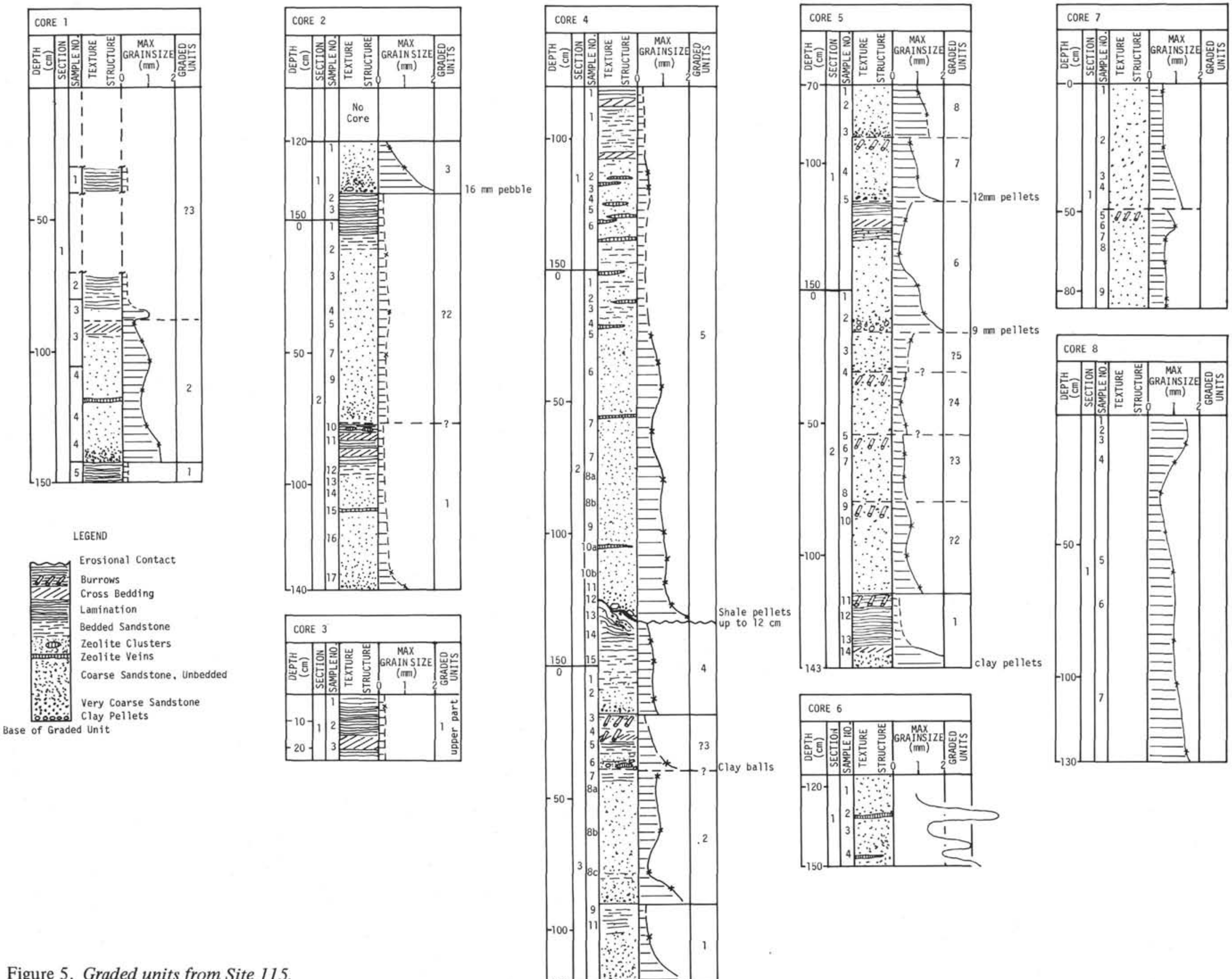

Figure 5. *Graded units from Site 115.*

and rounded clasts made of aggregate of flakes), micas, and possible glauconite. These grains are sometimes angular or subangular, and sometimes well rounded. Four per cent kaolinite has been measured in a sample from Core 4 by X-ray diffraction.

Age of the Rocks

The thickness of the palagonite rims on the sideromelane clasts is, as mentioned above, around 20 to 50 microns. The thickness of such a rim is controlled by many factors, of which the age is one. The only study of the rate of palagonitization of sideromelane in a submarine environment is that by Moore (1967) which would suggest an age of the order of 10,000 to 20,000 years.

The Site 115 cores have been compared with a number of glassy basaltic volcaniclastic rocks. The rim is thicker than in the youngest examples of such rocks in Iceland, such as the ash-ring of Karl (in Reykjanes) and the several ash-rings in the Myvatn area, between 10^3 and 10^4 years old. It is comparable in thickness to the rocks in various tuff-rings believed to be around 10^4 years old in the Azores. It is thinner than in the Diamond Head tuff-ring of Oahu, about 10^5 years old. It is comparable in thickness to various rocks in Iceland formed during the most recent glaciation, probably between 10^4 and 10^5 years old. It is appreciably thinner than in the hyaloclastite of Acicastello (Sicily), nearly 10^6 years old, and in the various basaltic tuffs and hyaloclastites interbedded with the Tertiary basalts of eastern Iceland, between 10^6 and 10^7 years old. These last have been buried to a depth of 0.5 to 2.0 kilometers, and have been involved in a form of low-grade regional metamorphism during which large-scale zeolitization has taken place, and the thickness of the palagonite rim reflects this alteration.

The conclusion is that the Site 115 rocks are quite young, late Quaternary in age, of the order probably of 10^4 to 10^5 years old, though in view of the large number of factors involved this estimate is not likely to be too reliable.

Provenance of The Rocks

Iceland or the Reykjanes Ridge seems the most likely source for the material as the only known areas of Quaternary volcanism in this part of the Atlantic. The bottom topography is such that the Reykjanes Ridge seems unlikely to be the source; on purely topographical grounds Iceland therefore seems to be the more likely source.

There are then two questions to consider: is the character of the material compatible with an Icelandic source and, if so, under what conditions is the material likely to have been generated?

The petrography of the volcanic clasts is, as far as it is possible to judge from simple thin section examination, entirely compatible with an Icelandic origin. The rocks are tholeitic and the whole assemblage (including bytownite phenocrysts, which are very prevalent in the Icelandic basalts) can be easily matched among the Quaternary volcanic piles in mid-southern Iceland.

The conditions under which the clasts formed needs a more extended discussion so as to indicate clearly the bases on which deductions regarding the mode of origin can be made.

Two broad types of fragmental glassy basaltic rocks can be distinguished according to the environment of origin and the manner of fragmentation. The first type consists of pyroclastic rocks in which fragmentation is due to volcanic explosions taking place in the eruptive vent (or, occasionally, at the place where basaltic lava flows from land into water). In most instances the explosive activity and the fragmentation of the magma are due to the escape of dissolved gases, and the particles are in consequence typically very vesicular.

When a basaltic eruption takes place in shallow water, the flow of a large quantity of water into the vent and its conversion to steam modifies the eruptive products to some extent. In particular it increases the degree of fragmentation of the material, a very large proportion of which is reduced to fine ash and dust grades (finer than 0.5 millimeters), it increases the proportion of the magma which is chilled to sideromelane, and it greatly increases the area of dispersal of the ash; but the particles are still characteristically highly vesicular.

Such an eruption took place off the coast of Iceland in 1963-7 and created the island of Surtsey and two temporary islands nearby. The author has elsewhere suggested the term 'surtseyan' for the style of explosive activity such as characterized the opening stages of the Surtsey eruption.

The second type of fragmental glassy basaltic rock is the hyaloclastite. As originally defined, the fragmentation of the basaltic magma to produce these sideromelane-rich breccias takes place entirely under water. (The term 'hyaloclastite' has since come to be loosely applied also to the products of surtseyan eruptions, but in this account the latter are regarded as separate and distinct from hyaloclastites.)

Fragmentation of the basaltic magma in hyaloclastites proper is likely to be due to a combination of thermal shock arising when red hot magma is quenched in contact with cold water, stresses set up by the flowage or expansion of a subaqueous extrusive body, and explosions.

The clasts in hyaloclastites range in size from more than 10 centimeters to fine dust. No statistical studies of the grain-size variation have hitherto been attempted, but experience in Iceland suggests that usually more than 50 per cent of the clasts exceed 1 millimeter in diameter, and the rocks are coarser than pyroclastics of surtseyan type. The fragments vary greatly in vesicularity. In some hyaloclastites, vesicles are completely absent, and the glass chips are then bounded entirely by fracture surfaces. In others the fragments are highly vesicular and are more or less indistinguishable from those of surtseyan ashes.

The vesicularity is a function both of the quantity of gas dissolved in the magma and the confining pressure at the place of eruption (that is, the depth of the water). It is likely that the initial gas content of basaltic magmas is commonly such that little or no vesiculation occurs at a depth greater than about 1000 meters, while the highly vesicular examples are likely to have formed in shallow water, probably less than about 200 meters deep (McBirney, 1963; Moore, 1970).

In the cores at Site 115 the clasts are mostly either weakly vesicular or nonvesicular, and clasts in which vesicles constitute 50 per cent or more of the total volume are rare. The vesicularity on the whole is much less than in pyroclastic deposits, and the material is hyaloclastic in character, formed probably in water of moderate depth. The minor amount of highly vesicular clasts which also occur could represent either admixed pyroclasts, or hyaloclastic fragments formed in relatively shallow water.

The first hyaloclastites to be described, those of Sicily, were formed below the sea and subsequently uplifted. The hyaloclastites of Iceland were mostly formed in the Quaternary ice sheets, in intraglacial meltwater lakes which resulted from the volcanic activity. These hyaloclastites probably differ in few important respects from submarine hyaloclastites (though their glacial environment is shown by their rather intimate association with morainic material), and there are no known textural differences between the hyaloclastites of these two environments.

For the hyaloclastic material of Site 115, which has obviously not originated by volcanic activity in site but has been carried in by turbidity flows, there is no means of distinguishing between a submarine or an intraglacial environment of origin. The authors' opinion is that intraglacial eruptions in Iceland constitute the most plausible source of the material.

Volcanic activity took place on a large scale during the glacial period in Iceland. Intraglacial basaltic eruptions generated an immense volume (probably of the order of 10^4 km^3) of pillow lavas and hyaloclastites, associated with ashes probably of surtseyan type. This suite of rocks is collectively referred to as *moberg*, and forms mountains rising up to 1500 meters above the general level scattered over half the country. These mountains are constructional features, the result of eruptions during the latter parts of the late Pleistocene. Older moberg masses formed earlier (late Pliocene-early Pleistocene) are buried by other rocks, and are now dissected by erosion and exposed in the fjordlands of, for instance, southeastern Iceland.

Volcanic eruptions take place from time to time in the present ice-sheets of Iceland. The volcano Katla (beneath the Myrdalsjokull) erupted in 1918, and Grimsvotn (below the Vatnajokull) erupted in 1934. In both, one of the first signs of activity was the appearance of a flood of meltwaters from the ice margin. In 1934, a total of about 10 km^3 of water was released in the space of a few days (Nielsen, 1937), and the maximum rate of flow of the Katla 1918 flood was about 10^5 m^3/sec. A great volume of detritus is carried down during such glacier floods or *jökulhlaups* (an estimated 10^8 tons in the 1938 *jökulhlaup*, which was probably not of volcanogene type). and large *jökulhlaups* during the Quaternary provide the most plausible explanation for the Site 115 hyaloclastites.

No study has been made of the nature of the debris carried down by a volcanogene *jökulhlaup*: the proportion of juvenile clasts to fragments of pre-existing rocks is not known. All that can be said is that the assemblage of sideromelane, tachylite and crystal fragments could be juvenile material generated during the same eruption that causes the *jökulhlaup*, or it could be produced by the erosion of pre-existing moberg, while the crystalline basalt fragments could be juvenile but are perhaps more likely to have been produced by erosion.

Chemical studies have not been made. Bulk chemical analyses of core samples would be pointless in view of the known fact that the process of palagonitization involves considerable chemical changes (see, for instance, Hay and Lijima, 1968), but microprobe analyses of the sideromelane would be worthwhile. It would then be necessary also to make similar studies of the sideromelane in Icelandic rocks.

Interpretation

From the petrology, the conclusion can be drawn that the Site 115 sediments have been deposited by a turbidity current mechanism. Not only textural and structural features, such as good sorting, graded bedding, lamination and erosional contacts, but also the considerable content of mixed deep and shallow water fauna support this interpretation.

At least fifteen graded units, representing presumably fifteen separate turbidites, are seen. A time interval long enough for burrowing by marine organisms has in some instances intervened between the deposition of successive units, which suggests that at least some of the graded units are due to different volcanic eruptions. The absence of obvious petrographic differences between the clasts in the different graded units is not incompatible with what is known about the extent of variations between the magmas erupted by successive eruptions in the same area of Iceland.

The provenance of the hyaloclastic material has already been discussed. There is little doubt that this material has been derived from Iceland.

Quartz, which is generally present in the Site 115 rocks as a minor constituent, is not unknown as a primary mineral in Iceland, though rare in that part of Iceland which is at present subject to *jökulhlaups*. Perhaps it is more likely to have been picked up from the sea floor over which the turbidity flows passed. Quartz, and the occasional fragments of other nonvolcanic rock-types, may have been carried into the Iceland area by floating ice. The fossils have presumably also been picked up from the sea floor at various depths. As for the petrology of the uncored softer sediments interbedded with the sandstone, little can be said. Presumably they are also turbidites (although not indurated) because of the high mean sedimentation rate, but a pelagic influence of these sediments cannot be outruled because of the comparatively high content of pelagic foraminifera and nannoplankton in the few samples available.

Additional Petrographic Description of the Volcanic Hyaloclastic Sandstone

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Halifax, Nova Scotia, and
J. R. Cann, University of East Anglia, England

Core 1, Section 1, 128-131 cm

The sample is a hyaloclastic volcanic sediment of basic composition consisting of:

(a) Isotropic yellow glass fragments (sideromelane) showing hydration rinds (palagonite) and darker devitrification centers. Some glass fragments contain olivine and plagioclase phenocrysts.

(b) Rounded lithic fragments composed of aggregates of plagioclase laths set in a dark oxidized groundmass.

(c) Fragments of individual olivine, pyroxene, plagioclase, quartz and carbonate crystals all rounded or shattered.

(d) Foraminiferal tests and reworked organic material.

Core 5, Section 2, 27-29 cm

This sample is similar to 115-1-1, 128 to 131 centimeters, except that both sideromelane and palagonite are absent.

Core 8, Section 1, 75-76 cm

This sample is generally similar to 115-1-1, 128 to 131 centimeters, except that sideromelane proper is absent and palagonite devitrified.

All three specimens are probably products of submarine volcanic eruptions. Of the fragments, those of type (a) and some of type (c) represent primary volcanic fragments, while those of the other types represent either material derived from the walls of the volcanic conduit, or material incorporated in the sediment in the interval between the eruption and its deposition. The presence of fragments of types (b) and (d), which must have been transported for some distance, argues against a local source for the volcanic material, and suggests that the material forming the sediment was moved from the site of the eruption to its present position by slumping or by the action of turbidity currents.

Opaque Mineralogy

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Halifax, Nova Scotia

Examination of polished sections has been carried out using a Reichert Zeto Pan microscope. Total magnification was X1350. In the descriptions given below titanomagnetite deuteric (high temperature) oxidation is quoted on a 1 to 6 scale, where:

Class 1: homogenous titanomagnetite

Class 2 and 3: magnetite with increasing amounts of ilmenite lamellae

Class 4: oxidation of ilmenite lamellae to ferrirutile and titanohematite

Class 5: appearance of black spinel spicules in remaining magnetite

Class 6: complete replacement of titanomagnetite by titanohematite, pseudobrookite and/or ferrirutile

Sample 115-8-1, 75-76 cm

Fairly sparse magnetite in the 1 to 100-micron range. Largely brown Class 1, but Class 2 grains are not uncommon while some quite definite Class 4, 5 and 6 grains occur.

Two features arising from these descriptions are noteworthy:

First, while fine-grained titanomagnetite has previously been found characteristic for oceanic basalts, the large magnetites of up to 100 microns, like those from Site 115 (8-1, 75-76) are commonly found in subaerial basalts.

Secondly, high deuteric oxidation titanomagnetites have been recorded for probably the first time from submarine basaltic material, notably in the hyaloclastic volcanic material of Site 115 (8-1, 75-76).

PHYSICAL PROPERTIES

As a consequence of the high pump pressures required in coring the hard sandstone layers, any softer layers were washed away and were not recovered in the cores. Consequently the cores recovered, and the measurements made on them, are not necessarily representative of the particular depths from which the rocks came. This is especially likely in view of the low average recovery (17 per cent). The only soft sediment recovered was at the top of 115-1-1, and this was disturbed anyway.

The sandstone density lies in the range 1.6 to 2.0 gm/cc and the velocity in the range 2.3 to 3.8 km/sec with the majority of values around 3.7 km/sec. The density variation seems to be due to graded bedding. A linear density gradient due to graded bedding shows up especially well at the base of Core 4. Natural gamma activity lies in the narrow range of 250 to 500 counts. This is an especially low activity considering that calcareous tests, etc. make up no more than 10 per cent of the total. The explanation probably lies in the unusual mineralogy of the sandstone. This, according to G.P.L. Walker, contains considerable volcanic glass. Glass is not known to possess much, if any, gamma activity. The source of most of the gamma radiation is probably the reported glauconite and phillipsite (?) and possibly the clay minerals in the palagonite which may make up as much as 50 per cent of the rock.

Paleomagnetic measurements were made by J. Ade-Hall on two oriented samples of volcanogenic sandstone. The upper sample had a strong horizontal component of magnetization, and neither a normal nor a reversed direction could be identified with certainty. The data are summarized on Table 2.

TABLE 2

Specimen	Polarity
115-1-1, 128 to 131 cm	none?
115-8-1, 75 to 76 cm	N

Depth of Reflectors

A strong reflector was detected just below the sea bed at about 0.1 second which exceeded even the sea bed reflection in strength. It is clear from the above measurements why this should be. If the sea bed density and velocity are assumed to be 1.4. gm/cc and 1.50 km/sec, respectively, the relative amplitudes of signals reflected from the sea bed and sandstone (1.8 gm/cc; 3.7 km/sec) are approximately 1:2 allowing for transmission losses across the sea bed interface.

The exact depths of the reflectors found close to the site at 0.06 second on the 160-320 Hz record and at 0.11 secs on the 80-160 Hz record cannot be gauged from the physical property measurements but from the above calculation they undoubtedly result from beds of the sandstone (see survey data for further discussion).

PALEONTOLOGY AND BIOSTRATIGRAPHY

General

The cores consist of hard layers of redeposited volcanic material mixed with deep-water marl or ooze. Apart from the cores, four center-bit samples and the final bit sample were available.

Nannofossil samples could be scratched from the hard cores, but no foraminiferal or radiolarian samples were taken. The latter groups were studied from a few softer core catcher samples and from the cuttings collected from the bit. The entire section is of Late Pleistocene age. Only a few diatoms were found in some samples.

Discussion

Foraminifera

All faunas studies are dominated by *Globigerina bulloides. Globorotalia inflata* and *Globigerina pachyderma* are common in most samples. All other planktonic foraminiferal species are rare and include such forms as *Globorotalia crassaformis, G. scitula, G. hirsuta, G. truncatulinoides, Hastigerina siphonifera, Globoquadrina dutertrei* and *Orbulina universa.*

The planktonic foraminiferal fauna differs from the Pleistocene at previous sites in showing a higher species diversity (Figure 6). This could indicate that warmer (Gulf Stream?) water influenced the Iceland Basin at certain times.

Foraminifera occur in the graded volcanic sandstone, where they are associated with mineral grains of the same size. This strongly suggests that the volcanic material has been redeposited from density currents and did not come down as an ash rain.

The benthonic fauna of several samples is mixed and consists of common deep-water forms (very large *Pyrgo*, large agglutinated forms such as *Rhabdammina* sp., *Bigenerina cylindrica, Karreriella bradyi*, lagenids, *Melonis pompilioides, Paromalina, Epistomina,* large *Gyroidina,* the ostracod *Echinocythereis*) and a very shallow (brackish?) assemblage of *Elphidium* and pelecypod fragments. Middle and outer shelf shell fragments are absent.

In some samples a relatively high number of planktonic foraminifera have an aberrant morphology, the later chambers being added to the test in an apparently random fashion. One could imagine that this is a response to chemical changes in the sea water caused by submarine volcanic activity in the region.

Calcareous Nannoplankton

Probably all cores from this site belong to the *Gephyrocapsa oceanica* Zone of the Pleistocene. Coccoliths are common to rare in the samples examined.

Pleistocene

Except for Core 1, the cores contain a coccolith assemblage of Late Pleistocene age. In Core 1, *Pseudoemiliania lacunosa* and *Reticulofenestra* sp. are also present, indicating a somewhat older age for this core. This is explained by reworking, as all the other lower cores contain coccoliths of the genus *Gephyrocapsa*, with a visible diagonal bar over its center, forms that are typical for the Late Pleistocene. As on previous sites, the Pleistocene assemblage is poor here not only in species, but also in specimens. *Scapholithus fossilis, Cyclococcolithus macintyrei, Scyphosphaera, Rhabdosphaera clavigera* or *Ceratolithus* are not present. *Syracosphaera* was found in Cores 1, 2 and 7; *Pontosphaera scutellum* and *P. discopora* occur sporadically, as does *Helicopontosphaera kamptneri* and *H. sellii. Coccolithus pelagicus* is present in varieties with a small central opening, almost closed and with a bar over the central opening.

Radiolaria

Radiolarians are present but rare in most of the core catcher and core water samples from the volcanogenic sediments of Hole 115. The most persistent species include *Theocalyptra davisiana* (Ehrenberg), *Ommatodiscus* sp., *Stylodictya validispina* Joergensen, and the spongy discoidal spumellarians *Spongodiscus biconcavus* (Haeckel) Popofsky, *Spongopyle osculosa* Dreyer and *Spongotrochus* sp. cf. *S. glacialis* Popofsky. Throughout Hole 115 these species plus others constitute a reduced assemblage quite similar to the Pliocene-Pleistocene assemblages from Site 114.

The best developed assemblage, although rare, consists of about 30 to 35 species recovered from a mixture of soft gray and tan mud adhering to the drill bit after the hole was abandoned. Dominant species include *Spongodiscus biconcavus, Spongopyle osculosa, Spongotrochus* sp. cf. *S. glacialis,* and *Stylodictya validispina.* Other species include *Theocalyptra davisiana, Actinomma antarcticum* (Haeckel), *A. medianum* Nigrini, *Actinomma* sp., *Theocorythium trachelium* (Ehrenberg), *Phorticium pylonium* (Haeckel?) Cleve, *Dictyophimus gracilipes* Bailey, *Cornutella profunda* Ehrenberg, *Euchitonia* spp., *Spongocore puella* Haeckel, *Lamprocyclas Heteroporos* Hays, *Peripyramis circumtexta* Haeckel, and *Helotholus histricosa* Joergensen.

ESTIMATED RATES OF SEDIMENTATION

With the assumption that the base of the *G. oceanica* Zone lies at 0.8 million years and that Core 8 is at the bottom of this zone, we obtain a minimum rate of sedimentation of 27 cm/1000 yrs (Figure 7). This is an exceedingly high rate for a deep sea sediment. The sediment lithology explains this, however: turbidites with volcanic material, the pelagic part probably being less than 1 per cent.

The probable lack of cores representative of the succession at this site and the rapidly varying sediment density preclude the application of any realistic natural consolidation correction to the sedimentation rate.

DISCUSSION

A discontinuous sequence of indurated volcanic sandstones of Pleistocene age was cored, down to a depth of 228 meters. Eight cores were taken, which yielded a total of 11.3 meters of 55 meters of cored section. The site is located in the deeper part of the Iceland Basin between the

FAUNA (degrees latitude → N)	50°	54	57	59	60°
Hastigerina pelagica				/	
Orbulina universa				/	
Hastigerina siphonifera				/	/
Sphaeroidinella dehiscens	/				
Globigerina dutertrei	/			/	
G. bulloides	●	●	○	●	●
G. pachyderma	●	●	●	○	○
Globorotalia inflata	○	○	○	○	○
Gt. crassaformis			/	/	/
Gt. scitula	/			/	/
Gt. hirsuta	/			/	
Gt. truncatulinoides	/			/	
Gt. menardii	/				
TOTAL NUMBER OF SPECIES	9	3	4	11	6
SITE	111	112	113	115	114

/ = Rare ○ = Common ● = Abundant

Figure 6. *Planktonic foraminiferal species found in the Pleistocene at Sites 111-115. Despite its high latitude faunal diversity is significantly higher at Site 115 than at the others.*

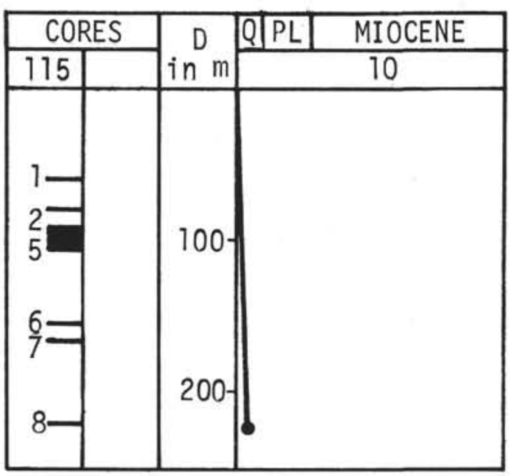

Figure 7. *Coccolith age vs. depth at Site 115.*

Reykjanes Ridge crest and Rockall Plateau, 65 kilometers from the base of the scarp west of Hatton Bank. A major objective of the site had been the age determination of two prominent reflectors which appear on the seismic profile records at approximately 0.3 and 0.8 second, and dating of the basement by means of the oldest sediments—and thus to check the age of Anomaly 22. However, the occurrence of the indurated volcanic sandstones at shallow depth prevented penetration to the 0.8 second reflector and to the basement, so that these objectives were not achieved. No Tertiary sediments were recovered and, therefore, no data were obtained on the onset of glaciation. The hole was terminated at 228 meters due to drilling difficulties and so no information was obtained on the age of the oldest sediments or of the age of the basement. The nature of the upper reflecting horizons was, however, discovered and the interesting sequences of turbidites of volcanogenic sandstones were revealed.

Extent and Origin of the Sandstone Beds

The petrological and lithological descriptions of the sandstones have shown that they are the product of submarine or subglacial volcanic eruptions providing a source of hyaloclastic glassy basalts. The good sorting, graded bedding and internal stratification of individual layers suggest that the sediments have been deposited by a turbidity current mechanism. Induration has occurred subsequent to deposition.

Some evidence can be obtained from the geophysical data on the lateral extent of the turbidite sandstones. The high reflectivity of the indurated layers at about 0.1 second prevents the penetration of much acoustic energy to the deeper layers, except at the low frequency (30 Hz) used in the *Discovery*-29 seismic profile. The layers act therefore as an acoustic screen obscuring the deeper sediment horizons which almost certainly exist, since the top 200 meters are all Quaternary in age. The westward limit of the beds is well determined by the three seismic profiles of *Glomar Challenger*-12, *Discovery*-29 (Figure 2) and *Vema*-27 (Figure 8) west of which deeper reflecting horizons can be seen. This boundary follows closely the 1550 fathom contour, and probably represents the extent of ponding of the turbidites against the older east flank of the Gardar Ridge, of which the bulk of sediments were laid down prior to the Pleistocene turbidites. The eastern limit of the ponding is the base of the western scarp of Rockall Plateau.

There is no precise information about the southern limit. A *Vema*-27 profile at 56.25°N does not show the sandstone beds. However some data may be deduced from the shape of the profile of the Maury mid-ocean canyon. On the *Glomar Challenger*-12 profile, and more clearly on the *Vema*-27 profile, it can be seen that the canyon here is very wide (30 kilometers), and that the floor of the canyon is the top of the indurated sandstone. This wide profile is also indicated in the bathymetry in Figure 1, and in more detail

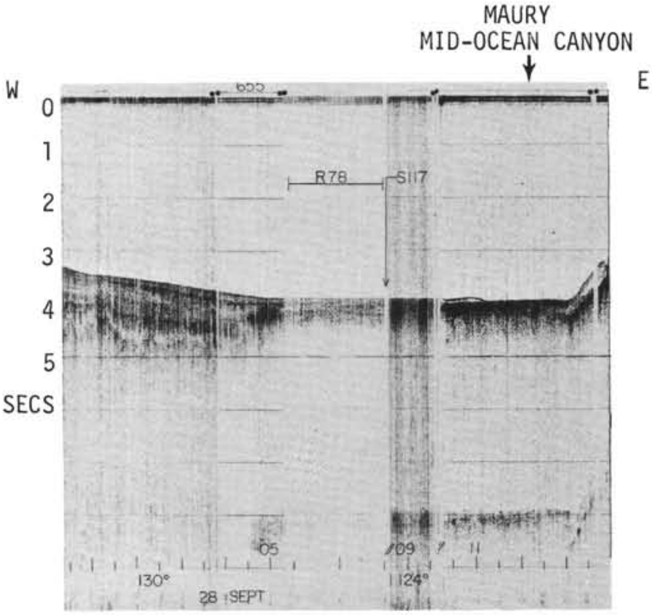

Figure 8. *Seismic reflection profile from* Vema-*27 southwest of Site 115.*

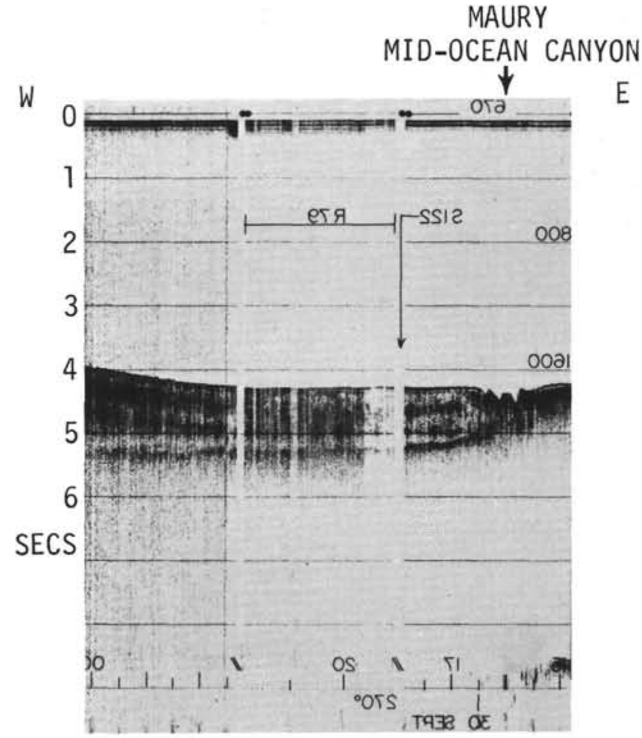

Figure 9. *Seismic reflection profile from* Vema-*27 at 56.25°N.*

in the bathymetric chart contoured at 20-fathom intervals in Figure 3 of Johnson and Schneider (1969). North and south of the region between 59° and 57.5°N, the canyon is much narrower and V-shaped (Figure 9). Johnson, Vogt and Schneider (1971) speculate that the canyon was formed as a result of Norwegian Sea overflow water from the Faroe Channel during times of lower sea level, and that it may be a fossil feature being steadily filled by sediments from the Gardar Ridge. Against this view is the evident continuity of the canyon and the lack of sediment infill over the Pleistocene sandstones. We suggest that the widening between 59° and 57.5°N is the result of the inability of the flow through the canyon to erode into the hard sandstone layers and the consequent lateral spreading. To the north, the sediment above the layer is either thicker, or the layer is absent. To the south, the V-profile is resumed at 57.5°N, either because the ponded turbidites were confined here, or because the canyon has cut back into the southern edge of the turbidites. In either case, the southern edge must lie between 57.5° and 56°N where the *Vema*-27 profile shows the layer to be absent.

It is not clear what barrier provided the southern limit to the turbidity currents since there is no obvious E-W ridge. It is possible that the eastward bulge of the east side of the Gardar Ridge at 57.5°N provided a basin during the Pleistocene and that it has been broached subsequently. No such basin exists in the present day topography.

The source of the volcanic rocks in the sandstones is discussed above by Walker. The age of the volcanic glass, judged from the degree of palagonitization, the nature of the hyaloclastites and the topography of the Iceland Basin as a control on transport paths, all point to Iceland as the provenance. Volcanic eruptions were especially frequent under the ice sheet during the glacial period, generating glacier floods or *jökulhlaups* carrying large quantities of hyaloclastics. These eventually debauch onto the continental shelf and could traverse it as turbidity currents. Two prominent submarine canyons (Figure 10) at 18.5°W and 20°W, possibly cut by earlier turbidity currents, could provide the path for them into the Iceland Basin.

A seismic profile of *Vema*-27 (A-B in Figure 10) illustrated in Figure 11 shows the thick sediments associated with the northern end of the Gardar Ridge. An interesting feature of this record is the apparent blanketing of deep reflections in the central part where there is no evidence of the basement rising to the sea bed. It is possible that here also acoustically opaque sandstones have been deposited on top of the Gardar Ridge sediments in the slight depression in the profile, a depression that is reflected also in the 1000-fathom contour northwest of the section. Sediments from the southwestern end of the Iceland shelf might travel this way.

The mean sedimentation rate in Hole 115 is 27 cm/1000 yrs. Out of 55 meters cored, only 9.3 meters of sediment were recovered, and these were the harder layers which were not washed out by the high water pressures required to drill the hole. The softer material then represents at least 80 per cent of the section, even if the parts of the hole not cored contained the same percentage of hard sediment. The high sedimentation rate applies to the entire hole and suggests therefore that most of the softer unsampled sediment must have been derived from turbidity currents. If these sediments are also volcanogenic, then they probably comprise the finer fraction of the turbidites which do not have the necessary conditions for induration.

The start of the glacial period was 3 million years ago (compare with results of Site 111); if it is assumed that the mean sedimentation rate of 27 cm/1000 yrs was constant during glaciation, the glacial/preglacial boundary would be

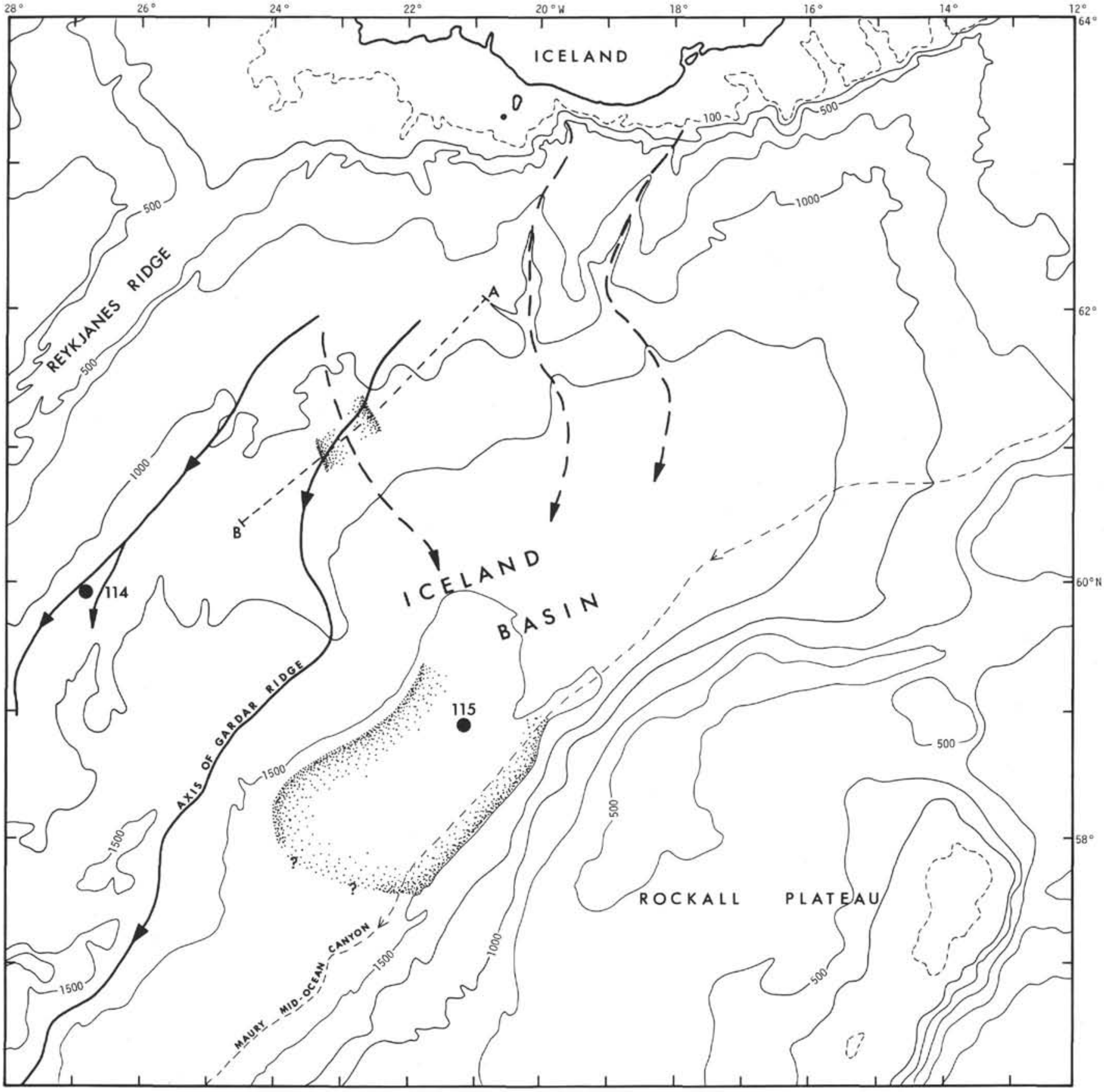

Figure 10. *Paths of sediment transport into the basin between Reykjanes Ridge and Rockall Plateau.*

at 800 meters (1.0 second assuming a velocity of 1.6 km/sec). It is probable that turbidity currents were most active during the glacial period when lowered sea level enabled more active erosion to take place on the coast and shelf of Iceland and when the widespread ice conditions gave rise to frequent *jökulhlaups.*

However, the processed seismic record of *Discovery*-29 suggests that the turbidite beds are confined to the top 300 meters of the section implying a considerably reduced sedimentation rate in the early part of the glacial period. If the irregular reflectors at 1.0 second (say 900 meters), lying beneath the horizontal reflector at 0.8 second (Figure 2), represent basement of an age appropriate to Anomaly 22 (56 million years), then a mean sedimentation rate of 1.1 cm/1000 yrs must have persisted throughout the Tertiary.

In conclusion, the indurated volcanogenic sandstones and the softer intervening clays were derived from Quaternary volcanic activity in Southern Iceland, crossing the shelf and traveling down the submarine canyons as mud flows or turbidity currents, and finally ponding and depositing in the Iceland Basin. Chemical induration of the lower parts of the turbidites took place *in situ.*

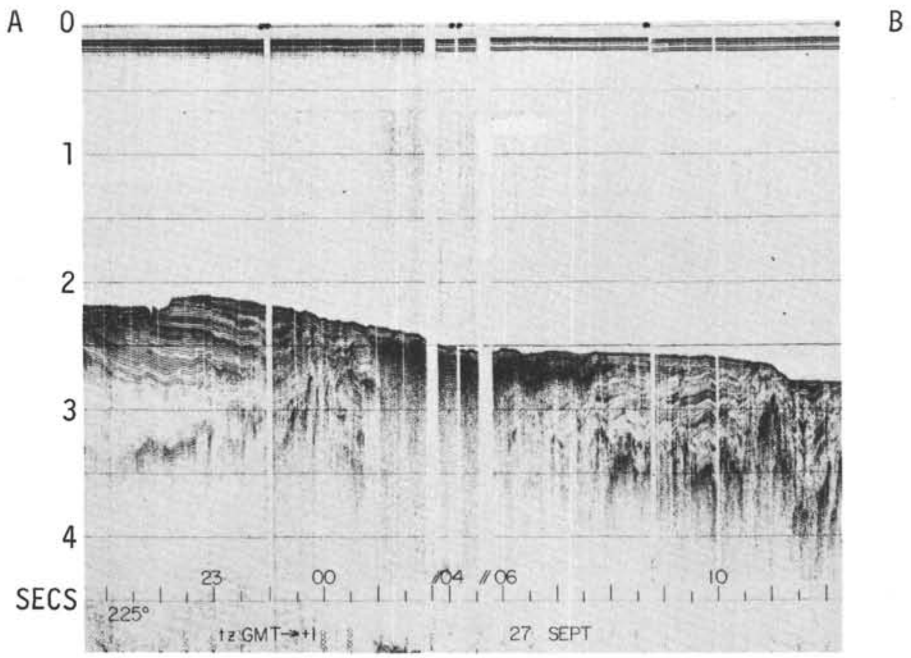

Figure 11. *Section of seismic profile by* Vema-*27 along north part of the Gardar Ridge showing possible masking of deep reflections by high reflectivity layer.*

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APPENDIX A. SHIPBOARD SMEAR SLIDE OBSERVATIONS

Site	Core	Section	Interval (cm)	Sand	Silt	Clay	Quartz	Feldspar	Pyroxene	Chlorite	Dark Mica	Light Mica	Dark Glass	Light Glass	Palagonite	Glauconite	Phosphorous	Pyrite	Authigenic Carbonate	Barite	Phillipsite	Other Zeolites	Micronodules	Other Minerals	Abundance	Estimated Carbonates	Foraminifera	Calcareous Nannofossils	Diatoms	Radiolaria	Sponge Spicules	Plant Debris	Fish Debris	Lithology and Comments
115	1	CC		C	R	D	C	R						A				C				R		X		10	R	R						Sandy clay; glass has wavy extinction; mollusc shells are bored; other minerals-?dolomite (R), heavy mins (C).
115	1	CC		Ċ	A	D	C	C	R	C			R	R	R			C	C							20	A	A						Gray silty clay; rich in planktonic foraminifera.
115	1	1	10	C	D	R	R	C	R	C				C	C			R	R			A				30	D	R						Gray sandy silt; volcanogenic material; pseudomorphs of zeolites after albite.
115	1	1	40		R	D	R	C	R	A				R				C	C			C						R						Gray volcanogenic clay; many pseudomorphs of chlorite after feldspar.
115	1	1	80	D	A	C	R	C	C	A				R	D			C	R			C				10	C							Volcanogenic silty sand.
115	1	1	86																			D												Zeolite vein.
115	1	1	93	D	A	R		C	C	A			D	R	A							R					R							Fine grained silty volcanogenic sandstone with chlorite matrix; chloritization of foraminifera tests observed.
115	1	1	120				R	C	C				D														R							Fine grained silty volcanogenic sandstone; chlorite matrix.
115	1	1	140	D	A	R	R	C	R	C			C	A	A			C	R								R							Same as above; arenaceous foraminifera.
115	CB																					D												Acicular zeolite from vein.
115	2	CC		A	A	C	R	A	A				C	C	A			C																Sandy volcanogenic silt.
115	4	2	18		C	D	R	C	R	R				C				C						X				R						Silty montmorillonite clay.
115	4	2	124		A	D	R	C	R	C				C	C							C					R	R						Silty volcanogenic montmorillonite clay.
115	4	2	150	R	D	A	R	C	C	C				C	D			C				C				5	C	R			R			Silty volcanogenic clay.
115	5	1		R	A	A	R	C	R	C			R	R	A			R				A					C	R						Silty volcanogenic clay.
115	7	1	75	R	A	A		C	R	C				C	R			R	R			A				5	C	D						Clayey volcanogenic silt.
115	CB			R	A	D		C	R	C					R	R		R	C			C				20	R	D						Marly volcanogenic clay.
115	Cuttings			R	A	D		C	R	C					R	R		R	C			C				20	R	D						Sandstone and zeolite fragments.

D = Dominant, 65+%; A = Abundant, 41%-65%; C = Common, 16%-40%; R = Rare, 0%-15%.

APPENDIX B. LISTS OF SELECTED PLANKTONIC AND BENTHONIC FORAMINIFERA AND AGE DETERMINATIONS

W. A. Berggren

Hole 115

Sample 12-115-1-1, 66-68 cm:
PF: *Globigerina pachyderma* (predominantly sinistral), *G. bulloides, Globorotalia inflata, G. scitula, G. crassaformis, Orbulina universa, Hastigerina siphonifera.*
BF: Sparse, *Gyroidina* sp., *Cibicides,* sp., *Planulina* sp., *Pyrgo* sp.
Also present: Sponge spicules, volcanic ash, ostracods.
Age: Pleistocene.

Sample 12-115-1, Core Catcher:
Data same as for preceding sample above.
BF: *Pyrgo,* sp., *Planulina bradii, Paromalina* sp., *Pullenia bulloides, Eponides* sp.

Sample 12-115-2, Core Catcher:
PF: Fauna very sparse, including *Globigerina bulloides, Globorotalia inflata.*
BF: Extremely sparse, *Pullenia subcarinata, Elphidium* sp.
Also present: Volcanic ash.
Age: Pleistocene.

Sample 12-115-3, Water Sample:
PF: *Globigerina bulloides, G. pachyderma, Globorotalia inflata.*
BF: Sparse.
Also present: Volcanic ash.
Age: Pleistocene.

Sample 12-115-Center Bit, 67-87 m:
PF: *Globigerina pachyderma, G. bulloides, Globorotalia inflata, G. crassaformis, G. scitula, G. hirsuta, Hastigerina siphonifera, H. pelagica.*
BF: *Pyrgo murrhyna, P.* cf. *laevis, Planulina bradii, Gyroidina neosoldanii, Hoeglundina elegans, Rhabdammina* sp., *Bigenerina cylindrica, Karreriella bradyi.*
Age: Pleistocene.
Note: This center bit sample contains a composite fauna representative of the interval from 67 to 87 meters. It contains abundant and well-preserved specimens of several benthonic species, particularly *Hoeglundina* and *Pyrgo.*

Sample 12-115-Center Bit, 115-153 m:
PF: Essentially same as above, plus *G. truncatulinoides, G. dutertrei.*
BF: *Elphidium* sp., *Hoeglundina elegans.*
Also present: Mollusc fragments, ostracods, volcanic ash.
Age: Pleistocene.

Sample 12-115-Center Bit, 162-175 m:
PF: *G. pachyderma* (100% sinistral), *G. bulloides, Globorotalia inflata, G. scitula, G. crassaformia, G. truncatulinoides.*
BF: *Vaginulina* sp., *Planulina* sp., *Pullenia bulloides, Elphidium* sp.
Also present: Volcanic ash.
Age: Pleistocene.
Note: Anomalous growth forms of various planktonic foraminifera present.

Sample 12-115-Center Bit, 180-223 m:
Abundant volcanic glass and ash-silt fragments with *G. pachyderma, G. bulloides, G. scitula* and *G. inflata.*
Age: Pleistocene.

Remarks: The sediments at Site 115 consist of volcanogenic sandstones. Core recovery was poor and most of the samples studies are water samples or center bit samples representing large stratigraphic intervals. The resulting faunal lists indicate the variety of faunal elements occurring in this region but are of little use in detailed biostratigraphic subdivision.

APPENDIX C. COCCOLITH SPECIES AND STRATIGRAPHIC ASSIGNMENT OF SITE 115

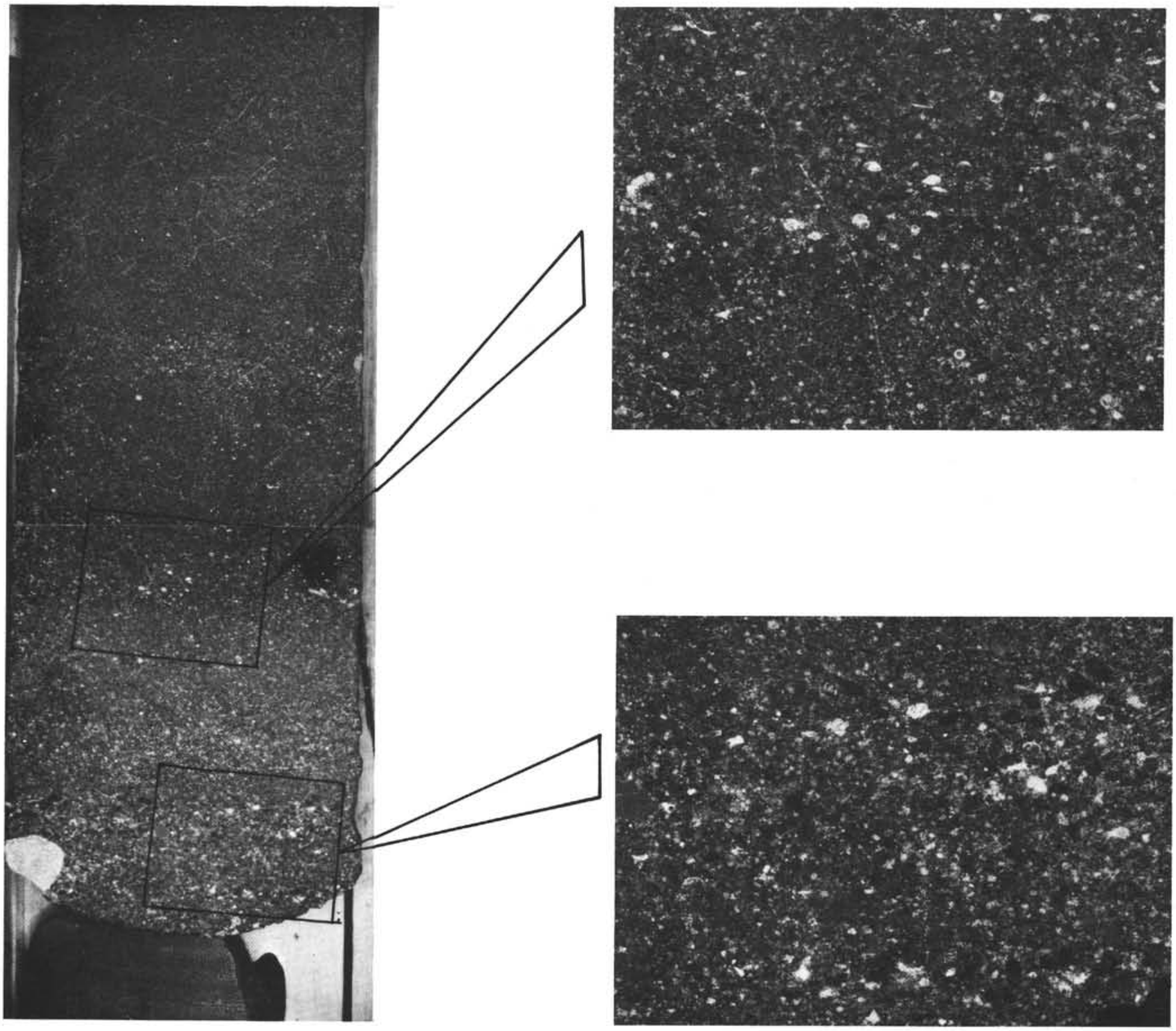
David Bukry

Hole 115

Middle Miocene to Upper Pliocene

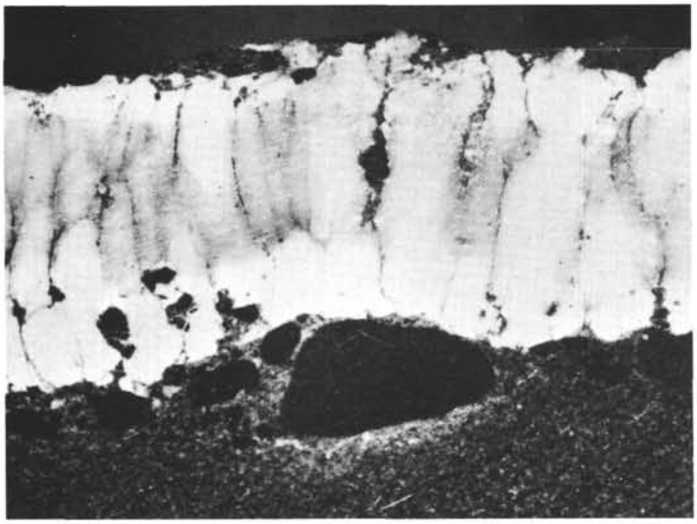
12-115-1-1, 63-64 cm; depth 59 m: [Reworked?]
Coccolithus sp. [small], *Cyclococcolithina macintyrei, Discolithina japonica, Helicopontosphaera kamptneri, Reticulofenestra* sp. cf. *R. pseudoumbilica* [small].

PLATE 1



Core 2, 87-96m., Pleistocene.
Turbidite of volcanic detritus. Coarse base has sharp contact with underlying fine-grained sediment. Details show how foraminifera and other fossils fit in grain size. (Photo J. v. Hinte, courtesy Imperial Oil Enterprises Ltd.)

PLATE 2



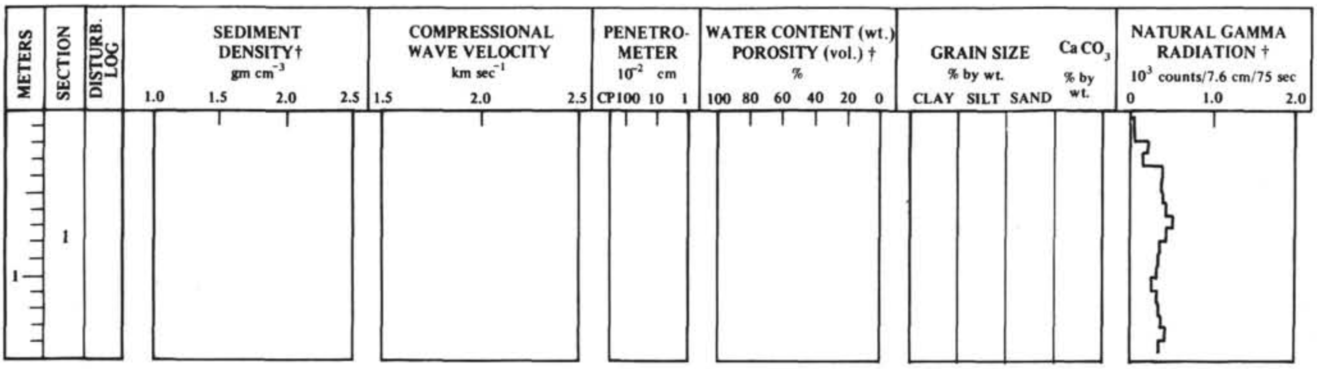
Core 4, 100-107m., Pleistocene.
Section 2, 5-23 cm. Turbidite of volcanic material; clasts with zeolithic vein at base, then coarse with grading, then convolute fine. Below clasts is fine top of other graded bed. Details of vein are X3; Upper one is outside of archive half of core, it shows nicely the large crystals and zoned nature of the vein. (Photo J. v. Hinte, courtesy Imperial Oil Enterprises Ltd.)

PLATE 3

Core 4, Section 2, 110-130 cm.
Graded volcanic sandstone. Coarse base with shale pebbles (Photo J. v. Hinte, courtesy Imperial Oil Enterprises Ltd.)

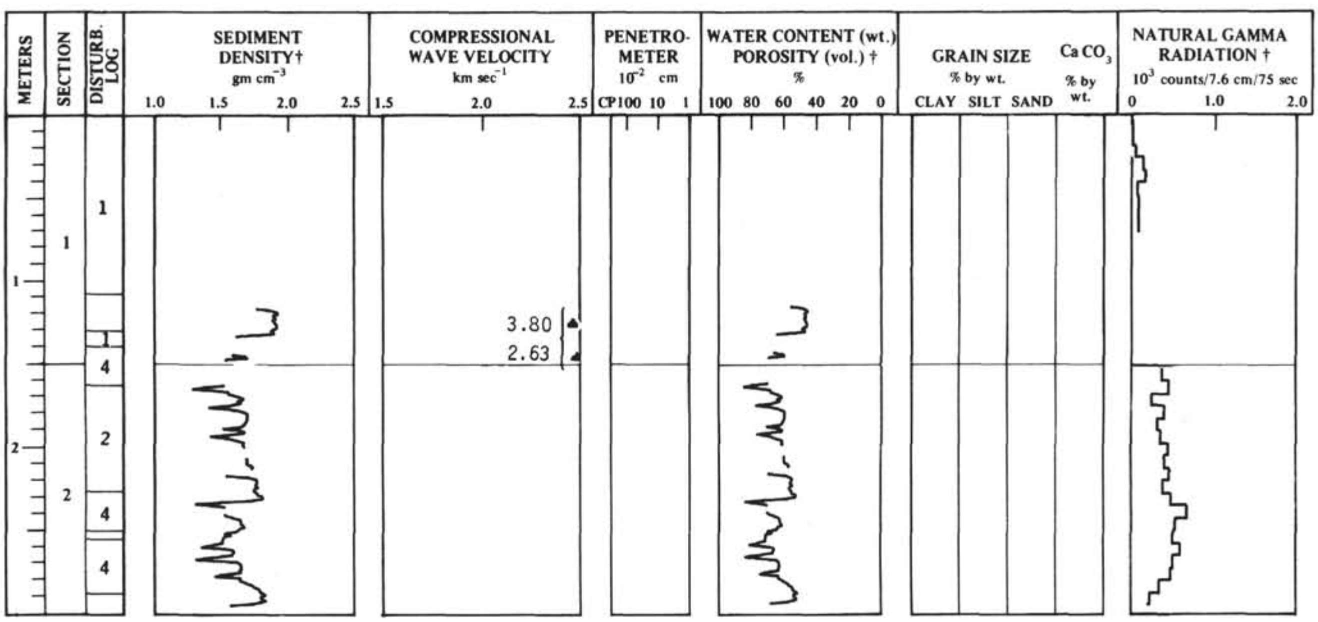
HOLE 115

CORE 1



HOLE 115

CORE 2



†Adjusted data, see Chapter 2

HOLE 115 58 TO 67 m

CORE 1

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		F	5YR2/1 Brownish black volcanic sandy silt with many planktonic foraminifera and some nannoplankton. Estimated carbonate content ~30%.	*Globigerina pachyderma, G. bulloides, Globorotalia inflata, G. scitula, G. crassaformis, Orb. universa*		PLEISTOCENE
				N4 Brownish black sandy volcanic mud with clay pellets, planktonic foraminifera and nannoplankton. Estimated carbonate content ~10%.			
	CC		F N R	Medium dark gray (N4), graded lithified hyaloclastic volcanic sandstone with zeolite vesicles. Planktonic and arenaceous foraminifera, some nannoplankton, and some mollusc shell fragments also present. Core Catcher: Medium gray (N5) soft sandy, silty, clay with abundant foraminifera, nannoplankton and few mollusc shell fragments.	Core Catcher: Fauna similar to above *Coccolithus pelagicus, Cyclococcolithus leptoporus, Helicopontosphaera kamptneri, Syracosphaera* sp., *Pontosphaera discopora, P. scutellum* Radiolarians very rare. *Theocalyptra davisiana.* C.B. Same assemblage. *T. davisiana, Actinomma* sp., *Stylodictya validispina, Ommatodiscus* spp.		

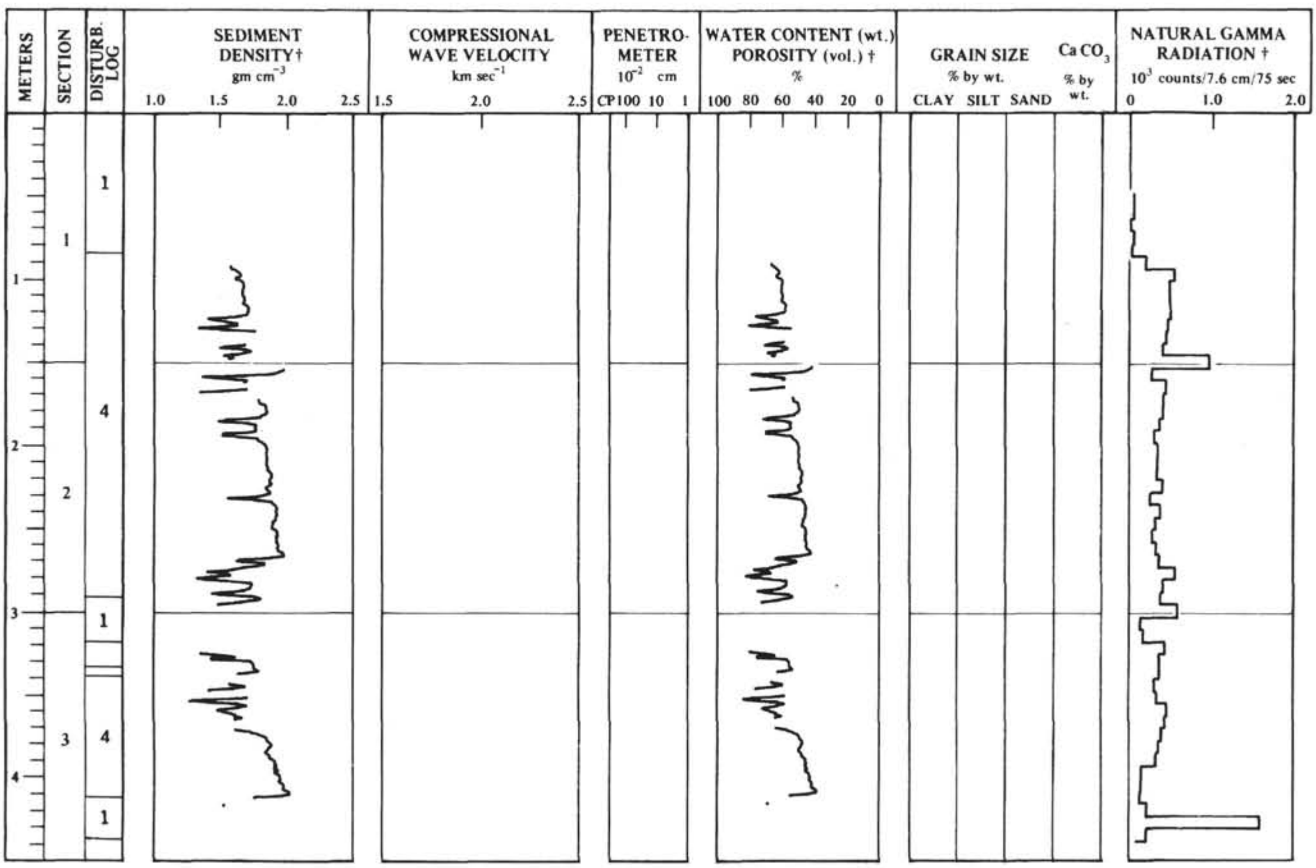
HOLE 115 87 TO 96 m

CORE 2

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1	NO CORE	N		Center bit before coring 2: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Pseudoemiliania lacunosa, Helicopontosphaera kamptneri, H. sellii, Pontosphaera discopora, Syracosphaera* sp., *Gephyrocapsa aperta, G.* cf. *oceanica*	*Gephyrocapsa oceanica?*	PLEISTOCENE
2	2			N4 5Y4/1 5Y2/1 Medium dark gray to olive gray or olive black, indurated hyaloclastic volcanic sandstone. The sediment is graded with parallel and cross bedding at the top of the unit and pebbles up to 16 mm in size at base of the unit. Sandstone contains some zeolitic veins and clusters; few foraminifera.	No radiolarians.		
	CC		R N F	Core Catcher: Gray, indurated sandy volcanic siltstone with abundant plagioclase, pyroxene and palagonite; small amount of volcanic glass.	Core Catcher: *Coccolithus pelagicus, Gephyrocapsa* sp., *Globigerina bulloides, Globorotalia inflata*		

HOLE 115

CORE 4



† Adjusted data, see Chapter 2

HOLE 115 96 **TO** 100 **m**

CORE 3

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
	CC		F N R	N3 Dark gray, indurated, parallel and cross bedded hyaloclastic volcanic sandstone.	Core Catcher: Water: *G. bulloides, G. pachyderma, Globorotalia inflata* Water: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Helicopontosphaera kamptneri, Pontosphaera discopora, Gephyrocapsa* cf *oceanica* Core water: radiolarians rare. *Theocalyptra davisiana*, discoidal and spheroidal spumellarians.	*Gephyrocapsa oceanica?*	PLEISTOCENE

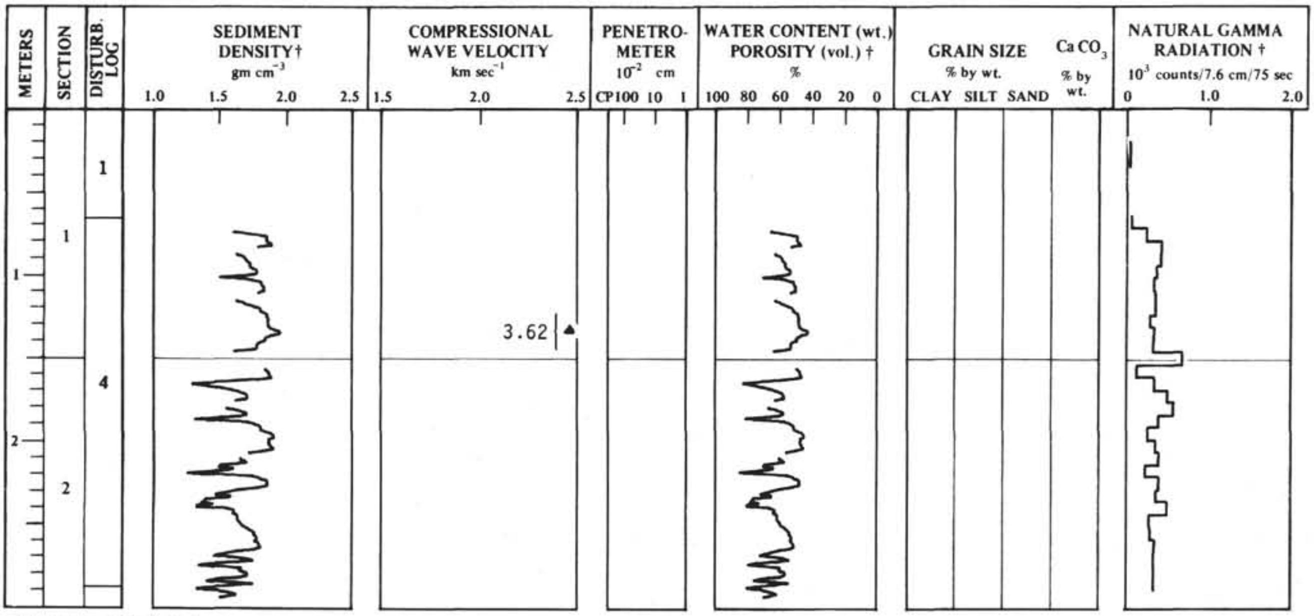
HOLE 115 100 **TO** 107 **m**

CORE 4

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
		NO CORE					
1	1			N5 N4 Medium gray to medium dark gray indurated hyalocastic volcanic sandstone with graded bedding. There are at least 4 graded units, each with a coarse grained basal part and a fine-grained laminated and cross-laminated burrowed upper portion. The contact between units is sharp, generally horizontal, but in one case (unit 4) irregularly inclined and paved with shale pebbles up to 12 mm across. Subhorizontal massive of imbricate zeolite veins or clusters are very common in Sections 1 and 2. Foraminifera and nannoplankton occurrence rare to common. X-ray mineralogy (bulk) Qtz. 6.5 Plag. 42.0 Kaol. 4.5 Aug. 47.0 Amorph. 73.3	Component in graded ash-layer: (turbidite) *Coccolithus pelagicus, Cyclococcolithus leptoporus, Gephyrocapsa* cf. *oceanica, Pontosphaera discopora, Helicopontosphaera kamptneri*		PLEISTOCENE
2	2		XM N				
3, 4	3						
	CC		R N	Core Catcher: Same as above	Core Catcher: Core water: radiolarians rare, assemblage as above. No coccoliths		

HOLE 115

CORE 5



†Adjusted data, see Chapter 2

HOLE 115 107 TO 115 m

CORE 5

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1, 2	1, 2	NO CORE		N4 5YR 2/1 Medium dark gray to brownish black indurated hyaloclastic volcanic sandstone with graded bedding. At least five graded units occur, with clay pellets up to 12mm in size at the base of each unit. Laminations & cross-laminations are quite common, burrows occur at 92-95 cm in Sec. 1, and at 32, 55, 80, & 116 cm, in Sec. 2. Clay pellets as well as sandstone contain some foraminifera and nannoplankton.			
	CC		N	Core Catcher: Same as above	Core Catcher: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Gephyrocapsa aperta, Thoracosphaera sp.*	*Gephyrocapsa oceanica* ?	PLEISTOCENE

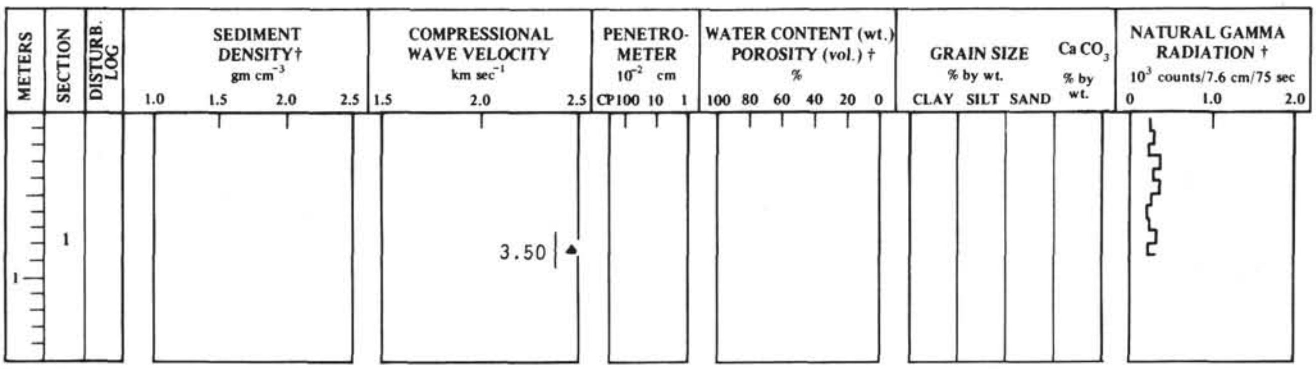
HOLE 115 153 TO 162 m

CORE 6

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1	NO CORE	N	N3 Dark gray, indurated and laminated hyaloclastic volcanic sandstone. Contains a zeolitic vein and some nannoplankton	*Coccolithus pelagicus, Helicopontosphaera kamptneri, H. sellii, Pontosphaera discopora, Gephyrocapsa cf. oceanica*	*Gephyrocapsa oceanica* ?	PLEISTOCENE

HOLE 115

CORE 7



†Adjusted data, see Chapter 2

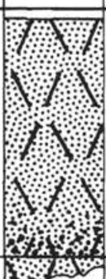
HOLE 115 175 **TO** 180 **m**

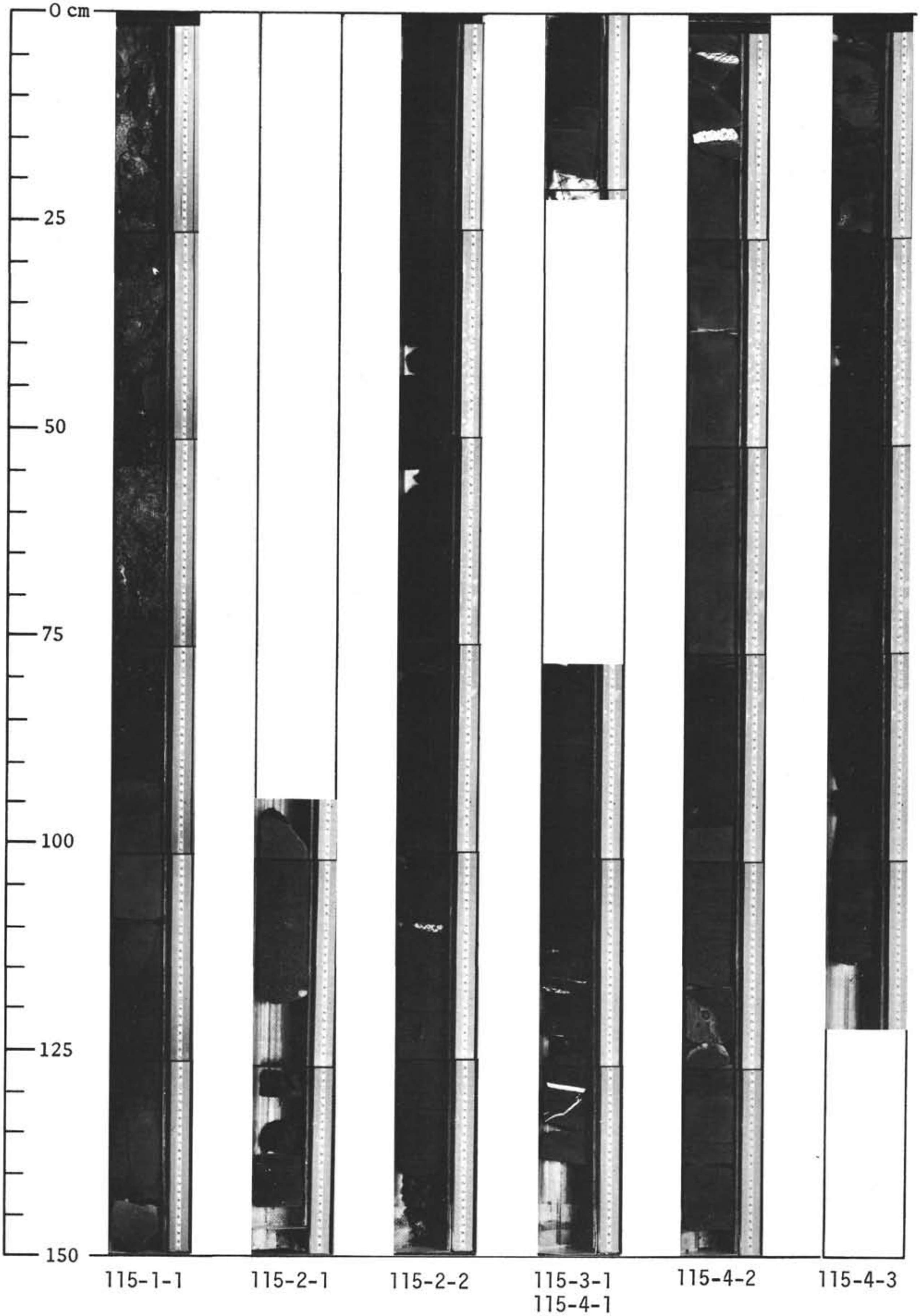
CORE 7

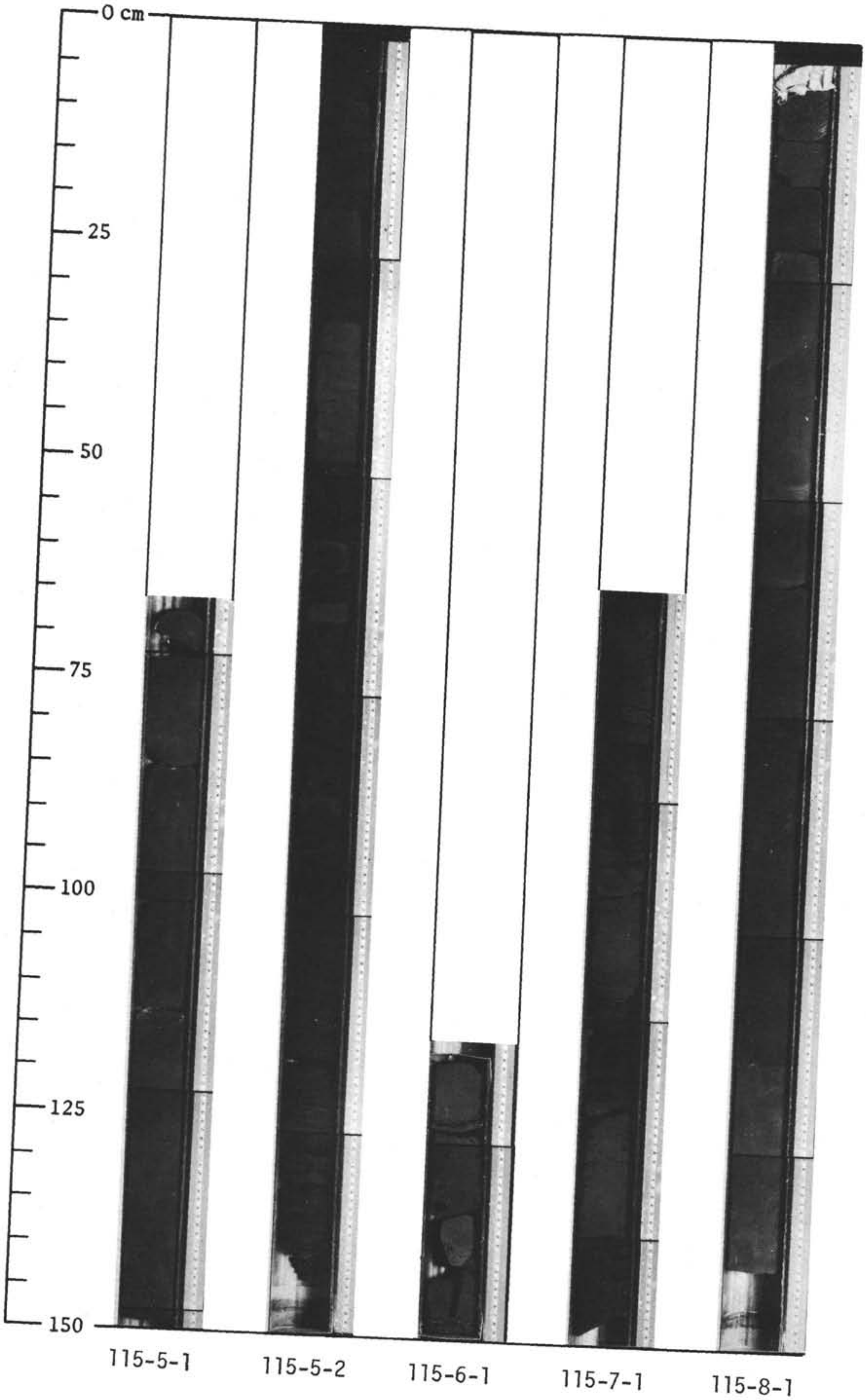
METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
	1		N, R	N3 Dark gray, indurated hyalo-volcanic sandstone. Two graded units occur with lamination and burrowing at the top of the core. Foraminifera and nannoplankton are common.	*Coccolithus pelagicus, Cyclococcolithus leptoporus, Pontosphaera discopora, Syracosphaera sp., Helicopontosphaera kamptneri, Gephyrocapsa* cf. *oceanica* Radiolarians very rare. *Actinomma* sp., *Stylodictya validispina, Heliodiscus asteriscus*	*Gephyrocapsa oceanica* ?	PLEISTOCENE

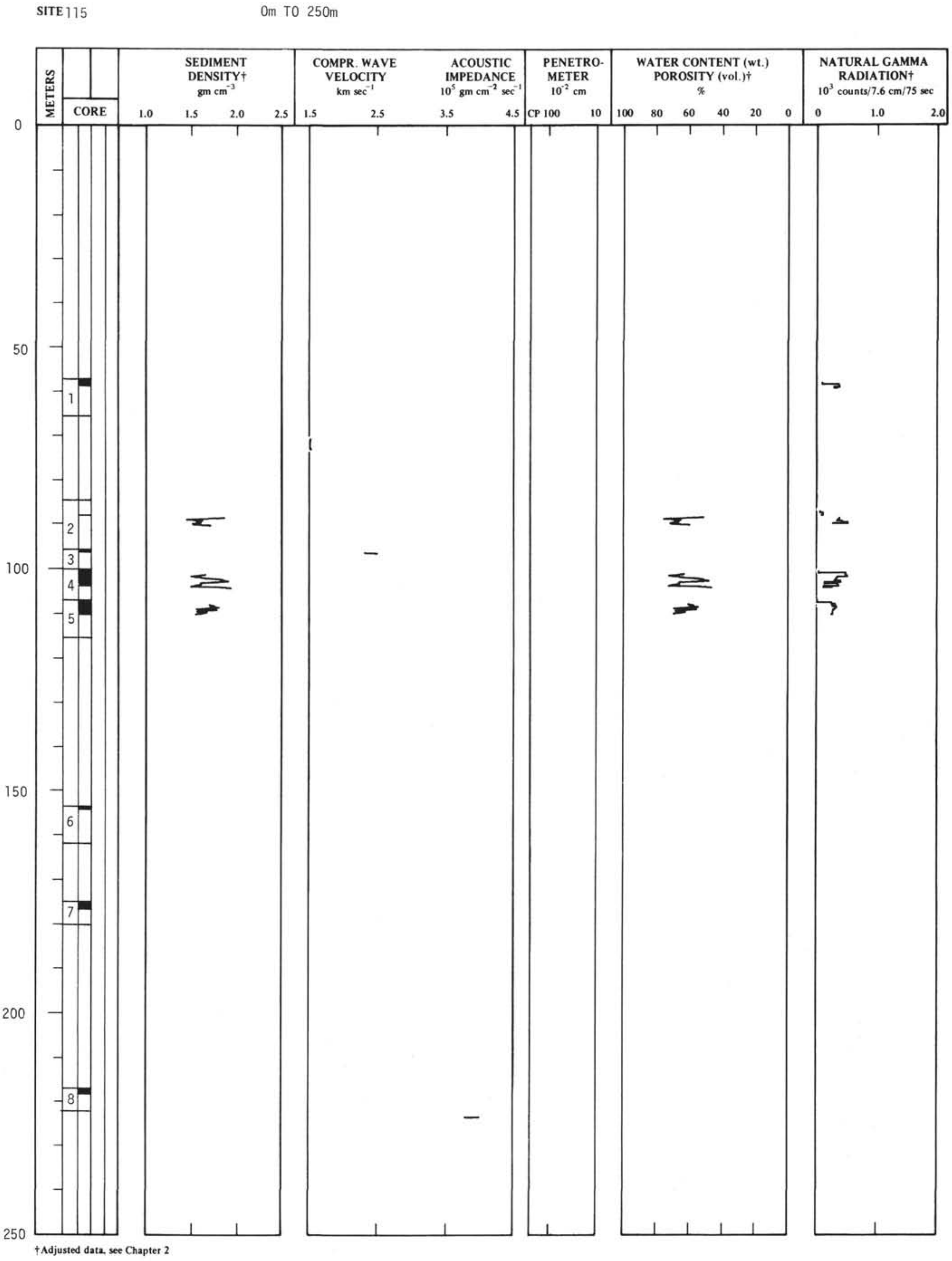
HOLE 115 223 **TO** 228 **m**

CORE 8

METERS	SECTION	LITHOL.	SAMPLES	LITHOLOGY	DIAGNOSTIC FOSSILS	BIO-STRAT.	TIME STRAT.
1	1		N	N3 N2 Dark gray to grayish black indurated, unbedded, hyaloclastic volcanic sandstone. Grain size increases towards top of core. Planktonic foraminifera are rare; nannofossils abundant	Center bit before coring 8: *Coccolithus pelagicus, Pontosphaera discopora, Rhabdolithus* sp., *Helicopontosphaera sellii, Gephyrocapsa* sp. Core Catcher: Drill bit: *Globigerina pachyderma, G. bulloides, Globorotalia scitula, G. inflata* Drill bit: *Coccolithus pelagicus, Cyclococcolithus leptoporus, Helicopontosphaera kamptneri, H. sellii, Syracosphaera* sp. *Rhabdosphaera clavigera, Gephyrocapsa aperta, G.* cf. *oceanica* Drill bit: best developed radiolarian assemblage (see Site 115 radiolarian report).	*Gephyrocapsa oceanica* ?	PLEISTOCENE
	CC		N F R	Core Catcher: Dusky yellow (5Y 6/4) sandy mudstone with abundant nannofossils, common radiolaria & sponge spicules & few foraminifera and diatoms.			

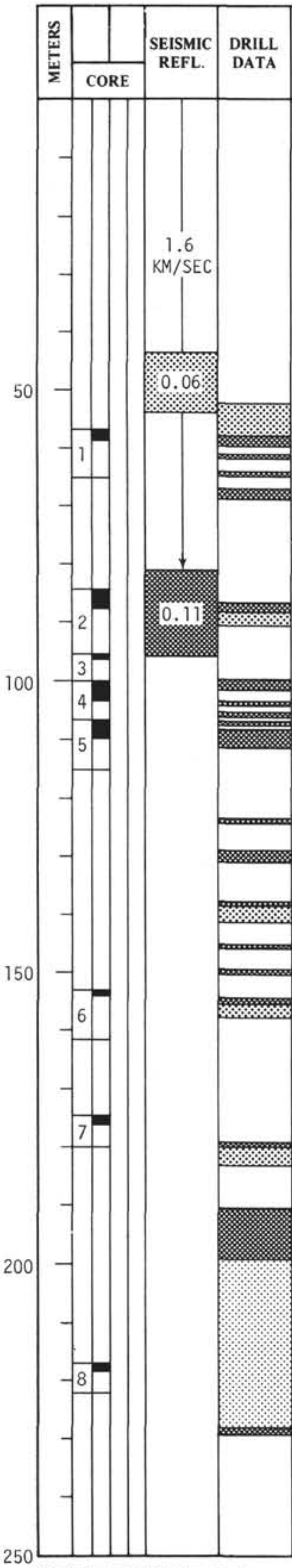

0 cm
25
50
75
100
125
150
115-1-1
115-2-1
115-2-2
115-3-1
115-4-1
115-4-2
115-4-3


0 cm
25
50
75
100
125
150
115-5-1
115-5-2
115-6-1
115-7-1
115-8-1



†Adjusted data, see Chapter 2

SITE 115 0 TO 250 m



LITHOLOGY

Brownish black volcanic sand, silt, and clay, containing much plagioclase, pyroxene, glass, palagonite, some quartz, chlorite, zeolites, coccoliths and foraminifera. Cores are disturbed.

Medium dark gray to browns black, indurated, hyaloclastic volcanic sandstone, with graded bedding. A total of at least 15 graded units each with a coarse-grained homogenous basal part (clay pellets up to 16 mm in size), and a fine-grained laminated or cross bedded upper part, which in many cases is burrowed. The contacts between units are sharp, usually horizontal, but in one case irregular. Zeolite veins and clusters are common.

SED. RATE (cm 10^{-3}y): ≥27

AGE † (m. y.): < .8-

TIME STRATIGRAPHIC SUBDIVISION: UPPER PLEISTOCENE

†See Chapter 2 (explanatory notes)