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MEMORANDUM

Geoenvironmental characterization of selected shallow-water sites on the western European continental shelf (SWAP)

M.D. Max, E. Michelozzi, F. Turgutcan and B. Tonarelli

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Geoenvironmental characterization of selected shallow-water sites on the western European continental shelf (SWAP)

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Executive Summary: The southwestern approaches to the British Isles (SWAP) is historically an area where considerable naval warfare has taken place. It remains a strategically important sea area. The physical and acoustic character of the sea bottom is of importance for naval activities, particularly those involving submarines and mines.

The seabed in the SWAP is unique in the northwestern European continental shelf because it is composed of large areas of rock and sedimentary rock at the seabed, with only a scattered, thin veneer of marine sediment. It is thus quite hard and locally rough, even where feature mapping and bottom sediment maps suggest a softer bottom.

This memorandum presents environmental information from three sites at which SACLANTCEN acoustic experiments took place in the SWAP. Simplified charts of predicted geoacoustic bottom response and general sea bottom morpho-type have been made with reference to non-navy data sets. The basis for predicting acoustic response in shallow water is geoacoustic terrane analysis, a method for extrapolating experimental acoustic response of a variety of geological conditions and attributes from known sites to broader areas.

Our bottom characterization utilized two modes of shallow reflection seismic profiling, side-scan sonar, and bottom and sub-bottom sampling. This characterization in itself does not derive physical and geoacoustic properties, but allows them to be estimated from archive data and refined according to new experiments. Tables of general acoustic and physical property characteristics for the materials found on the SWAP sea bottom, as well as sediment sample analyses, are presented along with figures of side-scan and shallow reflection seismic profiles showing the sub-bottom character to at least 60 m.

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Abstract: Geoenvironmental analyses for four experiment sites on the continental shelf to the west of Britain and the English Channel have utilized two modes of shallow reflection seismic profiling, side-scan sonar, and bottom and sub-bottom sampling to derive environmental information relevant to predicting bottom-acoustic interaction. Because of the geological development of the shelf and the history of sea-level rise and fall over the past 1,000,000 years, and especially over the last 15,000 years, solid rock and sediment materials having very different physical properties and frequency-dependent acoustic response are located at or very close to the sea bottom. Recent sediment is very thin to absent both on the inner and outer shelves, and features characterized as being products of recent sedimentation will respond, at higher frequencies, as solid rock materials. Bottom-acoustic interaction, therefore, is strongly dependent on the type of rock and sediment material in the bottom at any particular place. These have been grouped into a number of geoacoustic terranes, based on their physical properties and some transmission loss data from earlier acoustic experiments, which could be related to individual bottom materials. Acoustic response for individual materials can be expected to remain constant everywhere on this shelf, and thus characterization of response, at a number of selected sites through acoustic experiments, can theoretically be used to predict general response elsewhere where geologic conditions are similar.

Keywords: Southwestern Approaches ∘ bottom properties

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Introduction

Since the aim of this environmental analysis was to aid the positioning and design of experiments by SACLANTCEN, only geoenvironmental elements relevant to these experiments were considered. Two sites were occupied jointly by the Centre's Seafloor Acoustics Group (SAG) (Sites 1, 2 and 3) and Applied Acoustics Group (AAG) (Sites A, B and C). These were sites on the inner shelf over chalk terrane (Max, 1989) (Site 2/C) and on the outer shelf in a sand ridge terrane (Site 1/B) (Fig. 1). In addition AAG occupied another site over chalk terrane nearer the approaches to the English Channel (Site A). AAG occupied a further site to the west of the northwest of Site 3 (Fig. 1) not discussed here.

The areas have been mapped in detail by the Marine Geological Unit of the British Geological Survey. Both rockhead geology (Evans, 1982a; Fletcher and Evans, 1987) and seabed sediment maps (Evans, 1982b; Bradley, 1986) were consulted. Max (1989) compiled a geoacoustic terrane analysis taking into account the published maps and a large number of scientific publications on the area, which dealt with finer-scale bottom environmental information.

The inner areas of the continental shelf to the west of Britain and France are commonly only thinly covered by Recent sediments. Because of the history of sea level rises and falls during the last 100,000 years that were a response to ice cap formation and melting, this shelf has been subjected to subareal, rather than submarine, conditions for much of the time. Most recently, between 12,000 and 9,000 years before present, a major transgression of the sea from a water level low stand near the present edge of the continental shelf at about 160 metres lower than it is now, flooded the continental shelf while strongly eroding it. Much of the continental shelf is very flat and the rocks exposed at or near the seabed are relatively fresh as a result of this recent transgression. The sea bottom tends to be somewhat rougher and shallower over some of the older rock types.

Sediments in this inner continental shelf area consists of thin carbonate-rich sands with a low mud content over a lag gravel layer that was left behind during the transgression. Sediments only rarely exceed 1 m in thickness over the entire area.

Sediment on the outer shelf is thicker, but most of it was deposited during the time of the last sea level rise when large continuous asymmetrical sandwaves were formed. These are now relic features below the general wave base, and different from smaller sandwaves in shallow water that are presently moving in response to sedimentation patterns. These sandwaves were subject to some deflation and erosion as sea level

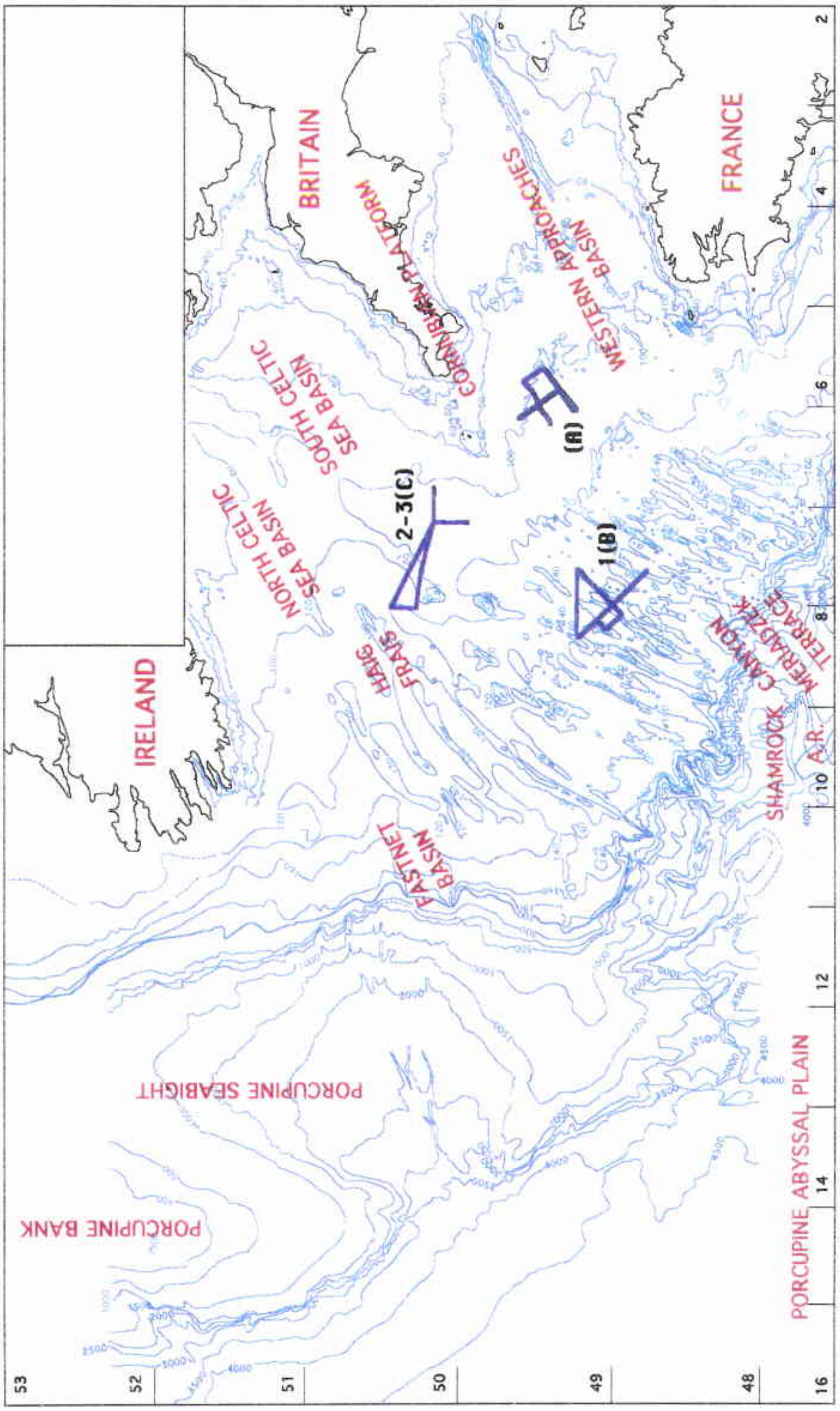

Figure 1 *Generalized bathymetry, location and sites. SAG Sites 1, 2 and 3. AAG Sites A, B and C. Sites 1 (B) and 2–3 (C) jointly occupied. AR, Aegis Ridge.*

rose, but their shape is retained. However, they have a lag gravel surface and locally a thin covering of Recent, finer-grained sediment.

This memorandum presents environmental information from three sites at which SACLANTCEN acoustic experiments took place in the SWAP. Simplified charts of predicted geoacoustic bottom response and general sea bottom morpho-type have been made with reference to non-navy data sets. The basis for predicting acoustic response in shallow water is geoacoustic terrane analysis, a method of extrapolating experimental acoustic response of a variety of geological conditions and attributes from known sites to broader areas.

Our bottom characterization utilized two modes of shallow reflection seismic profiling, side-scan sonar, and bottom and sub-bottom sampling. This characterization in itself does not derive physical and geoacoustic properties, but allows them to be estimated from archive data and refined according to new experiments. Tables of general acoustic and physical property characteristics for the materials found on the SWAP sea bottom, as well as sediment sample analyses, are presented along with figures of side-scan and shallow reflection seismic profiles showing the sub-bottom character to at least 60 m.

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Geology and the terrane setting of the SW Approaches

2.1. REGIONAL GEOLOGY AND GEOPHYSICS

The dominant geological and morphological feature of the area is the boundary between oceanic crust in the deep basins and continental crust in the continental shelf and slopes. This boundary is quite sharp to the west of the Porcupine Bank (Fig. 1), but immediately off the SWAP the boundary is formed from complexly disposed rotated fault blocks and igneous and volcanic rocks (Sibuet et al., 1985). This NW–SE boundary lies along a line of major transform movement, and is associated with irregular wrench and shear faulting and rotation of large continental crustal fragments, in addition to being a zone of extension and subsequent rifting (Masson and Miles, 1986). The shelf break to the southern Porcupine Seabight embayment, however, is geologically a more straight-forward faulted boundary with extensional (spreading?) tectonics reactivating older NE–SW Caledonian faults (Lefort and Max, 1984).

The shallow-water shelf of the SWAP contains two major sedimentary basins (Fig. 1); the Celtic Sea Basin and the Western Approaches Basin (Blundell, 1975). The Celtic Sea Basin is divided into a northern and southern part, with a possibly related narrow basin between Haig Fras and the Cornubian platform of southwest Britain (Fig. 1). The Western Approaches Basin is larger and broader (Whitbread, 1975), with no internal compartmentation bringing pre-basinal rocks to near the surface. The marginal and internal character of the basins are well known from commercial exploration, institute and university research (Hersey and Whittard, 1966).

Some of the ENE–WSW trending gravity lows (Fig. 6) are related to granite batholiths that extend southwestwards from the Cornish Peninsula and through Haig Fras. These are intruded into a basement ridge that separates the two major sedimentary basins. Other gravity lows of similar trend relate to sediment filled troughs, confirmed from seismic surveys (Naylor and Shannon, 1982; Edwards, 1984; Max and Lefort, 1984).

The magnetic signature of the Celtic Sea Basins is subdued, except in the vicinity of the Fastnet Basin where volcanic rocks occur near the surface. This basin is at the intersection of failed rift/transforms in the southern Porcupine Seabight and the unrifted crust (Lefort and Max, 1984) where shallowly-buried volcanics are common. High level magnetic Jurassic igneous rocks occur in the central Fastnet Basin (Caston et al., 1981). Volcanics and/or intrusive rocks at the surface, or at least at a high structural level, in the Western Approaches Basin are probably responsible for the

Table 1 *Simplified geological and absolute ages important in the SWAP. Date shown in Absolute Age column is the beginning of the interval (after Haq and van Eysinga, 1987)*

Geological ages			Absolute ages
Present		Recent	0
	Quaternary	Holocene	10,000 ybp
Cenozoic	Quaternary	Pleistocene	1.7 Mybp
	Neogene	Pliocene	5 Mybp
		Miocene	25 Mybp
	Paleogene	Oligocene	35 Mybp
		Eocene	54 Mybp
		Paleocene	65 Mybp
Mesozoic	Cretaceous		140 Mybp
	Jurassic		210 Mybp
	Triassic		250 Mybp
Paleozoic and Older			Older

relatively high frequency magnetic signature. Magnetic intrusive or volcanic rocks would also seem to be common to the north from the northern side of the western termination of the northern Celtic Sea Basin where it forms the eastern margin of the Porcupine Seabight.

2.2. GEOLOGICAL AGES OF MATERIALS RELEVANT TO THE CHARACTERIZATION OF THIS AREA

The geological time scale is a shorthand for describing the relative ages of rocks and sediments using a series of named intervals which succeed each other and are each divided into shorter intervals. The absolute ages, in terms of years before present (ybp) or millions of years before present (Mybp) are now known with precision owing to detailed isotopic age dating using a variety of different parent and daughter radionucleides. Table 1 explains the geological age terms used in this report.

2.3. CONFIGURATION OF THE BASINS

The Hercynian orogeny, which was primarily a plate collision event, took place in late Carboniferous to early Permian times in NW Europe (Weber, 1984). The trend of strike of the Hercynian structures is about E–W in a gentle arc passing from northern France through Britain and into Ireland (Max and Lefort, 1984; ECORS, 1985). The trend of structures from earlier tectonic events within the Hercynides are close to the trend of the Hercynian structures. This tectonism immediately preceded the widespread extension of the Laurasian (North American–Baltic) super continent that was the immediate cause of formation of sedimentary basins in the SWAP as well as elsewhere in the region.

The basins of the Western Approaches are fault-bounded troughs that were largely formed during pre-Upper Cretaceous, the upper crust deformed by faulting and the lower crust by ductile extension and thinning. Thick sedimentary successions of Permo-Triassic through Lower Cretaceous were deposited in the basins (Fig. 8) while the Moho rose beneath the basin floors, driven by isostatic compensation (Masson et al., 1985). The SWAP basins have probably formed in part by reactivation of Lower Paleozoic faults. Upper Cretaceous sediments cover a highly faulted sequence and are themselves not highly faulted (Naylor and Shannon, 1982).

NW–SE trending faults were active from Permian–Triassic times (Lefort and Max, 1984) and were both normal and dextral wrench. These transverse to basin faults were active during the late Mesozoic rifting of this margin and are trend-parallel to the Biscay–Labrador shear zone that helped configure the present continental margin of the French shelf, the SWAP, and the southwestern margin of the Porcupine Seabight.

At the margin of the continental crust, some large scale displacements may be as young as Eocene (Sibuet et al., 1984). They may be listric in form (Roberts et al., 1981), and similar to the smaller cuspate faults higher in the continental slope that expose bedrock.

The northern margin of the Celtic Sea Basin (Fig. 1) is a reactivation of the important Menai Straits Line (Max et al., 1983). The southern margin of the southern Celtic Sea Basin, which carries into the Bristol estuary, is probably an important Variscan structural zone or deep thrust front (Gardiner and Sheridan, 1981; Sibuet et al., 1985).

The southern side of the Western Approaches Basin is a fault in the acoustic basement that is steeper than the faults along the northern margin (Avedik, 1975). This geometry is regarded by Lefort and Bardy (in press) as representing reactivation of an older Hercynian thrust decollement. This asymmetric geometry is characteristic in the half-graben basins of northwestern Europe, in which it has been demonstrated from deep seismics, that there is a relationship between steep basin margin faults and subjacent, older crustal structure.

The detailed geology and tectonics of the northern part of the western end of the English Channel (Bouysse et al., 1975) show a complex of tight to open folds disposed among two main sets of NE–SW faults, some of which have reverse throw reflecting early Tertiary (Alpine) overtightening. In the central part of the channel structures tighten and faults become the controlling structures (Eden et al., 1971; Naylor and Mounteney, 1975; Boillot and Musellec, 1975; Hamilton, 1979).

3

Sea bottom elements

3.1. SEDIMENTS IN THE BASINS

All the basins contain sediments of Permian and younger ages, deposited since the closing stages of the Hercynian orogeny. These sediments occur in their most complete sequences within the sedimentary basins, although thinned or broken successions of the sediments occur broadly over the continental shelves and much of the present land area. Although complex stratigraphic relationships occur broadly across the one-time shelf, which extended from southwest of its present margin to the Baltic, the character of the sedimentary successions within the SWAP remains relatively consistent (Robinson et al., 1981; Ziegler, 1981; Naylor and Shannon, 1982). For instance, the character of the chalk in the Upper Cretaceous is similar throughout the SWAP, subaerial exposures, and southwestern North Sea, with a change to a muddier, deeper water facies sediment in the vicinity of the northeastern North Sea.

Within the Celtic Sea and Western Approaches Basins, often beneath a relatively thick chalk cover, is a sequence of Lower Cretaceous sediments of deltaic character overlying Jurassic and Triassic beds containing evaporite (salt-gypsum-anhydrite-carbonate) beds that locally have developed restricted diapiric structures. Some of the other, smaller basins may not have this horizon. The evaporites occur near the bases of the sedimentary basins (Naylor and Shannon, 1982). Diapirs do not reach near to the surface in the SWAP, and would have little effect here on acoustic energy interacting with the bottom.

The rocks of Permo–Triassic through Lower Cretaceous age have a generally laminated structure, with higher and lower velocity rocks interbanded. Individual units are anisotropic with respect to acoustic transmission, but beds and formations may not be anisotropic in the same directions or to the same extent. Small differences in anisotropy may not be a critical factor where the rocks outcrop, however, as they are all of sufficient velocity to reflect most of the sound at the seabed. Their navy usefulness may be related to the particular way in which they reflect sound.

From the cessation of active basin formation and crustal rebound marked by the unconformity at the base of the Upper Cretaceous, the basins were no longer deepening. Crustal extension had ceased and the basins began to simply fill up to the common level of the continental shelf. Thickness changes of sediments during this period of filling vary somewhat because of the impact of different sources of supply, global climate, water level variation, and the nature and temperature of the water. The Upper Cretaceous chalks formed broadly in the shelf seas, having somewhat thicker beds in basinal areas. Cretaceous sediments in facies with the shelf chalks also formed in restricted areas on the inner shelf and broadly along the outer shelf. Otherwise terrigenous sediments dominated the sediments deposited across this broad shelf for the remaining time interval to present, with the exception of some thin intervals of Tertiary limy sediments.

3.2. CHALK AND ITS SIGNIFICANCE

Chalk is a rock and stratigraphic term for calcareous geological strata of Upper Cretaceous age. Chalk is a limestone rock composed of soft, pure, earthy, fine-textures, usually white to light gray or buff limestone of shallow water marine origin. It consists almost wholly of calcite, formed mainly by accumulation of calcareous tests of pelagic (living in the water column) microorganisms and algae set in a generally massive matrix of very finely crystalline calcite (some of which may be chemically precipitated). Chalk was probably formed originally as calcite, rather than as less stable aragonite (also calcium carbonate but crystallizing in a different crystal system) as may commonly be the case in normal limestones. Owing to the inherent stability of calcite, recrystallization during burial did not take place and thus the chalk does not have the hard, dense character of normal limestones. Amorphous silica (cherts), including the variety 'flint', is common in discontinuous bands and lenses in the chalks of NW Europe.

Chalk is characterized by its porous, somewhat friable, and unindurated character (Gary et al., 1972) that may also contain many unannealed microfractures (Watts, 1983). Porosity in chalk varies from 38–48% (permeability of 4–13 millidarcy) in chalk that has not been subjected to deep burial and from 15–30% (0.1–1 millidarcy) (Hancock and Scholle, 1975; Watts, 1983). Young's modulus for chalk is around 1.79×10^5 psi (1,234 MPa) although very soft chalks may attain values as low as 2.5×10^3 (17.2 MPa). Because of the sponge-like texture of the low density rock (it is composed of solid calcite, $d = 2.72$, but in a highly porous crystalline structure) and its generally few internal structures, chalk has an abnormally high acoustic attenuation. Seafloor rocks that have very low acoustic return on side-scan sonargraphs are often suspected of being chalk (Caston and Max, 1978). In addition, the persistence of higher acoustic velocity cherts in the chalk causes scattering of acoustic energy. Chalk can be one of the finest naturally occurring absorbers of acoustic energy at low frequencies (Ellis and Chapman, 1985), and many of the petroleum traps hidden beneath chalk in the northwestern European sedimentary basins have proven difficult to resolve because of abnormal acoustic attenuation. [1]

[1] Marathon Oil Company, British Petroleum, personal communication to MDM.

3.3. SEA LEVEL AND ITS EFFECT ON SEDIMENTS AND THEIR PHYSICAL CHARACTER

Probably the most important part of the environmental history of shallow-water continental shelves is that they have all periodically dried when sea level has fallen. Major falls in sea level, at least during the last five million years have been due to the capture of large amounts of water in glaciers and ice caps during ice ages. During these periods, sediment deposited in shallow marine conditions is exposed to subareal conditions, with resulting compaction of the sediments and the replacement of sea water brines by fresh water in interstitial spaces. The change in water chemistry is an important driver of chemical reactions in sediments deposited in chemical equilibrium with sea water. Sediments on continental shelves that dry develop properties more characteristic of dry land sediments and sedimentary rocks. Fine grained and calcareous sediments especially are affected. Although more coarsely grained sands and gravels tend to maintain their porosity because the grain structure is self-supporting, finer grained sands, silts, and especially muds and clays always undergo great compaction upon drying or losing significant water. These fine-grain sediments are only partially grain supported and the grains can always be more tightly packed. Both increased pressures, introduced through burial, and drying or introduction of lighter density pore water, can cause collapse of the marine sediment structure. Marine clays, for instance, are known to compact into one-quarter of their wet volume with normal compaction.

In fact, only the latest Pleistocene and Holocene (younger than about 15,000 years) sediments on most continental shelves world-wide, are truly of fully marine character. Whereas deep water sediments have accumulated as the result of a continuous process of marine sedimentation and a continuity of depositional environment sometimes lasting hundreds of millions of years, many important shallow-water areas, such as the SWAP, have sea bottom material properties of recently flooded land. On shelves where there has not been an important source of terrigenous sediment, as in a delta, or where Recent carbonates are forming, such as the Bahamas and the Mediterranean calcareous sediment province, there usually is only a discontinuous veneer of true marine sediment.

The mid-Tertiary (Table 1) to Recent stratigraphic history of the SWAP may be summarized as follows (Evans and Hughes, 1984):

1. Withdrawal of the shore line to the outer shelf during the Oligocene.
2. Transgression during the late Oligocene to mid-Miocene period leading to deposition of calcilutites (Jones Formation) in outer shelf depths some considerable distance from a major land mass.
3. Abrupt change in the hydraulic regime of the area in the mid-Miocene (13–14 Mybp) due to the establishment of a connection with the North Sea and or uplift of the outer shelf. Deposition of calcarenites formed into linear tidal ridges (Cockburn Formation) of mid- to upper Miocene age.
4. Uplift of the outer shelf during the Pliocene with deposition largely restricted

to a narrow wedge along the shelf edge (lower Little Sole Formation).

5. Channels cut into the outer shelf with the late Pliocene/early Pleistocene (about 1.7 Mybp) shoreline at a level presently at −250 m. Transgression in the early Pleistocene brought about by subsidence of the shelf with deposition of shallow water clayey sands (upper Little Sole Formation).
6. Continuing subsidence of the shelf during the Pleistocene and uplift of the present adjacent onshore areas.
7. Late stabilization of shoreline at −130 m ending about 11,000 ybp.
8. Stepped rise of sea level to present level with only small and local wave-cut notches and strand features preserved.
9. Sea level currently rising at about 1 cm per year.

3.4. NEOGENE (INCLUDING PLIOCENE–QUATERNARY)

The outer continental shelf in the Southwestern Approaches is underlain by an oceanward-dipping wedge of Neogene strata up to 400 m thick that is divisible into three units. These have not been followed to the NW and SE from the area in which they were originally identified. The oldest is the early to mid-Miocene, parallel-bedded calcilutites of the Jones Formation that were probably deposited at between 150–200 m water depth, which rest with a marked eastward overstep on Paleogene and Cretaceous strata. In the east there is often a highly irregular rockhead in Eocene limestones below the sub-Neogene unconformity. The carbonate content of the Jones Formation ranges from 40 to 70%, with the remainder being largely sand; the formation is compacted sediment with thin zones of cherts and hard limestones that have been lithified through diagenesis (Evans and Hughes, 1984). It has a velocity of about 2 km/s.

The mid- to late Miocene Cockburn Formation, consists of silty calcarenites (carbonate sands with about 80% carbonate and the remainder silica and metamorphic sand derived largely from NW France). The Cockburn Formation, which is a series of now buried linear tidal ridges, are separated locally by an unconformity from the underlying units. The ridges in the Cockburn Formation have wavelengths of between 10 and 20 km, suggesting a water depth during their establishment of between 40 and 80 m (Evans and Hughes, 1984), which is substantially less than the present water depth. The Plio–Pleistocene Little Sole Formation, which rests on an unconformity upon Miocene strata, is divisible into a lower, wedge-like member, restricted to near the shelf edge, and an upper, more widespread, sheet-like member that is locally up to 300 m thick. It is composed of gray clayey sand that contains abundant planktonic foraminifera indicating that a primary sediment component is water-column derived, and does not have a prominent terrigenous component.

A well that was cored for stratigraphic section on the outer shelf, along the northern margin of the SWAP basin encountered Miocene–Oligocene (Neogene) claystones with thin limestones and sandstones overlying Eocene limestone, glauconitic sandstone and clay with siltstones (Paleogene) over the Upper Cretaceous chalks, but velocities were not reported (Bennet et al., 1985). This stratigraphic section is typical of the Cenozoic rocks of the outer continental shelf (Naylor and Shannon, 1982). The Neogene strata on the upper continental slope are generally continuous, with a smooth oceanward dip, but contain isolated infilled canyons and slumped horizons (Evans and Hughes, 1984). The seismic character of the units suggests that no abrupt demarcation existed at this time between continental shelf and slope.

The Neogene strata are truncated on the upper continental slope by the extensive erosion and slumping that formed the suite of canyons, which presently dominates the submarine topography.

3.5. PLEISTOCENE SEDIMENTS: THEIR EXTENT AND CHARACTER

There appears to have been little or no net deposition in the SWAP during most of the Pleistocene. The sequence of Pleistocene tills and glacial sediments in the northernmost part of the Celtic Sea (Wingfield, 1985), that just reaches into the north-central part of this study area from north in the Irish Sea, comprises a regular sequence beneath thin Recent sediments:

Top.

4. Superficial deposits – Flandrian and Devensian (Holocene)

3. Till complex – Devensian (Weichselian)

2. Marine interglacial – Ipswichian (Emsian)

1. Till complex – Wostonian (Munsterian – Saalian I and II)

Base.

For the greater part of the Pleistocene, most of the area was either covered by ice and subject to erosion, or was either subaerial or shallow water having no extensive net sediment deposition. Indeed, in the later part of the Pleistocene, deflation of finer grained material from the surface resulted in the formation of a local coarse-grained pediment.

The history of development of the present nearly flat character of the shelf probably starts with the early Pliocene erosion. During periods of maximum ice advance, in Saalian II times, ice covered the whole of the continental shelf south to the Bay of Biscay and eastwards into the English Channel to the Strait of Dover. The southern margin of the major, later Pleistocene Devensian glaciation, however, reached only as far south as the southern coast of eastern Wales (Evans and Thompson, 1979). The maximum advance and stable front of this Irish Sea glaciation has been followed across the Irish Sea to the east coast of Ireland (Garrard, 1977). The seafloor to the south of this last glacial advance was largely swept clean of Pleistocene deposits down to below the present 100 m contour (Stride, 1963; Belderson and Stride, 1966). Grounding ice may have been an important erosional agent (Kellaway et al., 1975). In the submarine areas of the continental shelves during the later glaciations, the major sand wave field of the outer SW Approaches was being fashioned (Belderson and Stride, 1966).

Outwash fans comprising a thin cover of sands and gravels up to 50 km to the south and southwest of the Irish Sea till front, which reached to a Pembroke (SW Wales)–Ireland line, give way to a sediment veneer that is found commonly over 20–70% of the rock floor (Belderson and Stride, 1966). Significant areas of bare rock occur (Stride, 1963).

The outermost shelf is generally believed to represent beveling by wave action during one or more of the low sea levels of the Pleistocene (Pantin and Evans, 1984). The first of these major sea lowerings took place at about 700,000 ybp (Williams et al., 1981). The Flandrian transgression began about 10,000 ybp and this rise in sea level is presently continuing. The Pleistocene erosional surfaces are now tilted seaward with gross difference in elevation of about +45 m from the vicinity of the Cornwall peninsula to about −110 m on the outermost shelf in the Plio–Pleistocene upper Little Sole Formation and its landward equivalents; a slope of 155 m in about 300 km. Variable movement in the shelf, therefore, has been important; the coasts of Britain are still rising in the SW while subsiding in the east adjacent to the North Sea.

Upper Pliocene to Pleistocene sediments, mainly on the outer shelf, have a thin cover of Pleistocene sediments of the Melville Formation and upper parts of the Little Sole Formation (Fig. 10) above local unconformities. Both formations appear to be composed predominantly of sand, with subordinate gravel and a minor proportion of mud; the upper Little Sole Formation probably consists mainly of fluvial deposits, accompanied by subordinate shallow marine deposits in its upper part, whereas the Melville Formation consists essentially of tidal deposits, which have been fashioned into tidal sand ridges (TSR). The abrupt NE termination of the TSR province is probably due to the lack of availability of sediment above approximately the 100 m contour, which could be textured into ridge-form by a deepening of water. Extensive planation predated and post-dated the deposition of the Little Sole Formation

Thin Recent sediment of the outer shelf passes down into the predominantly sandy Melville Formation of the probable late Devensian–early Flandrian age; this forms the bulk of the tidal sand ridges (TSR) where it may be over 40 m thick but in the intervening lows it is probably no more than a few meters thick. Seismic profiles indicate that the unit contains large and small scale cross-bedding and a complex of cross-cutting lenses and channels. Locally, areas of ice-rafted till and laminated till-like sediments occur at the top of the formation. The tidal sand ridges were formed during the late Devensian–early Flandrian lowstand. During the Flandrian transgression the TSR extended shorewards and increased slightly in size. The tidal sand ridges of the outer shelf are considered to be stable under the present current regime (Pantin and Evans, 1984; Evans and Hughes, 1984).

The main part of Pleistocene time is represented by a widespread erosional event that formed a pediment of coarse-grained gravels and sands that stabilized the bathymetry of the tidal sand ridges. These ridges are overlain by a thin veneer of Recent, mobile sandy sediments, probably never more than a few meters thick. Maps of the surface sediment (BGS Continental Shelf Map 1:250,000 series) over this area of the outer shelf, where the tidal sand ridges dominate and control the morphology, show no clear correspondence between mapped sediments and the actual position and thicknesses of sediments immediately below the surface veneer. Sediments below the surface sediments are of greater importance to modeling bottom interaction.

Apart from ice plough marks along the shelf break immediately to the southwest of SW Ireland (Pantin and Evans, 1984), some ice-rafted material has been recognized on the shelf slope to the west of the Approaches (Kudrass, 1973). This material serves to locally increase the roughness of the bottom above the normal range of roughness that would be expected for lower shelf. The large platform of the SW Approaches shelf does not otherwise record the presence of ice-texturing.

3.6. HOLOCENE TO RECENT SEDIMENTS

Holocene sediments on the SWAP continental shelf are unconsolidated and range in age from 10,000 ybp to Recent. Adjacent to land masses in the Irish and North Seas, there are extensive longshore banks of sand and gravel. Elsewhere, Recent sediments on the shelf are usually absent to thinly spread, with thicknesses rarely more than a few meters. Recent sediments in the Sole Bank, for instance, consist of 0–3+ meters of shelly sand resting on the commonly developed thin lag gravel.

Following the Flandrian transgression, the largely detrital Pleistocene sediments have been reworked by tidal currents and storms. These reworked clastics comprise much of the Recent sediment. A high proportion of the present seafloor sediment is calcium carbonate derived from micro-fossils and degraded shell material; this is especially true of the outer shelf (Murray et al., 1983). There is a low rate of terrigenous input from the adjacent land masses. Minor amounts of Holocene sediments of non-European terrigenous provenance are distributed both by bottom currents forced by the Iceland–Faeroes Ridge and by aolean regimes from North America (Grousset and Chesselet, 1986).

In a very general sense, the arch of rock continuing to the SW from the Cornwall area of SW Britain that separates the two main sedimentary basins within the continental shelf, also separates a more muddy depositional environment to the northwest from a more sandy environment to the southeast (Stride, 1963). It has been shown, however, that fine particle size sediment derived in the English Channel has been transported to the edge of the shelf because of the high bottom stress (currents) that hardly diminish from south of Cornwall to the shelf edge (Pingree and Griffiths, 1979). The finer sediments have been deposited in some of the canyons and along the continental slope. Strongly erosive turbidity currents are thus probably associated with the formation of these canyons (Kenyon, 1986). Sedimentology and morphology follow Bouysse et al. (1979) and Larsonneur et al. (1982) in the general disposition of sands and the orientation of current structures in the western approaches.

Along the upper continental slope west of Ireland and Scotland medium range side-scan sonargraphs show a variety of longitudinal and transverse sand bedforms (Kenyon, 1986) indicating a poleward flow of water. Asymmetrical sand waves on both the inner and outer shelves are taken generally to indicate current movement. The tidal sand ridge forms of the outer shelf have a smaller counterpart in intermediate water depths and much higher frequencies in shallow water. Comet marks/narrow sand ribbons occur where current exceeds 75 cm/s and sand waves where speeds exceed about 40 cm/s (CONSLEX Group, 1984).

The Recent sediments are generally rich in carbonate (see Tonarelli, B. et al., 1994), mostly from shelly fragments, but a number of samples yielded carbonate below 50%, which is the lowest shown by Larsonneur et al. (1982) for these areas. All three cores show more coarse grain sizes toward the bottom of the cores, which suggests that the normal upward fining sequence of sediment (especially for locally derived materials) is related to rising sea level and the recession of shore lines from these more outer shelf positions. Grain size analyses showed fairly uniform carbonate content from all specimens, suggesting that uniform depositional conditions and sediment sources cover broad areas of the shelf.

3.7. SEABED ACOUSTIC RESPONSE

The acoustic response of the seabed is well documented from the many depth sounding records available from the heavily traveled and fished continental shelf. The acoustic response can be directly related to both the geological map and the Recent sediment map. This acoustic response has been found from high-frequency acoustic devices in the range of 1.5 kHz and above.

The seabed can be divided into five general categories that are in part based on underlying solid geology and in part on sediment cover:

1. Rough variable seabed that usually indicates rock outcrops. On the small to medium scale, this is topographically variable from subdued to steep slopes with angular margins and rock facets following bedding or foliation.
2. Moderately rough areas with strong acoustic response reflecting the presence of till outcrop or coarse, gravely sediments that often appear in windows through blankets of finer sediments with weaker acoustic response. Topography is commonly moderately steep to subdued, but is rounded rather than being more

angular in character. These bottoms are commonly sandy gravels and gravel that is more common near the land areas and is more common progressively eastward into the English Channel (Bouysse et al., 1979).

3. Smooth to gently rounded seabed, with weak bottom reflection, can be generally distinguished only as small bedforms. Side-scan sonargraphs may be necessary to resolve these areas, which could appear on a depth sounding track as an irregular bottom. Thin Holocene to Recent sheet sediments from fine to coarse silts and sands. This bottom type includes areas of till outcrop lightly masked by thin sediment.

4. Smooth featureless seabed with insignificant bottom reflection, with no distinguishing features except rare artifacts such as trawl marks and wrecks are generally fine muddy sediments. These sediments mostly of pelagic content are most common on the outer shelf (Murray et al., 1983).

5. Sediment wave fields, largely sand waves but including gravel waves, especially in coastal waters. The wave fields of the outer shelf are relics of an earlier sedimentation episode of Plio–Pleistocene times, but for bottom interaction purposes they can be dealt with in a manner similar to the more recent, but smaller scale wave fields at the western end of the English Channel. The gross current transport direction in the western end of the English Channel is to the west (Larsonneur et al. 1982) and northward along the margin or the shelf (Kenyon, 1986). This general movement of water over an extensive period of time is probably the cause of the development of asymmetrical sand waves, whose pattern is semi-stable.

3.8. TERRANES IN THE SWAP

Four major terranes based on the shelf geology, one morphogeological terrane, and four subterranes based on surface morphology, have been identified (Fig. 2). Terrane identification for bottom interaction purposes has not been carried out below about 1,000 m. These terranes and subterranes effectively comprise the geoacoustic terranes that are discussed in Sect. 4 because of the close relationship between geology and expected geoacoustic response in the SWAP.

Because of the similarity of depositional and tectonothermal histories of some of the geological units, which have resulted in a natural geographical coincidence of units having similar acoustic responses, the units can be further condensed. The lower acoustic basement includes many rock types of an extensive range of geological ages, which overall have a similar range of acoustic response; this is entirely within the acoustic basement terrane. Some of the upper acoustic basement of Avedik (1975), especially around southwest Britain, is here regarded as forming part of the banded terrane, although most of the rocks also form part of the acoustic basement terrane. The Permian–Triassic, Jurassic, and lower Cretaceous rocks have a similar acoustic velocity structure and are found together. This group is referred to as the banded

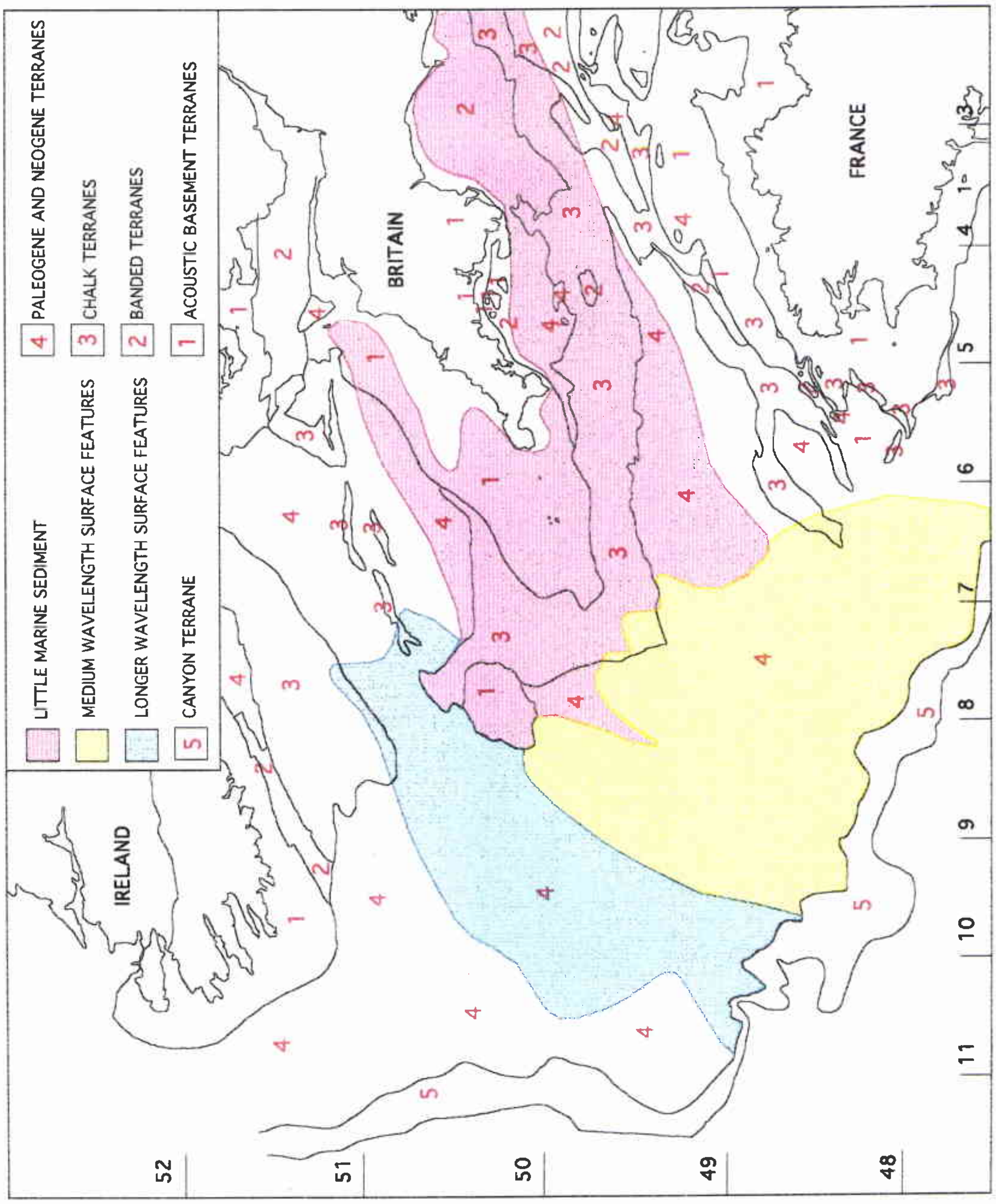

Figure 2 *Generalized distribution of low-frequency geoacoustic terranes (1–5). Colored patterns show areas surface morphology terranes. Deep-water terranes not shown.*

terrane, which describes the character of the bottom it forms. The upper Cretaceous in this area forms the chalk terrane, because of its unique geoacoustical response. The Paleogene and Neogene of the Cenozoic (Fig. 2) are combined in the Paleogene–Neogene terrane. The surface morphological subterranes (Fig. 2) have a lithological inference in that sand forms upstanding ridges while lower areas are formed from

Recent sediments and underlying terranes, but their impact upon acoustic propagation is mainly to introduce a statistical directionality difference into the way in which a propagating wave 'sees' the bottom.

The terranes and subterranes of the area are:

Terrane 1. Acoustic basement terrane

Terrane 2. Banded terrane

Terrane 3. Chalk terrane

Terrane 4. Paleogene–Neogene terrane

Terrane 1. Acoustic basement terrane. This terrane is generally found adjacent to land. The terrane includes all of the estuaries in the west of Ireland, Wales, and France that may have soft sediment bottoms because the whole of the enclosed area would be subject to sideswipe acoustic energy from headlands and rock pinnacles that commonly occur in them (Caston and Max, 1978). Although this terrane is fairly broad around the southern coast of Ireland and broadest off the west of France, it is narrow to absent off southern Britain, from Start Point eastward past Portland. The deep geology of the crust is complex (Bois et al., 1991), but is not discussed here because for the purposes of describing acoustic character, all the schists, gneisses, and igneous rocks have a relatively high velocity, low attenuation character with respect to all other rocks and sediments in the area.

This terrane is a composite of rocks of various ages that have been subject to at least lowest greenschist facies metamorphism, especially in France, southern Cornwall and southeasternmost Ireland. Rocks as old as 2,200 Mybp are found in the Channel Islands (Fig. 1) and in other areas south of the Hercynian Front, but they occupy small areas and were themselves mobile belt geological terranes during the end-Precambrian (c. 600 Mybp) Cadomian orogeny (Bishop et al., 1975). Around France this terrane has many syn-kinematic Hercynian granites emplaced in shear belts in the Hercynian schists. Older rocks were largely taken up in this Hercynian orogenic event that spanned late Carboniferous times, and were often not much affected by the event.

In southwestern Britain the whole of the Cornish peninsula and the Haig Fras outlier are composed of largely Devonian and Carboniferous rocks that have been thoroughly tectonized by polyphasal deformation while being lightly metamorphosed during the Hercynian orogeny (Shackleton, 1984). The structural grain is about E–W.

In southern Ireland and southwestern Wales around Pembroke, the Hercynian rocks are also folded and steep dipping with a general E–W foliation, but the degree of metamorphism is not so great. The rocks in this area, which may be the most external zone of the Hercynides (Gardiner and Sheridan, 1981; Max and Lefort, 1984), contain no granites or schists and their range of velocities is about 1 km/s less than the other rocks in this zone to the south.

The common structural grain is about E–W and, for the most part, rocks are steeply dipping along this grain while being segmented into irregular blocky units even on the small or outcrop scale by faults that largely trend NW–SE (Lefort and Max, 1984). Within this zone the sea bottom is rough, sharp, and jagged with many rock facets formed by bedding planes and schist faces and the normal cross-faults. Granite outcrops, such as at Haig Fras, are more rounded as the rock is more massive even though the granites may also be foliated. Sediment often occurs in low areas, but is thin. Re-entrants and oblique angles in the actual bottom surface are common, and small rock pinnacles and small cliff faces are common.

Terrane 2. Banded terrane. The banded terrane is a combined unit of early basin sediments, that are mostly buried in the basins or represented by thinned sequences that outlapped the deeper parts of the basins. The banded terrane is found generally along the margins of the sedimentary basins.

This terrane includes Permian, Triassic, Jurassic and lower Cretaceous sediments (Fig. 2) that have not been much tectonized and were not metamorphosed. The terrane is composed of interbedded sandstones, shales, medium to high velocity limestones, some evaporites, and some conglomerates.

The bottom formed from this terrane is characteristically faceted. Ridging on the bottom that is caused by banding or bedding generally trends E or ENE, with shallow to moderate dip both to the NW and SE caused by folding. Rocks more resistant to weathering and erosion stand as pinnacles and small cliff-faces on the bottom. This results in the bands forming a series of steps in the bottom with softer, silty and mud layers selectively excavated from the upstanding sandstone beds through erosional processes. Faulting in the area is generally on a NW trend (Lefort and Max, 1984) and this results in the segmentation of the bands by faults and joints. The blocky bottom is thus a result of original bedding, selective erosion, and structural history.

Terrane 3. Chalk terrane. The chalk terrane occurs beneath a large portion of the direct southern approach to Holy Loch in the Celtic Sea. It also occurs around the western end of the Cornubian peninsula and forms a broad area beneath the northern English Channel from the shelf to the west, and a narrower, and somewhat segmented bottom along the south side of the Channel northwest of France (Fig. 1). Smaller, elongate inliers of the chalk occur leading from the northern margin of Haig Fras into the Bristol Channel and narrow exposures of chalk occur along and near the acoustic basement terrane of western France.

Almost all of the chalk terrane has a nearly flat, nearly peneplaned surface, that may slope gently away from the nearest land area or southwest toward the continental margin. Figure 1 bathymetry shows these regional slopes, but not what could be called the engineering character of the surface. Figure 4 shows the detailed character of a chalk bottom surface.

Outcrops of the chalk terrane also occur along the continental slope at nearly all depths down to the abyssal level where subsided continental crust and the sedimentary basins have been recognized in seismic section, drilling and grab sampling (Sibuet et al., 1985). Chalk appears to be widely present over the outer and lower slope as well as possibly in the canyon terrane. Although chalk occurs commonly in the continental slope to the west of the slope break, the chalk terrane is restricted to the sedimentary basinal areas of the SWAP. This is because chalk in the slope/canyon system has significantly different potential for tactical utilization in the bathymetrically unique canyon terrane.

Terrane 4. Paleogene–Neogene or consolidated sediment terrane. This terrane is the most broadly occurring terrane. It occurs mainly on the outer shelf, with more restricted areas in the eastern Celtic Sea and the Western Approaches Basin. The Paleogene–Neogene terrane consists of sedimentary strata, some of which have lithified through diagenesis that does not require deep burial or thermal energy to transform sediments into rock. These important impedance contrasts are induced by hard limestones and cherty beds (Evans and Hughes, 1984) that occur mainly in the eastern two-thirds of the terrane and irregularly in the isolated patches of the inner shelf. A sonic log for part of the Jones Formation at the base of the Neogene shows an increasing velocity with short period velocity spikes correlated with impedance contrasts at these horizons.

3.9. LONG WAVELENGTH SURFACE FEATURES (12–20 KM)

Bottom corrugations (Figs. 1,20) lie generally along the NE–SW Caledonian orogenic trend and pass into linear features at the shelf break. The straight courses passing from the shelf break to the NW are probably structural in origin, rather than being due to a combination of bottom current and canyon head progradation alone, and the ridges are probably Paleogene and Neogene sediment cored. These were formed when the water was between 40 and 80 m depth, consistent with formation in late Quaternary times when the shoreline lay between the 130 and 120 m contour (Evans and Hughes, 1984). For the purposes of acoustic bottom interaction, however, there would probably not be much difference, especially in the outer shelf area, as the largely unconsolidated upper Paleogene–Neogene terrane would respond similarly to the Melville Formation.

3.10. THE SHELF BREAK

The shelf break is a line separating the continental shelf from the continental slope. The principal shelf break is at a depth of between 180–220 m and is often taken at the top of a gentle scarp, up to 20 m high. It forms the boundary between the slightly seaward dipping, near-horizontal seafloor of the continental shelf, that is affected by tidal currents and waves, and the much steeper continental slope that is influenced by contour currents, deep ocean circulation patterns and stable thermoclines and turbidity currents.

The shelf break cuts across the major extensional basins of the SWAP. The slope break of the main shelf lies at least 20 km landward of the most easterly of the listric faults that mark the edge of the rotated blocks of pre-rifting strata underlying the continental slope (Montadert et al., 1979). Along the southwestern side of the Porcupine Seabight, however, the base of the steep slope is quite close to the oceanic/continental crust boundary (Roberts, 1974).

Canyons on the upper slope (Stanley and Moore, 1983) are cut into Plio–Pleistocene and thus their formation is probably related to Pleistocene sea level low stands. Where the slope break is defined by an erosional scarp, it follows the sinuous path of the 180–190 m contours. Terraces in front of the scarp are related to an earlier lowstand episode, when sea level was even lower. The variability of the slope break profile reflects the interplay between erosion, faulting along major structural lines, and episodic deposition whose character changed with rise and fall of sea level.

Headward erosion of the canyon backwalls locally cuts into the lower platform to remove sections of the uppermost slope and produce steep slopes not directly related to any lowstand erosion episode (Fig. 1). Pre-Neogene rocks are exposed in the steep faces of the continental slope, especially in the canyon areas (Bailey, 1975; Sibuet et al., 1984). Fresh rock faces are exposed locally by slope failure that results in the generation of large slumped masses that can be traced downward from canyon areas into turbiditic deltaic systems (Kenyon, 1987).

3.11. CONTINENTAL SLOPE

The continental slope is steep and deeply incised with canyons. The digital SWAP chart shows the positions of the major canyons, but does not show the full details of the morphological complexity because a simplified map was digitized. Neither time nor the availability of a full set of digital information warranted a more complex slope map in places.

Very little marine sediment is present on the continental slope, which exposes large areas of bedrock formed from sedimentary, igneous, and sedimentary rocks having a wide variety of physical properties. From the standpoint of reflectivity, however, most rock faces will be strongly reflective. For a detailed classification of individual reflectors, a more detailed bathymetric and morphologic GIS is necessary.

The canyons in the continental slope trend roughly NE–SW down the overall slope to the east of the Meriadzek Terrace but, to the west, a number of canyons are more oblique trending to the general slope. The oblique trends are believed to be due to deep-seated lines of weakness in the rocks of the continental margin. There are numerous small branching gullies running into the canyon axes, especially near the heads of the canyons. Thus the topography is rough and resembles that of the badlands in the arid, mountainous parts of the western USA. The canyon walls usually slope at greater than 7° and, in places, exceed 25°, which is the limit to which slopes can be measured by our precision echo sounder. The lower walls and the floors of the canyons correspond to strong reflectivity on the side-scan records. Submersible traverses across the walls and floor of a branch of the Shamrock Canyon by the Groupe Cymor (1981) showed that, as well as rock outcrops, there were signs of erosive activity including small overhanging cliffs and piles of boulders.

There is little available information about surface sediments on the continental slope, except adjacent to the Meriadzek Terrace. Although sands are known to be present down to at least 200 m, Bouysse et al. (1979) show a tentative boundary between 'coarse sand' and 'very fine sand' in depths of about 500 m, near the head of Black Mud Canyon to the south of the Meriadzek Terrace, just off Fig. 1. Auffret and Sichler (1981) describe diverse types of surface sediments in depths of between 2000 m and 3000 m on the southwestern end of the Lower Meriadzek Terrace and on the Aegis Ridge, which is a deep prolongation of the Lower Meriadzek Terrace. Although the sediments are dominantly muddy foraminiferal oozes, some samples contain up to 90% sand, much of it derived from shallower water. On the basis of the sediment type, Auffret and Sichler (1981) predict the occurrence, in depths of 3000 m on the Aegis Ridge, of relatively strong bottom currents, reaching 30–50 cm/s, whereas much weaker currents prevail in the shallower, 2000 m, depths. The sediments of the Upper Meriadzek Terrace do not appear to have been sampled but at some, as yet unknown, depth the surface sediments should change from dominantly sandy in the shallower water of the shelf to dominantly muddy on the upper slope. This 'mud line' is related to a decrease in the hydrodynamic activity. Hydrodynamic activity is usually relatively strong and complex near shelf breaks. The sediment type along the planned route is little known. It is suspected that medium-sized sands will give way to muddy sand and mud at depths of somewhere between 200 m and 500 m.

The GLORIA system has been used to rapidly map the major features in the area, which had already been the subject of swath mapping surveys. The side-scan also aided in the drawing up of an improved bathymetric map compiled at the Institute of Oceanographic Sciences (IOS), UK (Kenyon and Hunter, 1985). Bathymetric data sources for this detailed bathymetric chart include IOS research cruises, which use precision echo sounders, and cruises by the CNEXO ship *Jean Charcot* using the multibeam system, SEABEAM. All of these data are fixed by satellite navigation. Most of the SEABEAM data are from the canyoned areas to the east and west of the Meriadzek Terrace and some have been published by Groupe Cymor (1981). The final contouring was drawn using the GLORIA interpretation as a guide. The strongly-reflective areas in most cases correspond to slopes that are steeper than 10°.

It is suspected that some backscattering of sound from these slopes is due to their being free of the cover of mud that is usually found on the continental slope and in the deep ocean. The faceted and steep slope in this vicinity, therefore, probably closely resembles the bare, rock-faced slopes immediately to the NW (Masson et al., 1989).

The Meriadzek Terrace, and its passage from the continental shelf, is one of the largest of the strips of smooth floor in the continental slope. It can be seen to be divided into an Upper Meriadzek Terrace and a Lower Meriadzek Terrace by a prominent escarpment which is called the Petrock Escarpment (Petrock of Bodmin, besides having a suitably geological name, was a Cornish saint, as was Meriadzek). Both parts of the terrace appear to be free from any relief features or other strong acoustic targets and have gradients of less than 2°.

The Upper and Lower Meriadzek Terrace has gentle slopes, free from large obstacles. However, boulders or wrecks, although unlikely to be present, are too small to be resolved during the GLORIA side-scan survey. The terrace narrows upslope to a neck of only 4 km at a depth of 300 m. The Meriadzek Terrace is bounded by steeper slopes except at the narrow corridor linking it to the Celtic Sea shelf. As the gradients increase to between 3° and 5° the characteristic wavy shape of slump folds and slump faults are detected on some parts of the terrace. These are due to a downslope creep of the sediments, resulting in slope parallel ridges, several kilometres in wavelength and up to 50 m high. Similar features have been described from elsewhere on the northwestern European continental slope by Kenyon et al. (1978). It is not known whether they are still active. The immediate cause of such mass movements is an increase in steepness of the slope, due to either an increase in the rate of deposition of sediment or to movement on the deep-seated faults that underlie the slope. As neither seem likely to be occurring at the present time in the geological history of this region, catastrophic failure would seem to be unlikely.

The Meriadzek Terrace is subdivided by a slope that, at its eastern end, is 1400 m high with a gradient of up to 14° and, at its western end, 500 m high with a gradient of 5°. At its foot there is a series of deeps. Such a configuration is in keeping with this being the site of a large deep-seated fault in the rocks of the continental margin. Although sedimentation processes have not had time to fill in the deeps, movement on this fault is not likely. Few large earthquakes occur on the margins of the Atlantic and there have been none in the northern Bay of Biscay over a period of 15 years from 1965–1979. The escarpment continues to the east across the canyoned slope to at least as far as 7°45′E. It appears to have been considerably eroded by an canyon-forming processes. To the west, the trend of the escarpment coincides with the trend of the lower Shamrock Canyon.

4

General geoenvironmental description of SWAP sites

Site 1 Site 1 is on the geomorphic outer shelf where water depths are sufficient to preclude all but the strongest storms from contributing to sediment distribution patterns. Bottom currents are also less than in more nearshore waters. While the area is not characterized by the weak deposition to erosional character of shallower waters, it is not an area where thick sedimentation is taking place. Bottom should be relatively smooth, but not flat.

The prevailing bottom morphology is of long NE–SW trending, asymmetric sand waves, with the steeper side toward the NW. These are relic, having been formed when the sea level was lower, over 11,000 years ago. The sediment surface of these large dunes is probably somewhat coarser than when they were deposited because of erosion during the rise of sea level. Gravel pediments and coarse sand may be common on the tops of the sandwaves. Troughs and lower areas will probably have Recent, fine-grained sediment, but there may be only shallowly buried more coarse grained patches. Recent sediment maps do not have sediment thickness contours.

Beneath the sandwaves is upper Tertiary and Plio–Pleistocene sands and gravels, often with thin limy and limestone partings and beds. Troughs between the sand waves may directly ground on this unlithified sediment.

Site 2 Site 2 is a chalk bottom formed from Cretaceous marls that were buried, lithified, and exhumed during weak tectonic activity. There is a thin, patchy sediment cover. Acoustic properties of chalk are relatively well known, with $V_p = 2.2$–2.6, $V_s = 1.1$–1.5 and attenuation high. Recent sediment thickness is not known in detail, but is reported as thin, and thinning toward the west. The site picked for AAG, which should be coincident with SAG Site 2, should be dominated by fine sand, whose lateral continuity and thickness is not known. The bottom should be relatively smooth, but with a possible small-scale roughness where chalk is exposed and depressions are not sediment filled.

Site 3 This site is on the Hercynian terrane identified as one of the three main geoacoustic terranes in the SWAP. It is composed of lightly metamorphosed and deformed sandstones and shales and is injected by granites. This is a high-velocity, low-attenuation material. The terrane is coincident with a bank on which detailed bathymetry shows a strong increase in the roughness, in comparison with surrounding bottom. Local relief in the bottom is up to 15 m. Sediment cover is variable, ranging from gravel banks to fine muds in low places with strong lateral variation.

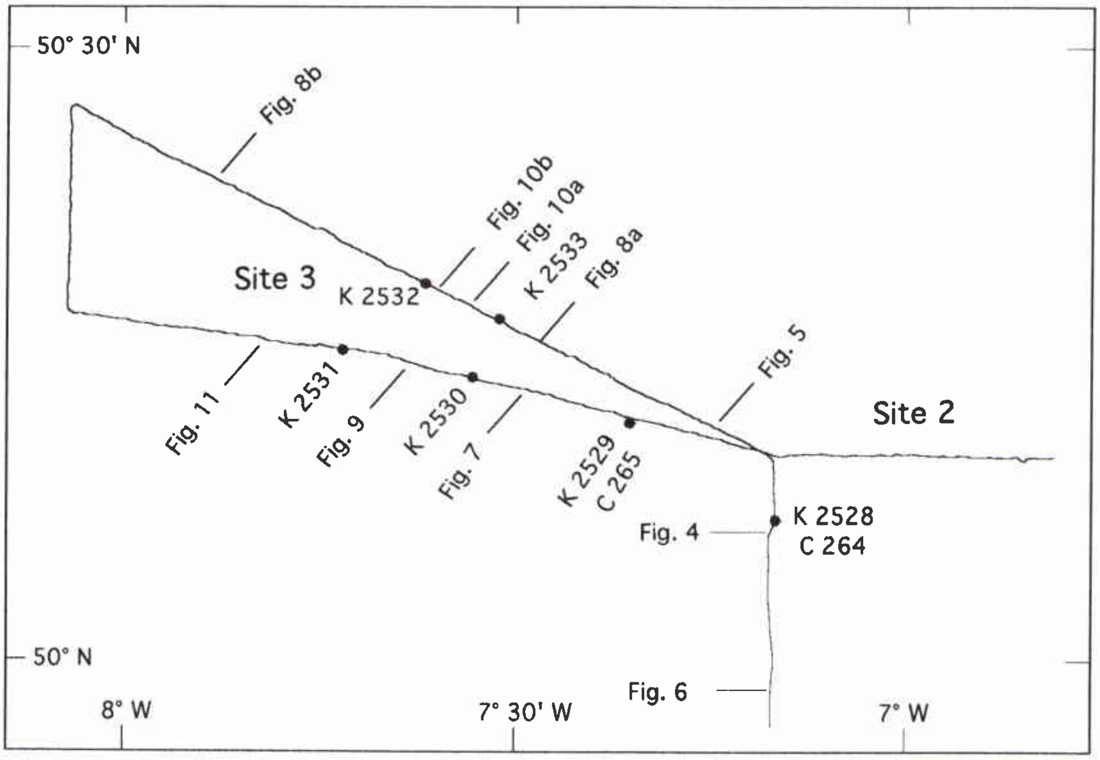

Figure 3 *Survey tracks for Sites 2 (C) and 3. Site 2 is to the SE, Site 3 is to the NW. Core (C) and Grab (K) sample sites shown. Locations of Figs. 4–11. Uneven track line resulted from GPS jumps between fixes; true course would be a smoother line but no corrections have been applied. Fault, f.*

4.1. SITES 2(C) AND 3

4.1.1. Survey and sampling

Both sites were surveyed using uniboom and sparker in one long survey track (Fig. 3). These geophysical research tools show the internal seismic response of the near-sea bottom materials within the bottom and provide a virtual section of the uppermost seabed geology. Sea conditions were slightly rough and both bedding and internal reflection surfaces are consequently not as well defined as they could be. The uniboom was of much more use in determining the internal reflection character than was the sparker.

Side-scan sonar was also used at the same time as the reflection seismic equipment. Side-scan uses backscatter analysis of an indefinite number of lateral scans to build up a track record of the backscatter character of the seabed for, in our surveys, about 75 m to either side of the ship. The backscatter character is directly related to the presence of different materials, such as sand, gravel and rock, and can depict different morphologies such as sand waves, rippled areas and stony bottoms. Sea conditions were not bad enough to seriously degrade the side-scan and bottom character is well seen.

Two main types of backscatter are registered on side-scan records. Firstly, major relief features give strong reflections (whiter tones) from large slopes facing towards the ship and weaker reflections (gray tones) or shadows (black) from slopes facing away from the ship. The spectrum of reflections from small-scale roughness elements can also cause dramatically different values of backscattering. Stronger than average returns normally come from the rough surfaces of exposed rocks, biological features such as corals, shells or burrows and small, current-induced bedforms such as ripples. Even changes in sediment type should be detectable by side-scan sonar; for instance, muds should absorb more sound than sand. Depending on the frequency of the side-scan used, images of large objects, such as ships, or small objects, such as oil drums, can be immediately identified. Lines within patterned areas indicate the trend of rockhead features on the bottom (Fig. 3). Fold structures in the smooth basement terrane are more numerous than shown. The margin between the chalk terrane and the basement terrane is a fault. Paleogene–Neogene (P–T) terrane is an unconformably onlapping contact at the tip of a sedimentary wedge.

The survey began in the eastern part of the chalk terrane, passed across the basement terrane and out into the P–N terrane (Max, 1989) (Fig. 1). The survey confirmed the position of the boundaries between the different terranes.

4.1.2. Site 2: Chalk terrane

Site 2 is a chalk bottom formed from Cretaceous marly muds that were buried, lithified, and exhumed during weak tectonic activity. Throughout the area chalk strata are either at the surface or covered by only a very thin layer of relatively coarse Recent sediment. There are no important sediment or other morphological variations. The bottom is virtually flat both bathymetrically and morphologically.

Geoacoustically, there is a central area having an uppermost unit of minor varying thickness and a NW marginal area that might be the beds dipping off shallowly toward the SE.

Internal acoustic character Shallow penetration to depths no greater than about 20 m showed parallel banding having different internal characters. In particular, an uppermost, discontinuous layer is very dark and suggests strong internal scattering or reflection. There was a possibility that the uppermost of the beds in what appeared to be synclinal folds (Figs. 3–5) could have been sediment infill rather than being part of the chalk succession. These were cored and found to be chalk. Coring at the second site to the NW (Fig. 2) also proved chalk immediately below the thin sediment cover. Therefore everything below the acoustic surface was within the chalk terrane. Several surfaces below it, which locally intersect the sea bottom, are probably boundaries between beds. No important faulting or important range-dependent variations occur, although several small apparent faults were observed (Fig. 6).

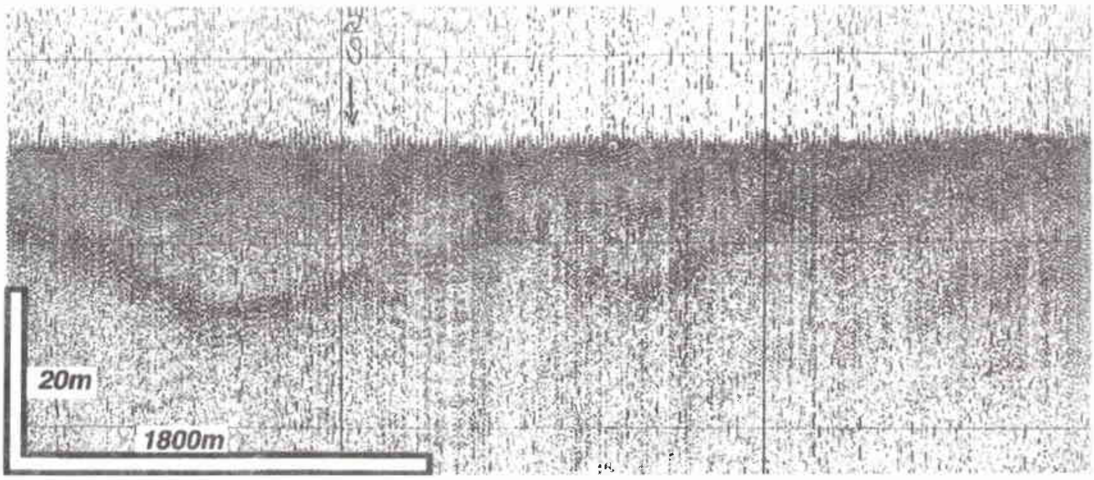

Figure 4 *Uniboom. Chalk terrane at Core 264 and first site. Chalk strata to surface, possible infilled channel proved chalk.*

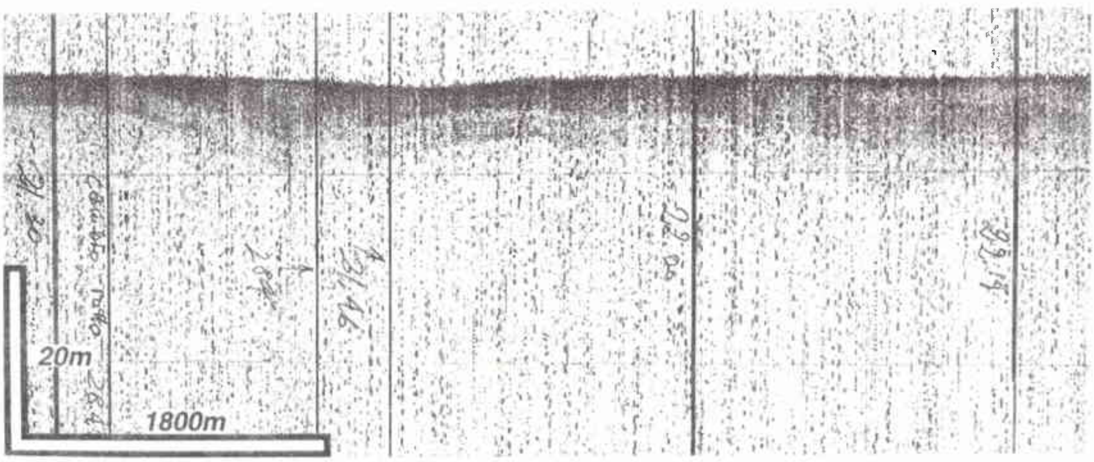

Figure 5 *Uniboom. Upper dark layer and sedimentary layering in chalk near Core 265 and second site.*

Minor folding apparently has an about E–W trend because it is well seen on the N–S line, but more gently varying depths on fold culminations and troughs are seen on the WNW trending lines. This assumes that the structures are about equally developed over the relatively short ranges of 10 km in this survey area.

Near the NW margin of the chalk terrane, pinch-out of uniform thickness higher beds occurs (Fig. 7). This indicates that the beds were once more continuous and may have covered the basement terrane.

Bottom character The bottom is virtually flat. The upper surface of the chalk

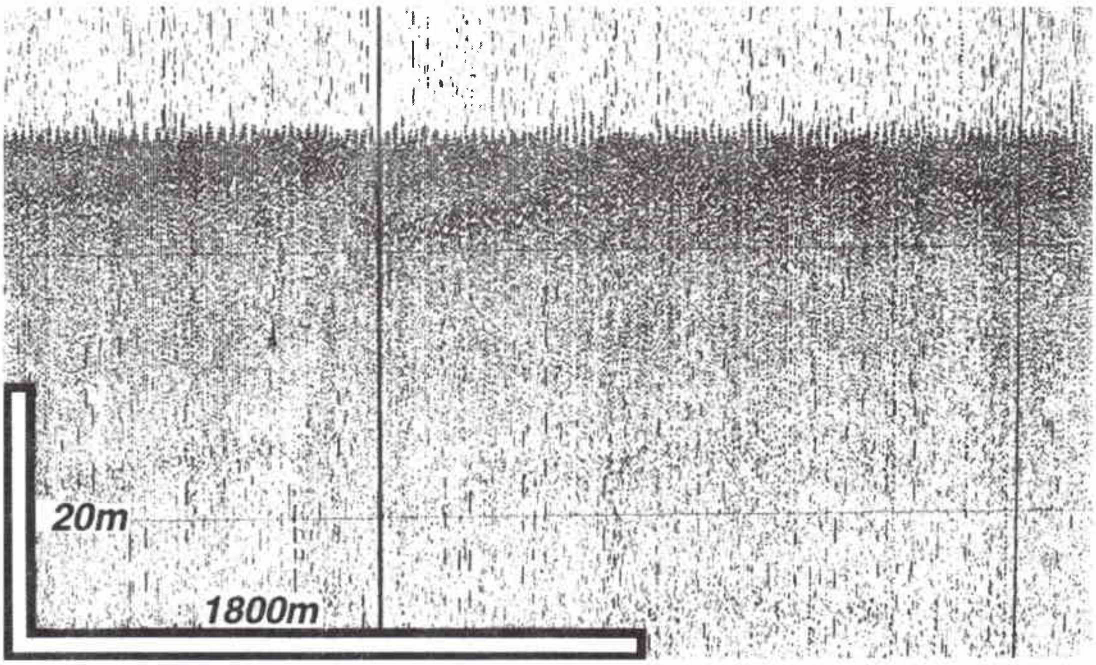

Figure 6 *Uniboom. Possible faulting of reflective layer near top of chalk succession; 2 n.mi. from end of southern termination of survey.*

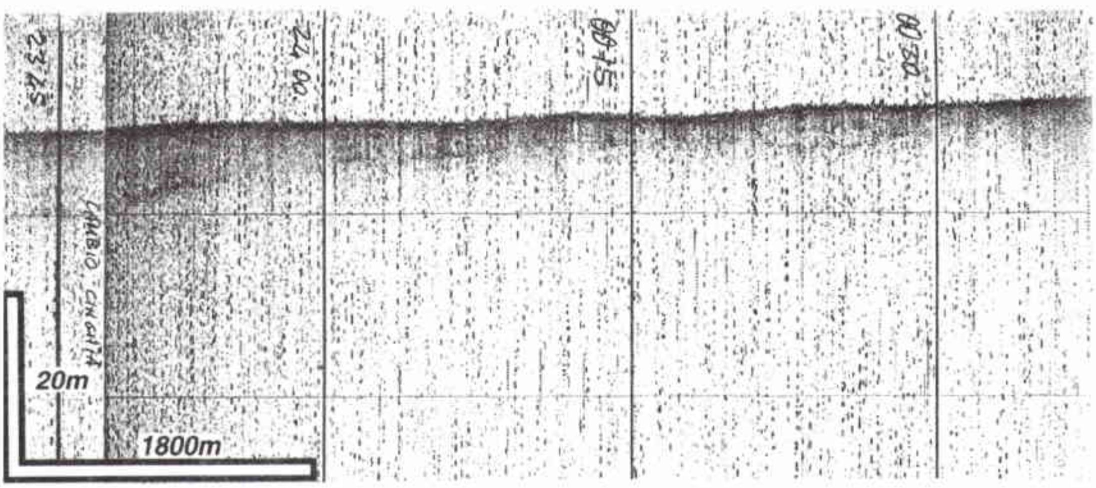

Figure 7 *Uniboom. Feather edge of chalk pinching out on basement terrane; southernmost survey line.*

bottom has relief on the order of less than a metre, with some upstanding chalk features often not completely covered by sediment streaks. Resting immediately on the chalk is an older, somewhat acoustically darker rippled sediment, probably formed from coarse sand and gravel, which is locally buried by an acoustically lighter, infilling sand disposed in long streaks and irregular shaped patches (Fig. 8a,b). The

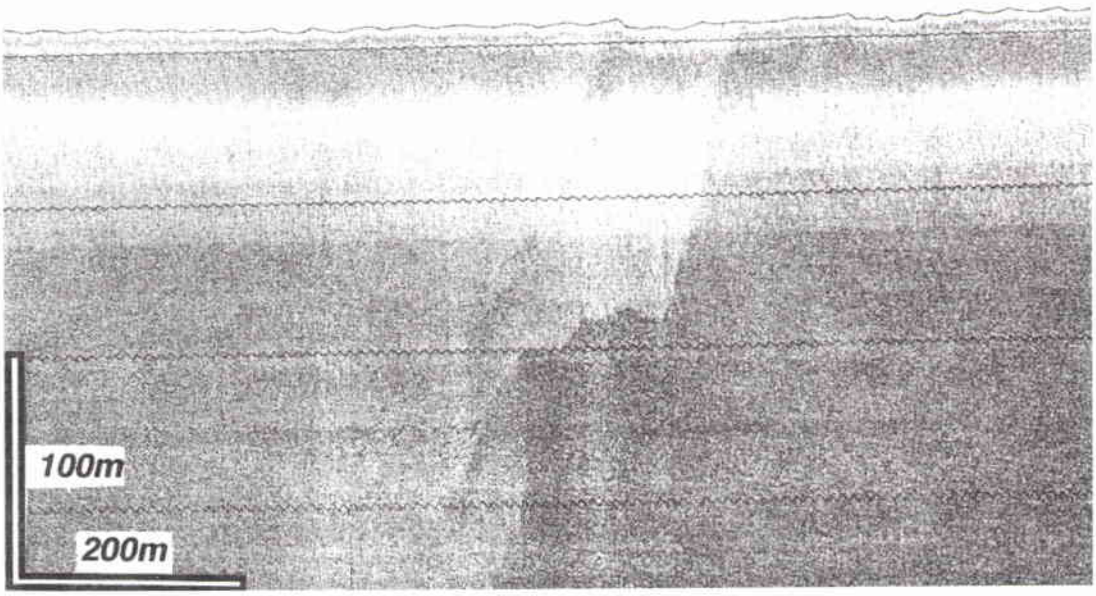

Figure 8a *Side-scan. Two main sediment types showing irregular boundary; usually boundaries between sediment types are more linear.*

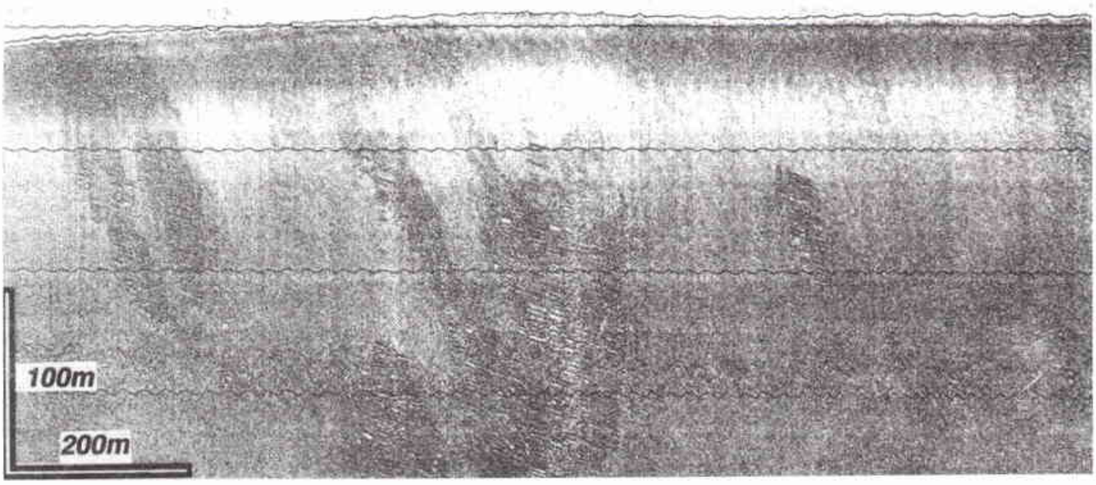

Figure 8b *Side-scan. Two sediment types with current-like features showing in darker (older?). Note local continuation of diminished apparent amplitude of relief features in darker bottom type in lighter bottom type.*

younger sands also occur directly on chalk.

Bottom samples Cores were taken at both Sites 2 and 3 (Fig. 3). Both cores penetrated an upper layer of shell-fragment dominant sand and a lower layer of coarse gravel in which flint and partially silicified chalk were the dominant clast types. No stratigraphic sections are presented; a strongly downward coarsening clastic tran-

Table 2 *Generalized analyses of Cores 264 and 265; depth levels in cm.*

Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt	$CaCO_3$ (%)
Core 264										
05	0.3	91.0	5.8	2.9	2.06	1.38	0.45	2.49	0.71	69.5
10	19.9	75.8	2.2	2.2	0.42	1.96	-0.29	1.37	0.58	81.0
15	62.6	35.9	1.0	0.6	-2.23	3.13	-0.04	-.76	0.43	68.8
Core 265										
05	0.0	19.5	53.3	27.2	6.86	3.24	0.26	1.05	0.51	58.5
10	24.6	66.6	5.6	3.1	0.35	2.53	0.13	1.46	0.59	58.1
15	9.3	65.5	16.3	8.9	2.80	3.47	0.34	1.67	0.62	43.7
20	42.4	48.4	5.6	3.6	-0.36	2.88	0.25	1.17	0.54	59.9
25	67.4	29.3	1.9	1.4	-5.87	7.67	-0.61	0.85	0.46	56.5

Table 3 *Analyses of recent sediment from Site 2–3 grab samples.*

Grab	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt.	$CaCO_3$ (%)
Site 2 (C)										
2528	00.4	90.8	04.4	04.4	01.84	01.61	00.43	02.37	00.70	71.5
2529	01.2	73.9	16.0	08.9	02.96	02.98	00.62	01.53	00.61	50.3
Site 3 (C)										
2530	22.9	71.2	03.3	02.6	−0.12	01.96	00.05	01.99	00.67	71.5
2531	00.0	92.0	04.2	03.8	01.83	01.32	00.29	02.88	00.74	58.8
2532	00.0	85.5	08.8	05.7	02.51	01.80	00.50	03.04	00.75	74.0
2533	37.4	55.7	04.1	02.9	−0.41	02.84	00.15	01.00	00.50	45.2

sition contains no other stratigraphic variation. Some granitic and metasediment basement rock types also occurred in highly immature fragments. Both cores bottomed in weathered chalk.

A grab at Core Site 264 showed only shelly sand, while a grab at Core Site 265 showed a more muddy sand fraction. Other grab samples from Site 2 and from Site 3 to the NW showed a similar range of surface sediment size fractions.

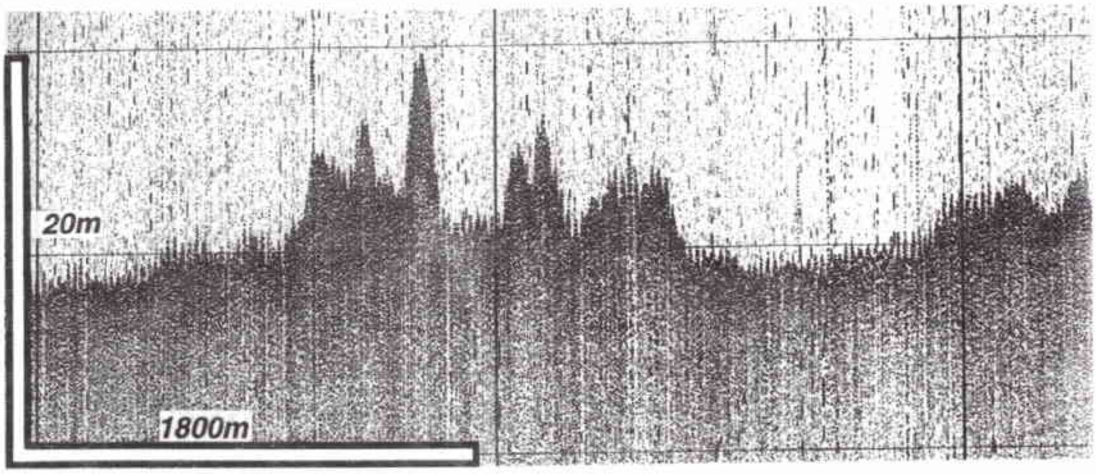

Figure 9 *Uniboom. Strong relief on shallowest part of bank on basement terrane.*

4.1.3. Site 3: Basement terrane

The basement terrane is composed of Devonian and Carboniferous terrigenous sediments deformed and metamorphosed during the Hercynian orogeny. Granites have been mapped in the seafloor both directly and by geophysics (Fletcher and Evans, 1987). The area forms the Haid Frais Bank (Fig. 1), coming to within 75 m of the surface at its western end outside of this area; in this area 85 m is about the shallowest depth recorded. The south-central area of the bank has a NE–SW ridge of strong roughness, with pinnacles and irregularly-shaped areas of rock exposed.

Geoacoustically, the terrane could be characterized as having a very high velocity and being essentially internally range-independent.

Internal acoustic character A highly reflective character marks the bottom; there are no internal reflectors. On two passes across the bathymetrically shallowest part of the bank a rough surface exists (Fig. 9). Elsewhere the basement terrane has a smooth bottom which is not as flat as the surrounding sedimentary terranes.

Bottom morphology and character Except in the areas where rock exposures are common, the generally flat bottom displays the same general character as the bottom of the chalk terrane. A darker, older, and a lighter, newer, sediment occurs in patterns that are indistinguishable from those seen on the chalk terrane. In the vicinity of the strong roughness, the most complex side-scan records show exposed rock and sediments (Fig. 10a,b) similar in their backscatter response to the sediments elsewhere on this and the other terranes.

Grab samples Because of the anticipated hardness of the bottom, no cores were attempted. Two grabs (2531 and 2532) were taken on the smooth basement terrane area between the edge of the chalk terrane and the rough bottom area, and two grabs were taken within the rough basement area (Fig. 3; Table 3).

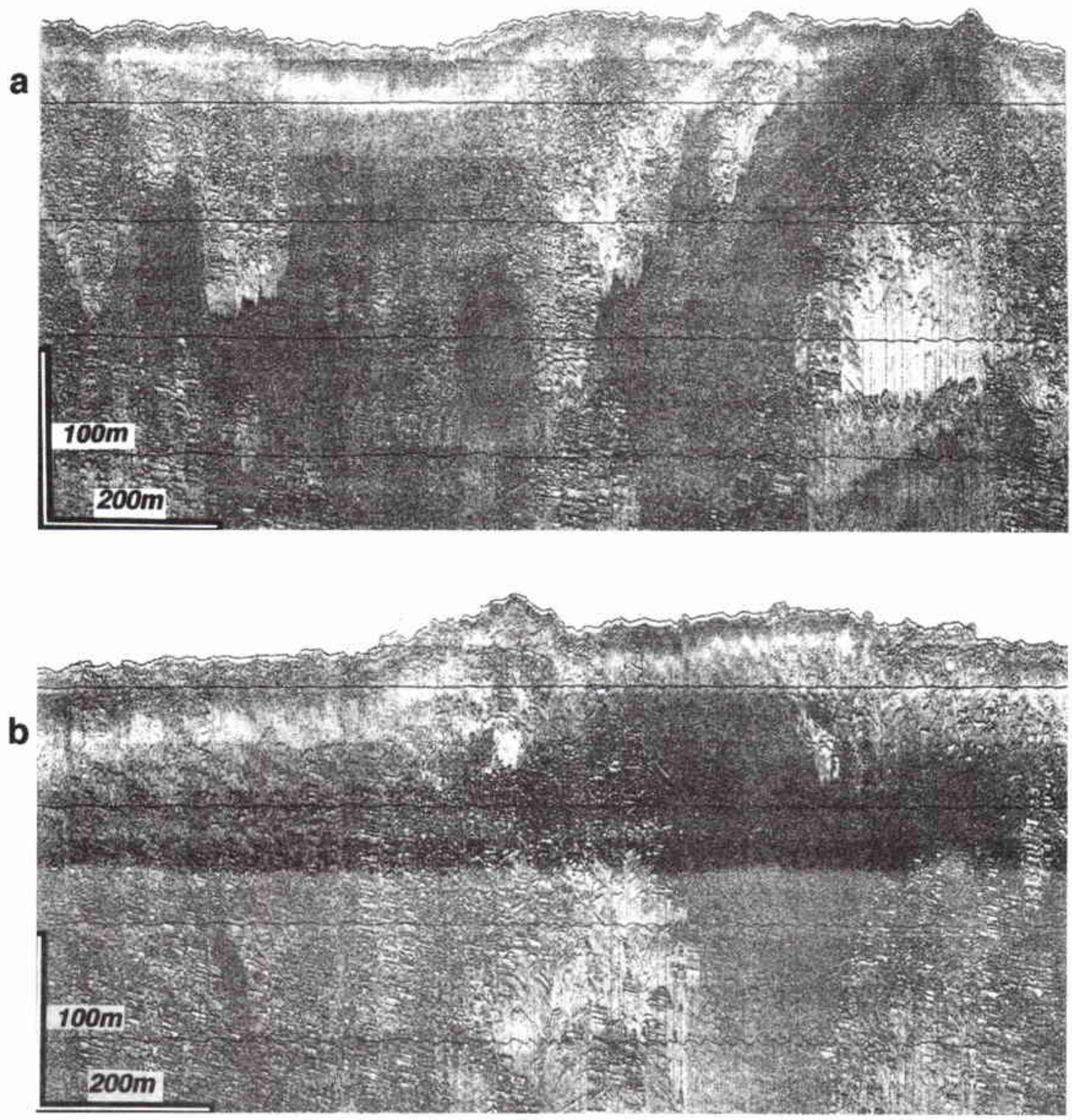

Figure 10 *(a) Complex side-scan patterns on shallowest part of bank. Blocky texture probably jointing in bare rock. (b) Complex side-scan patterns on shallowest part of bank. Blocky texture probably jointing in bare rock.*

All cores showed similar coarse shelly sand with coarse gravel up to 3.5 cm across. The thickness of this sediment unit is almost certainly no thicker than that seen over the chalk terrane. All terrigenous material would appear to be locally derived and is immature in shape, indicating short transport distances.

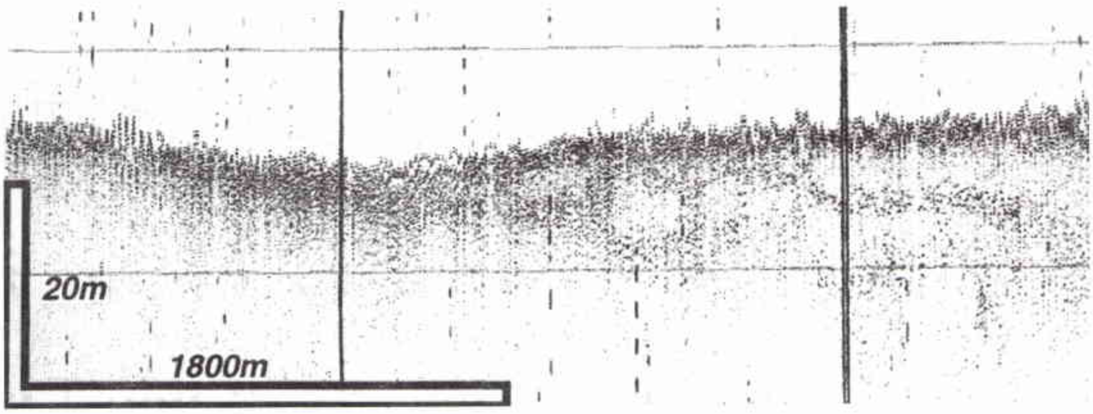

Figure 11 *Uniboom. On-lap of Paleogene–Neogene sediments (P–N terrane) onto basement terrane (left).*

4.1.4. Paleogene–Neogene (P–N) terrane

The survey tracks were continued to the NW to pin-point the contact between the basement terrane and the Paleogene–Neogene terrane. The boundary shown between the basement and P–N terrane (Max, 1989) is confirmed and located in detail.

The contact is a feather edge of onlapping sediments that thicken to the NW (Fig. 11), rather than being a fault contact. Because the acoustic experiments at sites 2 and 3 did not take place over this bottom type, it is not described here.

4.1.5. Conclusions: Sites 2 and 3

Sub-bottom reflections, which are apparent folding within the sedimentary basins, coincide with side-scan images of apparent folding of bedding traces. There is a continuity of orientation of the linear boundaries between the two sediment types shown on the side-scan sonar. The younger sediment type often occurs in linear strips similar to sand ribbons. These trend generally to the NE, except in the eastern part of the area where there is a slight divergence from this more general direction along the two survey lines (Fig. 12). These probably reflect a strong NE–SW bottom current in the area, at least during storm conditions when water movements would be at their greatest.

The younger sediment does not appear to have current features on its surface, which is common where sediment is thin and there is water flow rather than oscillatory movements. The older bottom, however, is commonly speckled with patterns that in a few places appear to be en-echelon ripple fields, and in others reflect a similar scale unevenness in the surface. When plotted out, these small features on the older bottom are always orthogonal to the survey line (Fig. 12). Because it is unlikely that orientation of the ripple fields imaged were always fortuitously located with respect to the survey lines, it must be concluded that there is a statistical randomness in

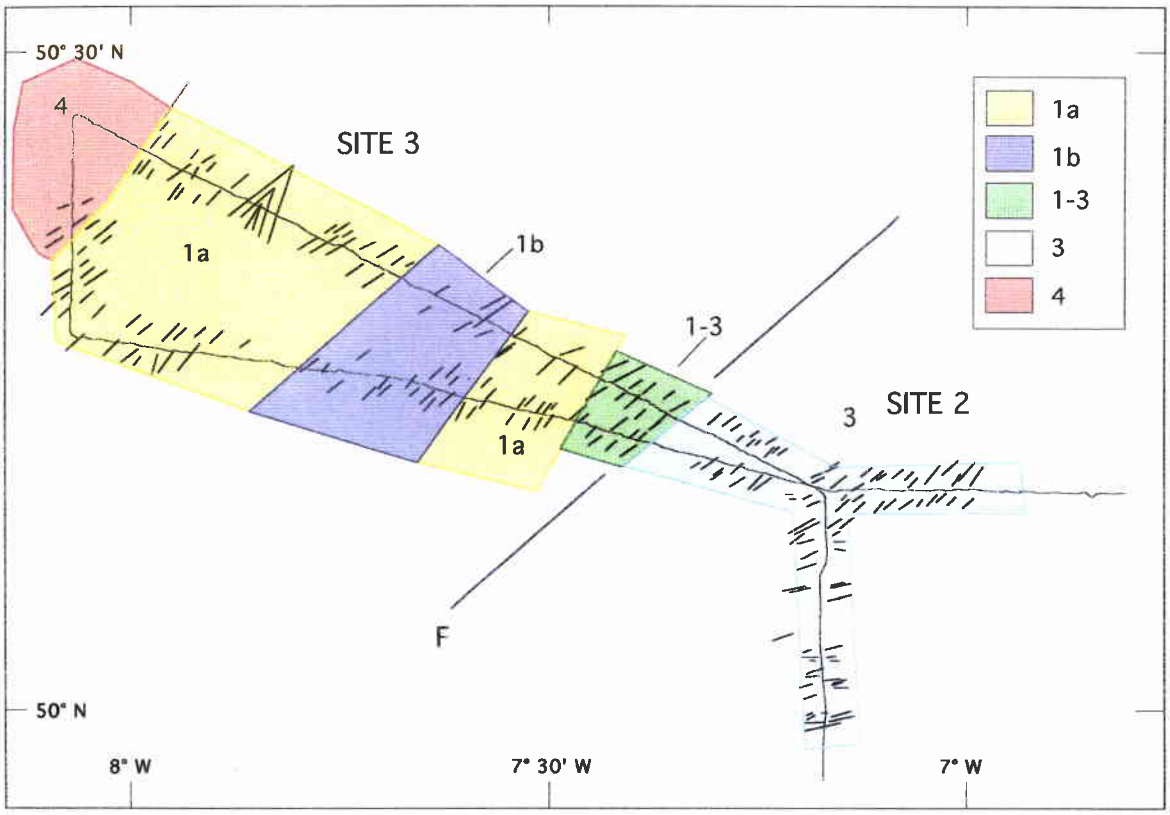

Figure 12 *Seismic reflection and side-scan sonar interpretation of survey from Sites 2 and 3. Terranes and margins of terranes described on figure. Longer lines in vicinity of the survey tracks represent the orientation of the boundaries between terranes. Smaller dashes show the relative abundance and orientation of small features. 1a, Acoustic basement terrane, probably low grade metasediments; 1b, rough bottom with no clear bedding, probably granite in acoustic basement; 2, Transitional margin, terrane boundary at surface uncertain, possibly complexly faulted; 3, Chalk terrane with highly featured bottom probably reflecting chalk bedding on eroded surface only little covered by recent sediment; 4, Paleogene–Neogene (P–N) terrane with few bedding features indicating a more complete peneplaning (eroding to a flat surface) than the chalk terrane.*

small-scale bottom roughness and that the geometry of the side-scan at any point was the determining factor in the imaging of the small-scale features.

Sediment thickness at the two core sites was similar. A sandy upper layer formed almost entirely from shell fragments overlays a 5–10 cm coarse gravel of locally derived bottom materials. There was no significant variation in the composition of the grab samples taken at the core sites and on the basement terrane bank, where it is likely that sediments are no thicker (Bradley, 1986).

A fairly range-independent geoacoustic model can be established for the sites, at least within their individual terranes; bottom roughness can also be treated as having no significant variation, at least off the rough bottom area on the basement terrane bank. Total sediment thickness can be modeled as between 10 and 50 cm with a coarse sandy upper part having a porosity of greater than 50%. This is underlain by a coarse gravel resting on relatively fresh chalks or basement terrane. Completely unconsolidated mud within both the sand and gravel would probably exert virtually no influence on the acoustic properties compared with modeling water in porosity alone. At lower frequencies, it may prove unnecessary to model any sediment at all, with the proviso that the sea bottom may be somewhat more reflective than would be suggested from the physical properties of the underlying bottom materials.

4.2. SITE 2(A)

The site was selected primarily to study the asymmetrical backscatter response in an area where a strong asymmetry in the morphology of the seabed had been reported. A limited uniboom survey was undertaken in order to ascertain the scale of modern sandwaves that commonly form in high energy sedimentary environments such as the approaches to the English Channel. No grab sampling or side-scan sonar surveying was carried out.

4.2.1. Survey

The uniboom shallow reflection seismic survey showed that there was virtually no Recent sediment or sandwaves more than a few meters high within the surveyed area. The bottom is an extremely flat and featureless erosional surface cut into a stratigraphic sequence of chalks, limestones and sand, mud, and siltstones. Bedding features are apparently flat or lying at shallow angles to the seabed (Figs. 13,14). Often complex structure including faulted dipping strata (Fig. 15), faulted anticlines (Fig. 16), and synclines (Fig. 17) clearly illustrate the planation of an sedimentary sequence that is older than the bottom surface.

The seabed geology is relatively straight-forward in that only three main geomaterials make up the central part of the area. The geological interpretation here follows the solid geological map (Lott and Bouysse, 1983). North of 49°30′N the bottom is composed of chalk and to the south the bottom is composed of an essentially conformable Paleogene sequence of clay, sand and calcareous beds overlying a basal hard, white limestone (Fig. 13). Mapped seabed sediments do not vary much. They consist of coarse sands and conglomerates less than 1 m in thickness except in a few 3–6 m amplitude sandwave fields. No sandwaves were found in the course of this survey, indicating increased bottom currents. Bottom type is strongly variable from north (rock–chalk bottom) to south (rock–limestone and limy sandstone bottom). Anticlinal closures shown by back-to-back diamonds, synclinal areas by opposed diamonds on apparent axial trace are seen. Dashed lines show true strike with dips

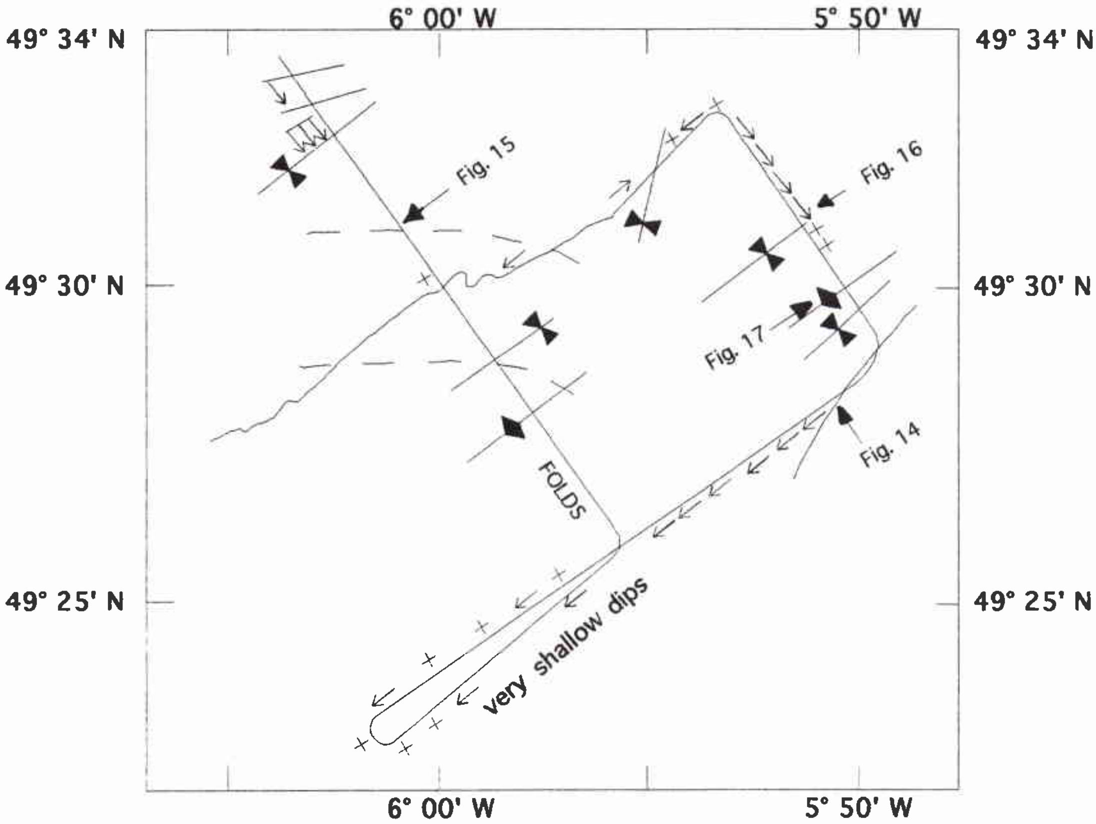

Figure 13 *Location of shallow reflection seismic survey of Site A (Fig. 1). Locations of Figs. 14–17 shown. Interpretation of shallow reflection seismics.*

shallow to moderate to the SW. Small arrows along track line show dip direction. Furthest NW part of track line shows solid lines which are faults separating chalk to the south from older rocks to the north. The NE–SW trending fault and fold structures of Lott and Bouysse (1983) were also identified in finer detail on this survey in the older chalk as well as the younger sedimentary sequence.

The chalk has fewer acoustic impedance contrasts and apparently only moderate internal scattering whereas the Tertiary sedimentary rocks are strongly acoustically laminated parallel with stratigraphic bedding and are almost always darker on the seismic record, indicating higher random or scatter energy return from within impedance packages.

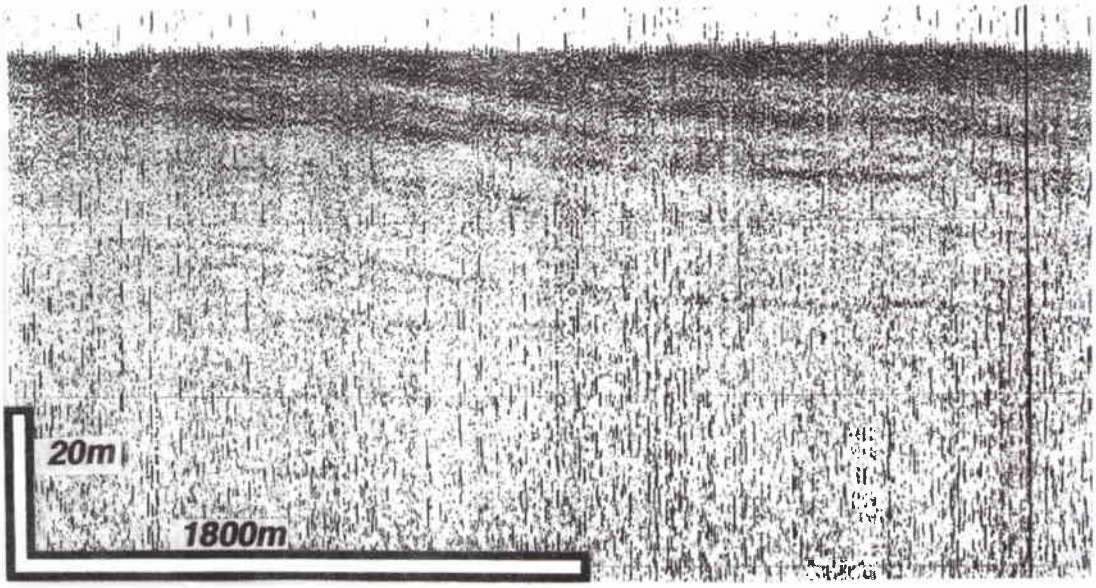

Figure 14 *Uniboom. Shallow dipping sediments along the middle of southern survey line. Apparent dip is shallow along entire line to south. True dip of beds is not known.*

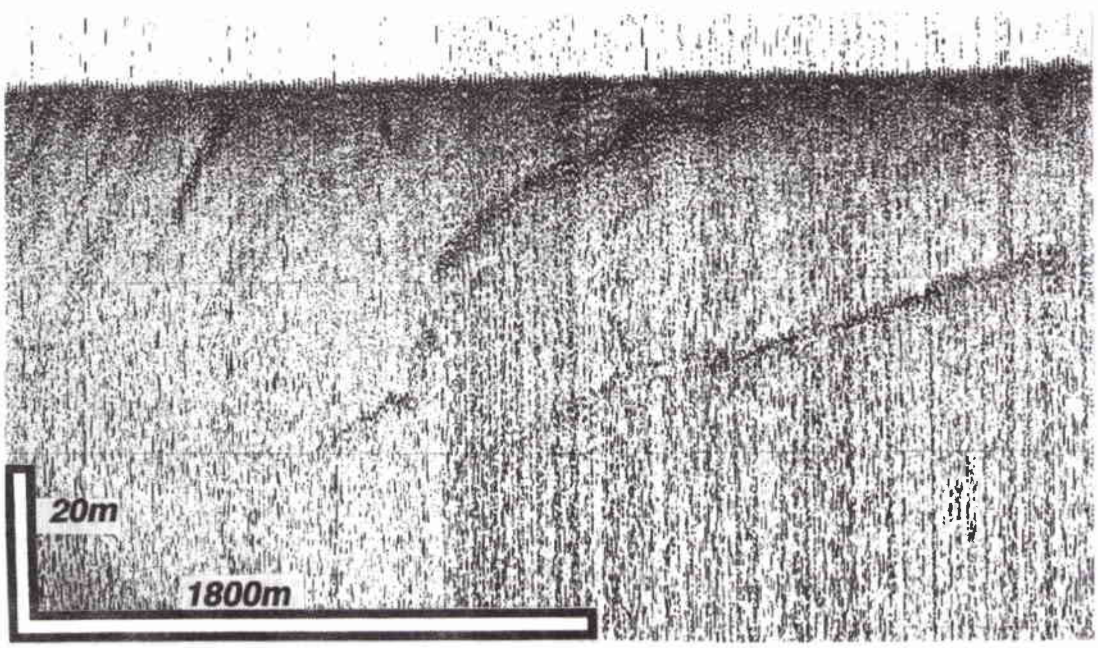

Figure 15 *Uniboom. Faulted dipping strata. Possible contact between more thinly bedded Tertiary sediments in left and more massively bedded limestones and chalks in east.*

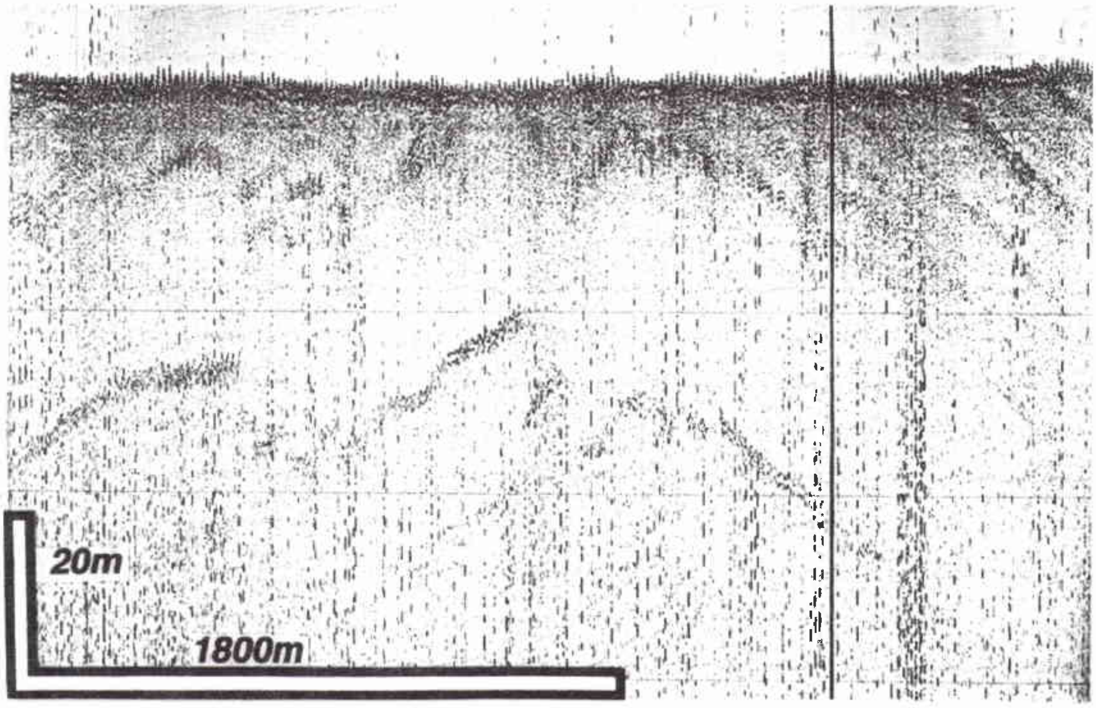

Figure 16 *Uniboom. Faulted anticline.*

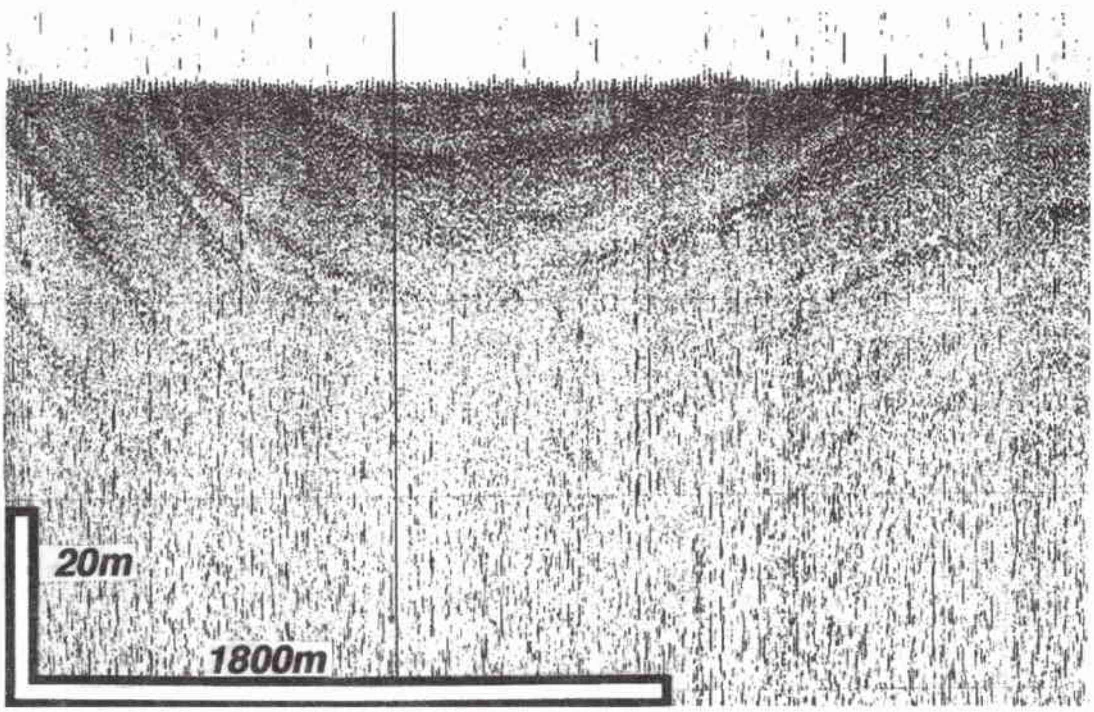

Figure 17 *Uniboom. Syncline.*

4.2.2. Backscatter elements

No large scale morphologic elements that could strongly influence backscatter occur within the site. The bottom is very flat, but several localities display abnormally high reverberation. Variations in backscatter could have two causes.

1. They may be due to small-scale differences in the very thin surface sediments. It is not anticipated that these sediments would cause a strong variation because they are composed of the same materials throughout the area and are not dissimilar in their internal physical properties from the solid geological materials they overlie. Backscatter variation would probably be fairly random, depending on the location and size of sediment patches. Because the sediments in-fill low areas in the eroded rock-head, they might have the effect of reducing backscatter, rather than being a primary cause of it.
2. Different rock materials in the seabed may have significantly different roughness because the three different materials are internally different. The chalk is fairly massive, with few strong planar structures and would tend to weather to an uneven to flat, relatively smooth bottom with potentially the lowest roughness. The weathering nature of the limestone is not known, but similar limestones often have blocky weathering surfaces, often with a strong planar orientation following bedding. The Tertiary sedimentary rocks and interbedded sand, silt, and limestones tend to weather in parallel ridges that will lie about E–W across this area. This unit has the potential for the greatest bottom roughness and the strongest azimuthal control of backscatter.

Areas of high reverberation from a more reflective bottom were identified in a large patch at 49°44–43′N, 6°W and along a short track distance at 49°11′N, 6°07′W. Both sites are located here for reference to Figs. 1 and 13 because they are not within the three detailed site areas here, but were acquired during other work. Normally, there are two or three multiples (Fig. 18) of the shallow reflection seismics. Because the number of multiples is directly related to the reflection or reverberation character of the bottom, an increase in the number of multiples indicates a more reflective bottom. In both of these localities the reverberation is characterized by five or more multiples (Figs. 19a,b). This is a common shallow-water effect where energy from the echo-sounder reflects off the bottom and sea surface a number of times; each time being more attenuated and revealing the fine-scale variations in bottom reflection character. The actual bottom is the 'first bounce' of energy from the high resolution (16 kHz) Krupp-Atlas echo-sounder. Multiples of the bottom reflection are caused when energy reflects from the surface back to the bottom and is again detected as part of the depth sounding record. Absorbant bottoms have few multiples; highly reflective bottoms have more multiples. This bottom, with five discernable multiples, is very reflective.

Site 49°44–43′N, 6°W A Cretaceous chalk substrate with south-dipping bedding underlies bioclastic, glauconitic limestone. This sequence locally passes up into dolomitic, glauconitic sandstone. The entire seabed is consolidated rock. Up section,

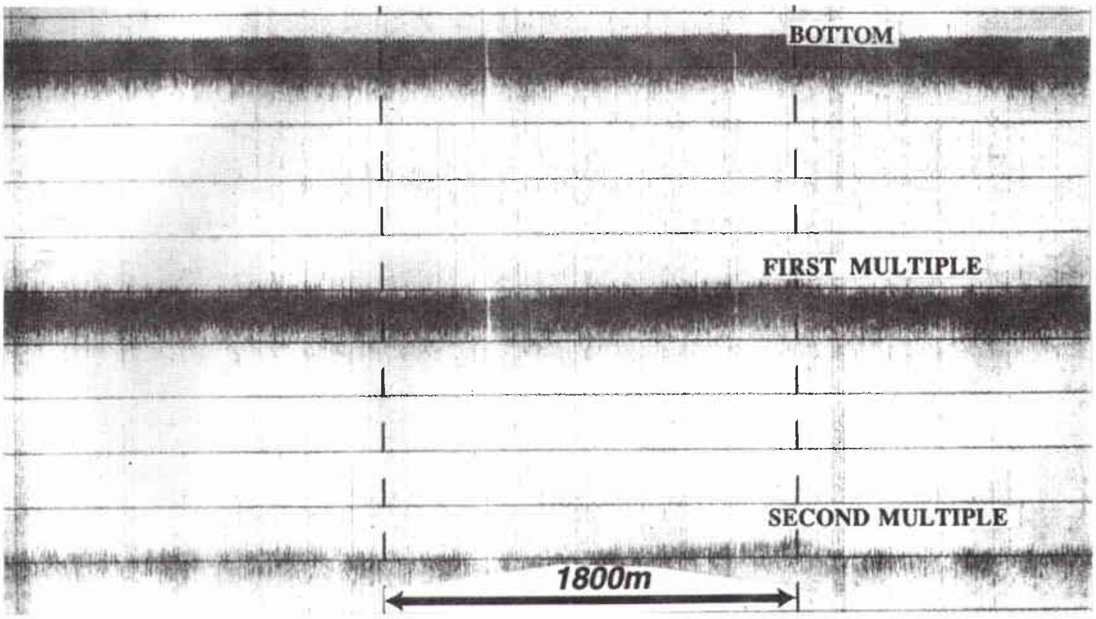

Figure 18 *Normal reverberation character of bottom expressed as a function of the number of multiples.*

slightly to the south of the high reverberation area at about 49°41′N, beds of hard, white chalk with flints are encountered.

Surface sediments are undifferentiated, gravely sands. Bed-forms are elongate sand patches having relief of less than 1.5 m, with broad intervening gravely areas over essentially exposed sedimentary rock substrate. Elongate axes of sediment patches are oriented about WSW–ENE. 50–75% of the sand is composed of shelly carbonate fragments having a mean grain size of the lower half of the medium sand range (2.0–1.5 phi). Only 0–50% of the gravel fraction is composed of shelly debris, the remainder is mainly flints and hard chalks bonded by cryptocrystalline silica.

Site 49°11′*N*, 6°07′*W* The substrate consists of upper Paleogene, pale green to gray glaucontic sandy, bioclastic limestones and glauconitic, medium to fine-grained sandstones. Some well cemented horizons occur, giving a strong bed to bed hardness contrast. This site is within several hundred metres of the base of the Neogene, where it unconformably overlies Cretaceous sediments.

Surface sediments are mainly undifferentiated, gravely sands. Elongate sand patches are oriented mainly about WSW–ENE, and are also separated by narrow gravely strips up to 50 m across. Commonly the sand covers up to 80% of the seabed, but may be no more than a thin veneer of a few centimentres thick. Locally there are small sandwaves and streaks with a wavelength of 3–3.5 m. Their crests are oriented about NW–SE. They are generally present on sand patches and sheet deposits. Mean sand size is the coarse half of medium sand (1.0–1.5 phi). About 75% of the sand

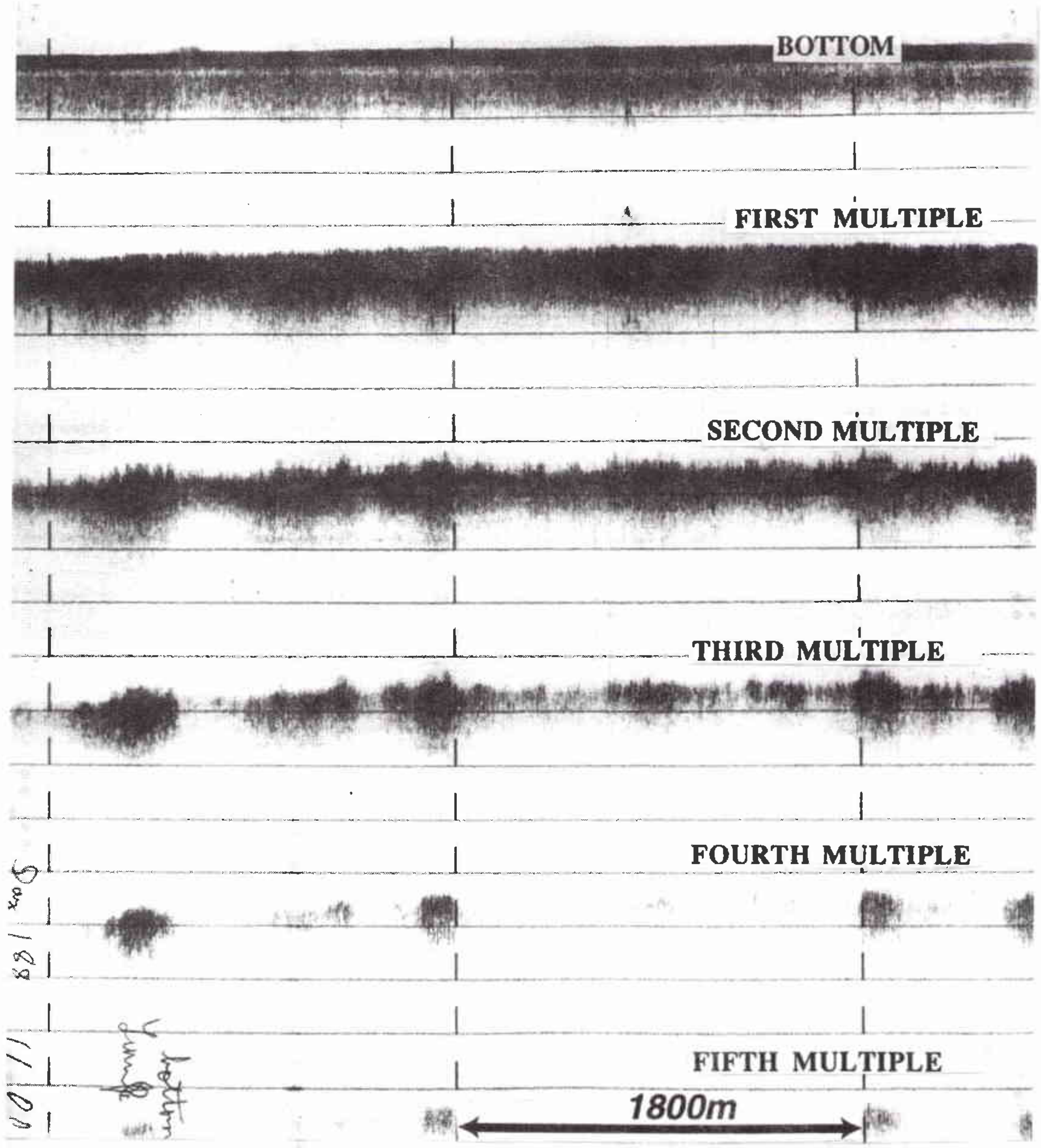

Figure 19a *Reverberation from otherwise flat, featureless bottom. Note that although the bottom appears to have no significant reflection variations on the first reflection, each successive multiple, in which energy is progressively dissipated, shows clearly that some parts of the bottom are more reflective than others.*

fraction is composed of shelly debris. Virtually all of the gravel sized fraction is fresh shelly debris.

Cause of high reverberation bottoms. It is not possible to determine whether the greater reflectivity of the bottom is due primarily to the presence of more reflective

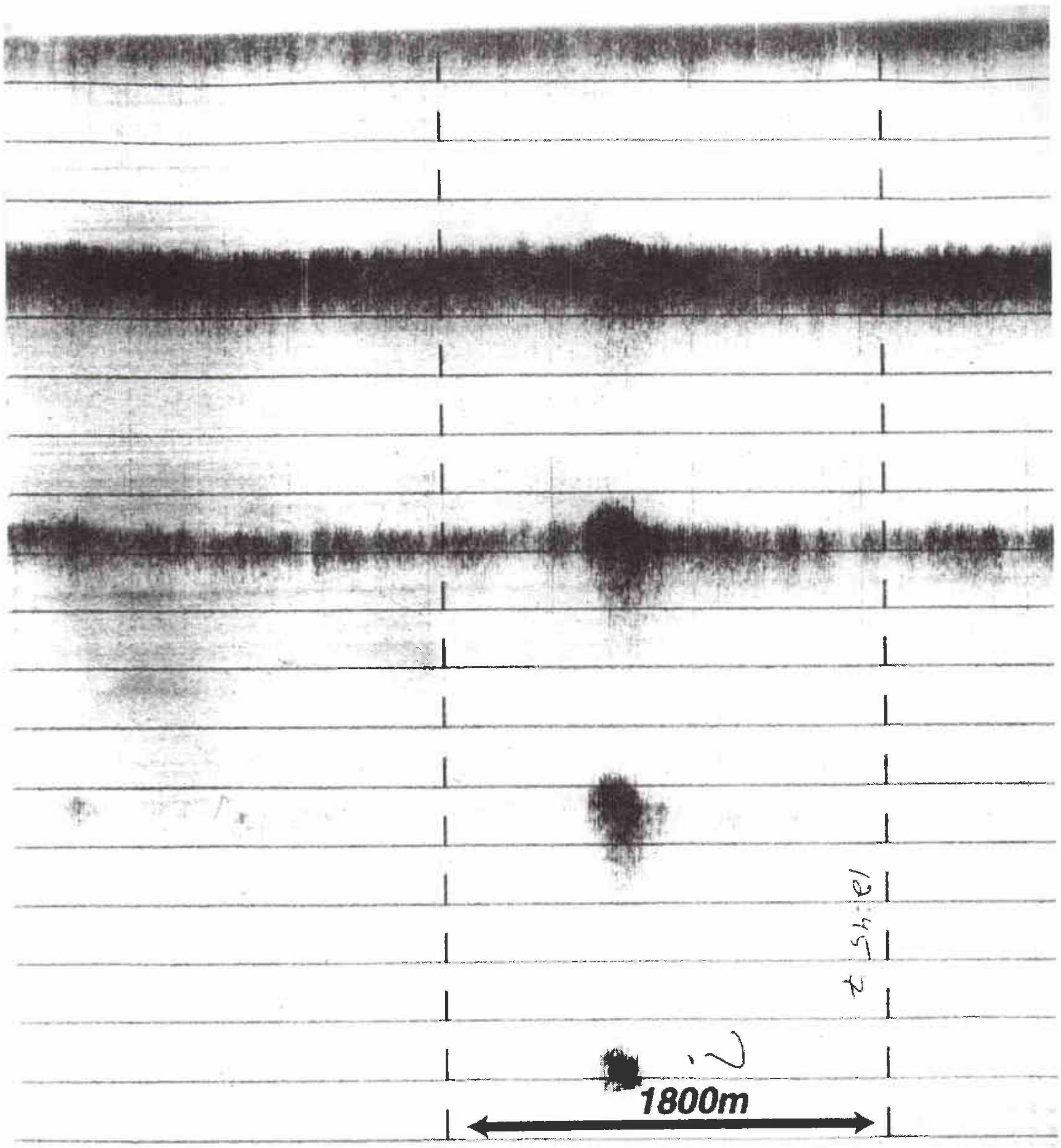

Figure 19b *Reverberation from otherwise flat, featureless bottom. From side-scan sonargraph of the same position, the isolated reverberation feature appears to be a shell bank. Note that on the bottom (first return), there is no indication of this shell bank because the strength of reflection from the rest of the bottom has saturated the depth sounder.*

rock strata or gravel pediments composed of flint at the surface. Both geological elements are present in the area and could be anticipated in the areas of high reverberation. Each could be responsible for the more highly reflective bottom seen on our survey lines.

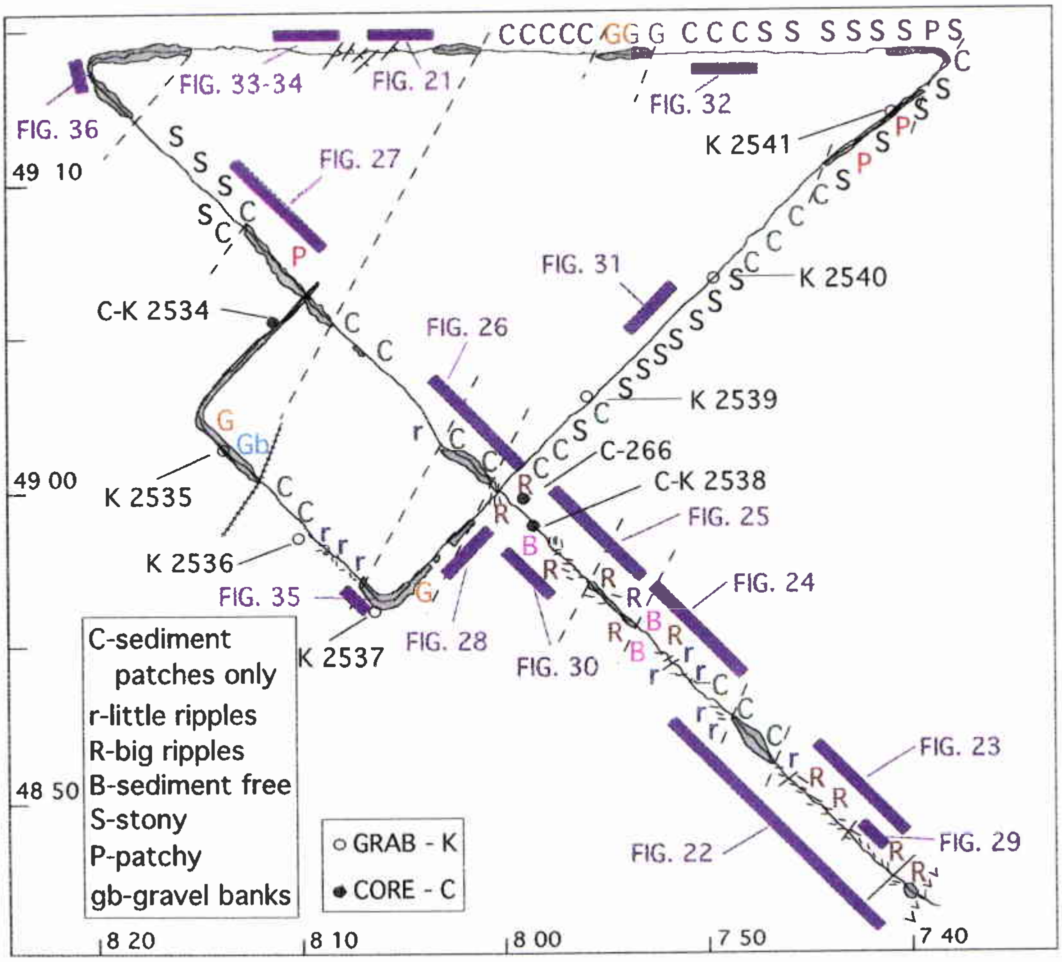

Figure 20 *Survey track plot, core (C), and grab (K) sample locations, for Area 1 (B). Locations for s 19–36 also shown. Interpretive overlay shows bottom types, sub-bottom information, and general bottom character. Patterned areas shown straddling track lines are bathymetrically upstanding sand waves. Dashed lines show orientation of roughness elements on rockhead bottom where there is little or no sediment.*

4.3. SITE 1(B)

This site (Fig. 20) was selected because of a strong NE–SW ridging on the seabed. These ridges are composed of sands and gravels that formed in an unusual set of relatively straight and continuous, nearly parallel ridges prior to or associated with the beginning of the most recent sea level rise (Table 1). They are formed directly on the eroded surface of the stratigraphically younger part of the Paleogene–Neogene (P–N) terrane.

Although the ridges are essentially Recent sediments, they have undergone a complex history of erosion after their initial formation, during the continued rise of sea level to its present level. Their surface at the sea bottom is very different from that which originally formed, in that the originally relatively soft sediment surface has been deflated by current action and the finer grained materials, to coarse sand, have been removed. This has resulted in the formation of a lag layer at the surface which is formed from the more coarse materials, usually gravels, but with some boulders. This armored bottom is characteristic of the continental shelf to the west of Britain. Closer inshore, and where Recent sediment supply is abundant, thick coverings of Recent sediments may occur over the lag bottom.

4.3.1. Survey and sampling

Uniboom and sparker shallow reflection seismic and side-scan sonar studies were made along a single track that was designed to transect the ridges at two angles and pass both along a trough and a ridge crest. Grab samples were taken. Core sampling was attempted on the top of a ridge crest, on which patches of apparent Holocene sediment were imaged on side-scan. However, the core literally bounced when it hit the bottom, denting the core mouth, and the circular fin support assembly was strongly bent when the core fell on its side on the surface. This indicated that the patches identified as Holocene sediment were very thin or were some type of diagenetic material such as a calcareous cemented bottom. Alternatively, a boulder could have been struck by chance.

Video pictures of the surface showed a number of large rocks standing above a gravely surface that had thin, patchy, softer sediment cover. The video camera was fixed to the grab sampler at the other locations, although not at this site to view the sampling process and obtain a visual esitimate of bottom hardness character. Where grab sampling was observed, the bottom was everywhere seen to be very hard, with virtually no penetration of the grab sampler jaws into the bottom. Additionally, when the grab was observed to strike bottom, close, and drag, very little fine sediment rose into the water. Visibility was maintained throughout sampling operations.

4.3.2. Internal acoustic character of the P–N terrane

The P–N terrane is generally formed from shallowly SW dipping sedimentary rocks that are highly banded acoustically (Fig. 21), reflecting the presence of a rapidly alternating sequence of sandstones, siltstones, mudstones, and some limestones (Max, 1989). Because of the vertical exaggeration (see scale on all seismic reflection figures), the real dip of the sediments is much less than is apparent.

The acoustic impedance sequence appears in places to be strongly cyclic with repetition of reflection strength sequences probably reflecting a rhythmic alternation of depositional environments and consequently, the type of sediment deposited on the shallow water marine shelf.

In the far southwest of the survey, nearest the continental shelf, and in the area in which a more complex stratigraphic succession has been identified by Evans and

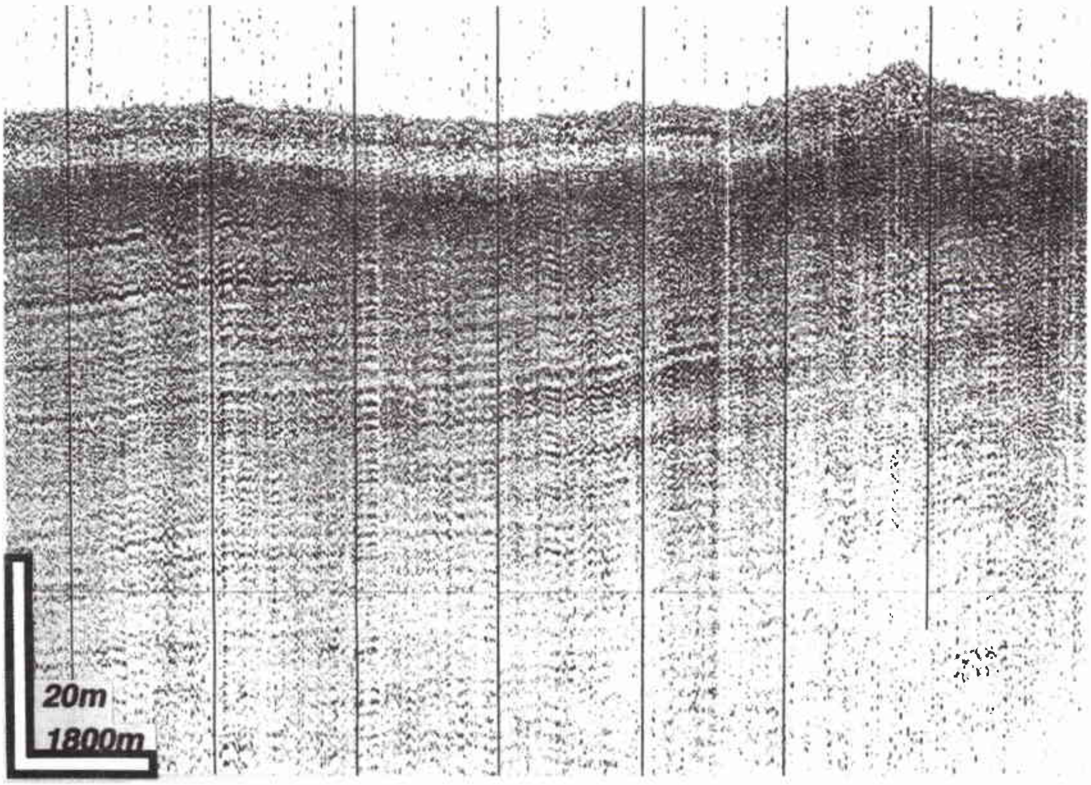

Figure 21 *Sparker. Strongly banded acoustic impedance structure. Note in upper left, every fifth reflection is somewhat stronger. These would mark the second order reflection packages, with the weaker reflections being internal third-order.*

Hughes (1984) and Pantin and Evans (1984), development of local unconformities and continued development of younger sediment in the ridges, which is not so strongly acoustically laminated, has taken place (Fig. 22).

4.3.3. Nature of the P–N terrane surface

Large flat areas (Fig. 21) of the seafloor are an erosional surface cut into the partially lithified sediments of the P–N terrane. Throughout the area the reflections representing bed margins truncate at the seafloor, indicating that there had been down-cutting of a seabed whose surface was more level than the sedimentary sequence it cut down into.

Usually this surface is a simple erosive planation with no significant channeling or formation of sediment wedges. Near the shelf margin, however, significant channeling and infill occurs (Fig. 23). Away from the margin over only a short distance, channeling that strongly resembles braided stream deposits occurs (Fig. 24). Elsewhere, especially further away from the shelf edge, only small, tributary channels are common (Fig. 25), that are probably part of a complex dendritic stream erosion

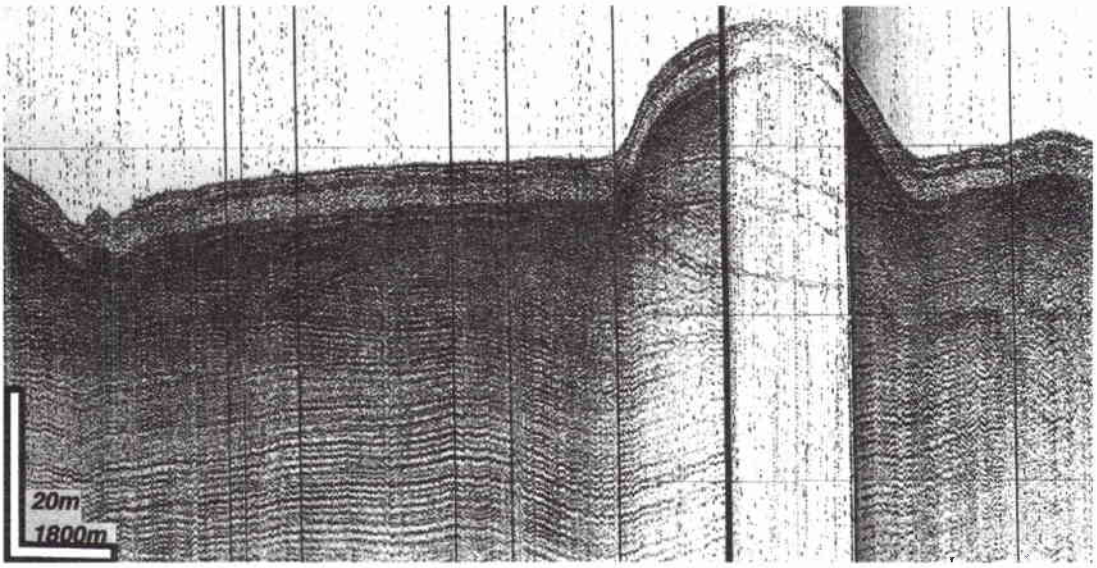

Figure 22 *Sparker. Strongly parallel banded acoustic impedance structure (probably bedding), tilted and then eroded. Sea bottom roughness is probably on rock.*

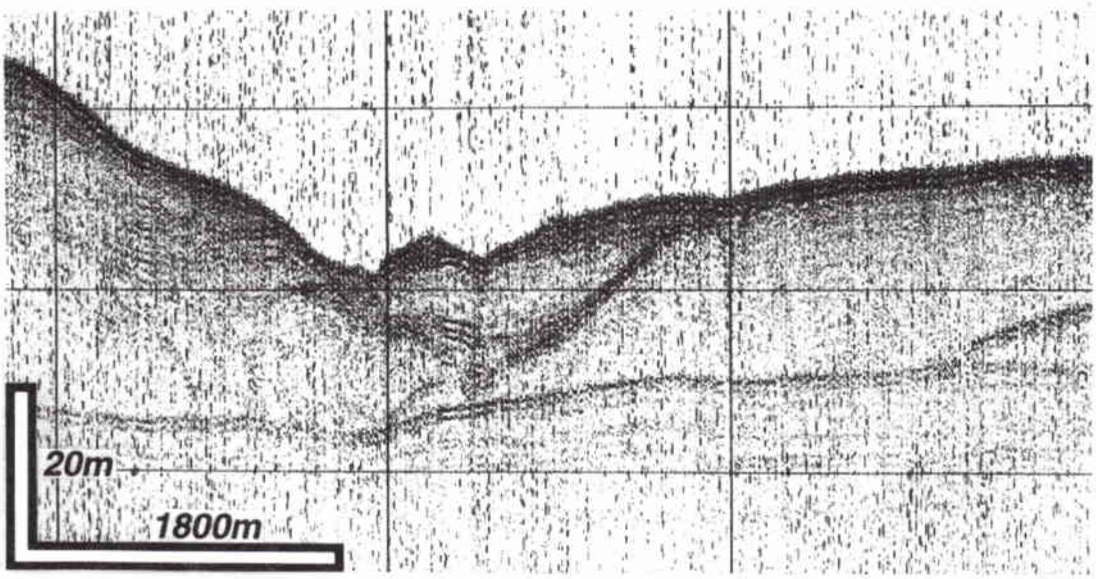

Figure 23 *Uniboom. Strong channeling, multiple erosion surfaces and sediment wedging near the southwesternmost survey track. Note small triangular hillock for correlation with Fig. 22.*

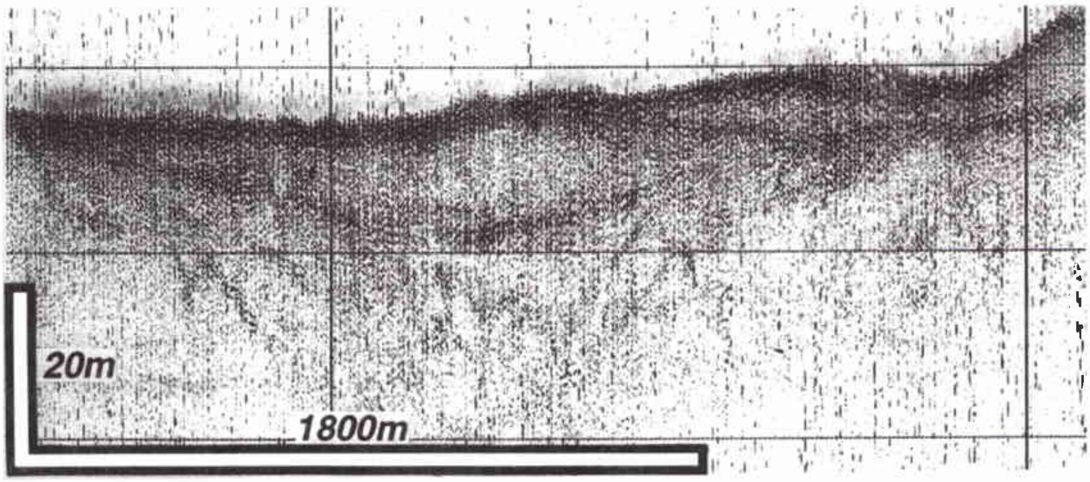

Figure 24 *Uniboom. Weaker, but complex channeling and late sediment infill above apparently imbricated channel.*

system that has not been mapped by us. Virtually none were seen north of the crossing of the main survey track (Fig. 20).

4.3.4. Ridge features

Large, parallel NE–SW trending ridge features form a field of bottom corrugations (Fig. 1) which terminate almost abruptly at the shelf margin. The almost straight courses of ridge traces passing from the shelf break to the NE were formed in water between 40 and 80 m depth, in late Quaternary times when the shoreline lay between the 130 and 120 m contour (Evans and Hughes, 1984). Their surface reverberation character, however, would probably not be much different at any particular height on the ridges, between the surface of the ridges and troughs, and almost anywhere on the widespread consolidated sediment terrane. During sea level rise, the entire shelf, including the ridges, underwent deflation that produced a lag surface dominated by only the coarsest clastic material, and local cementation in shallow water conditions.

Larger ridges rise over 60 m above the general seafloor, but in this area they were generally below 25 m. This imparts a strongly corrugated effect to the bottom morphology that presents strongly contrasting orthogonal profiles. In the NE–SW direction, profiles are essentially shallowly wedge shaped, controlled mainly by the regional slope of the continental shelf. In the SE–NW direction, profiles show the asymmetrical ridging, which has the steeper faces of individual ridges facing the north. The sand ridges stand as almost completely acoustically transparent bodies dramatically on the otherwise flat bottom (Fig. 26). Slight pull-ups below the ridges are probably the result of the higher speed of sound in the ridge than in the surrounding water; this pull-up does not occur everywhere. Occasionally, especially in the smaller and broader ridges, there is some internal structure (Fig. 27), but nothing that formed a recognizable sedimentary pattern. At one locality there appeared

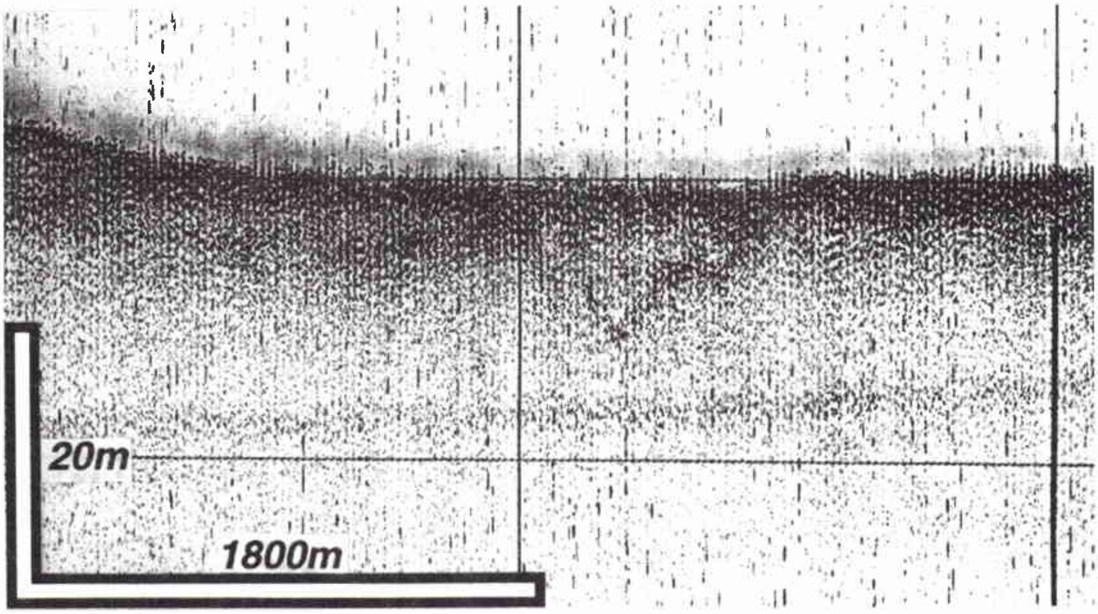

Figure 25 *Uniboom. Small, tributary-type channel, infilled to general erosion level.*

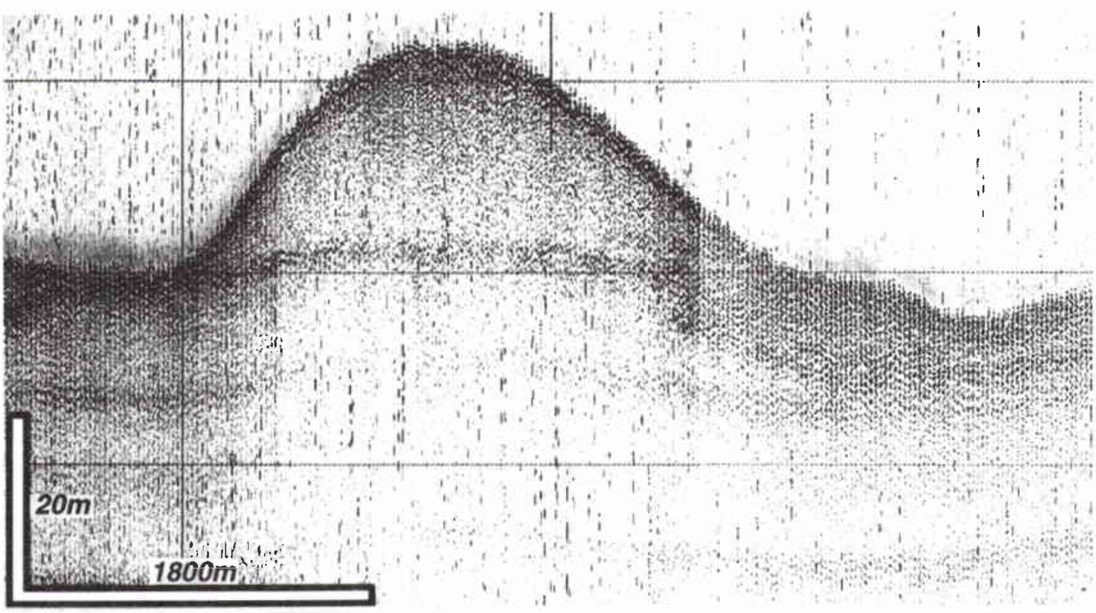

Figure 26 *Uniboom. Slightly asymmetrical ridge clearly standing on continuation of eroded P–N Terrane where its bedding is parallel to the sea floor trend.*

to be a field of smaller sandwaves, also standing on the erosion surface (Fig. 28), but the side-scan record of this area only showed a stony bottom with no parallel ridges. These probably represent irregular gravel or sand mounds, rather than symmetrical current features.

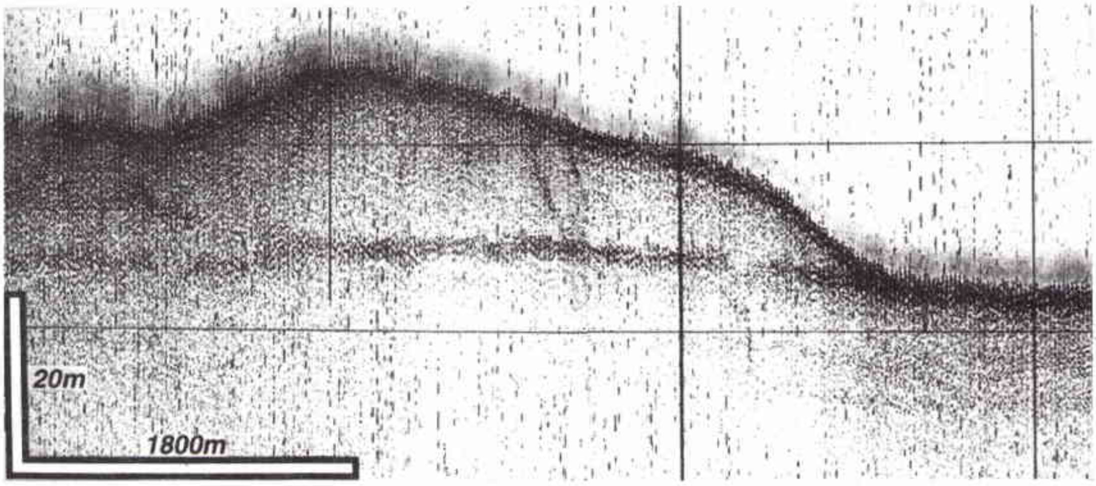

Figure 27 *Uniboom. Minor internal structure in a low ridge. Note well-defined margin.*

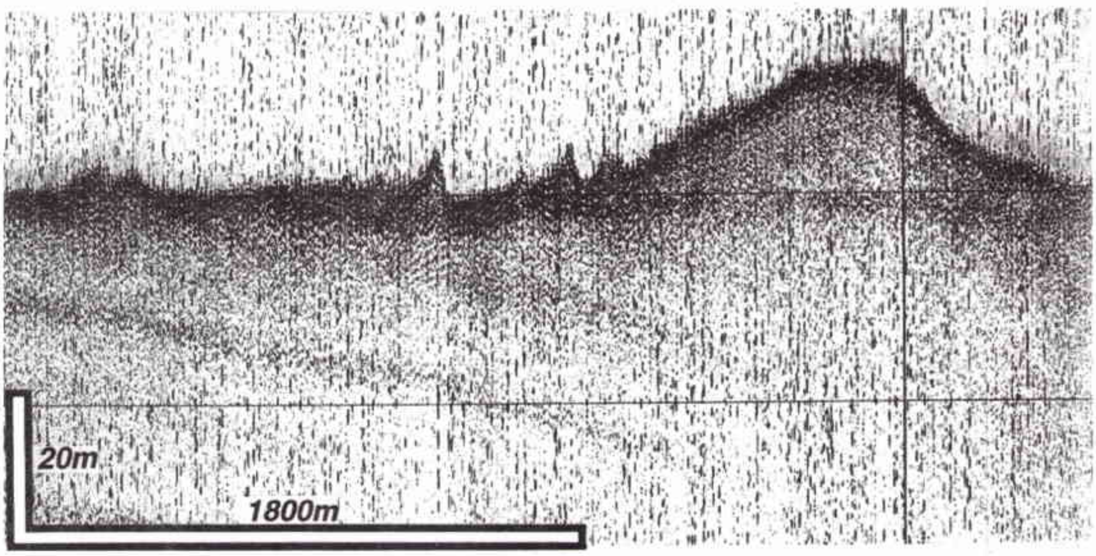

Figure 28 *False small sand or gravel ridges that on side-scan do not show as linear bottom features or sand waves; probably only debris piles of indeterminate origin..*

More broad and lower profile ridge features to the north, in the Irish sector of the SWAP, may be cored by older sediment and may also be partially controlled by reactivated geological structures extending well into the sea bottom rocks and sediments.

4.3.5. The sediment surface

The P–N erosional surface has two general expressions. Sediment locally forms a thin veneer over the eroded P–N terrane, or the eroded surface is very flat with no acoustically imaginable inhomogeneities. Here it is apparently flat and completely featureless, with no macroscopic sedimentary structures. Locally, where sediment is thicker, near the southern end of the survey line, however, small ripple fields were observed (Fig. 29). These persisted in diminishing prominence, to about the flank of the first major 'sandwave' (Fig. 30), where there is only a mottled bottom of thin sediment. Because the sediment appears to be largely shell fragments, it is possible that the greater amounts of shell sand near the continental margin may reflect a one-time greater shelly fauna productivity near the shelf edge. On the other hand, it could simply indicate greater sediment deposition caused by bed load convergence along the continental margin (Graciansky et al., 1985).

Elsewhere the bottom appears starved of Recent sediment and a stony bottom, seen in short range on the video camera, has been imaged over large areas (Figs. 30,31). Thin sediment commonly forms in streaks and patches, but the bottom is characteristically stony (Figs. 32,33). In one place along the northern track (Fig. 20), broad, asymmetrical sandwaves have their steep faces toward the southeast (Fig. 33), reflecting the general movement of bottom currents toward the shelf edge (Graciansky et al., 1985). On both sides of this virtually unique sand wave field, stony ground shows through, and the uniboom record shows virtually no seafloor relief associated with their position (Fig. 34). Therefore, they must have a relief of or less than a metre.

The ridges display an entirely different surface. There are irregular, and more regular shaped gravel banks lying amidst less reflective bottoms (Fig. 35) that are not as rough as the eroded P–N surface. Rarely there are ripple marks in the elongate gravel patches (Fig. 36).

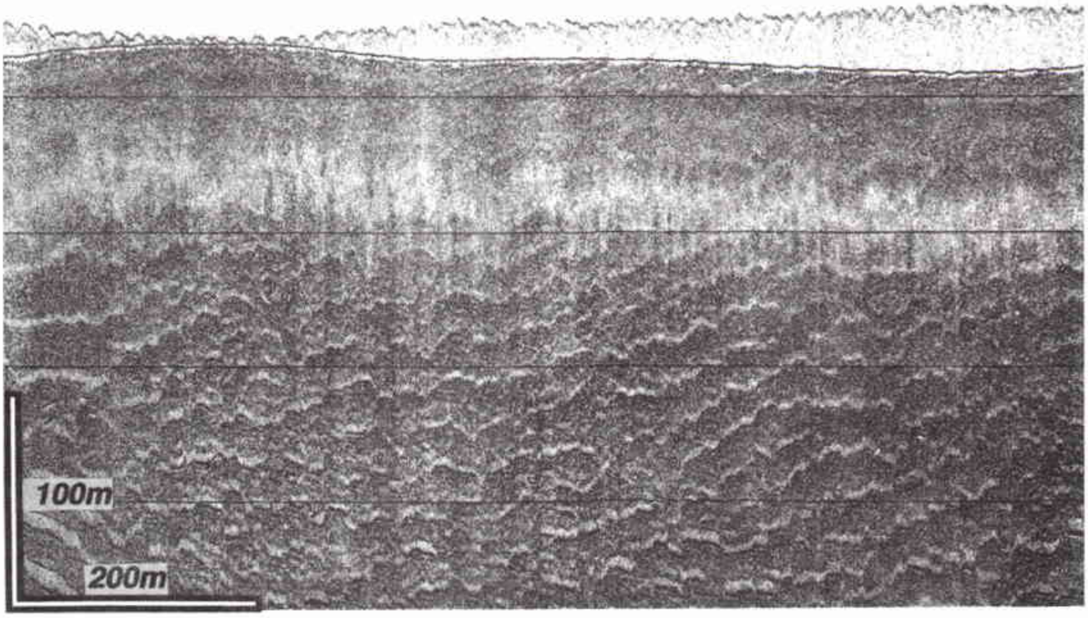

Figure 29 *Side-scan. Well-defined ripple field.*

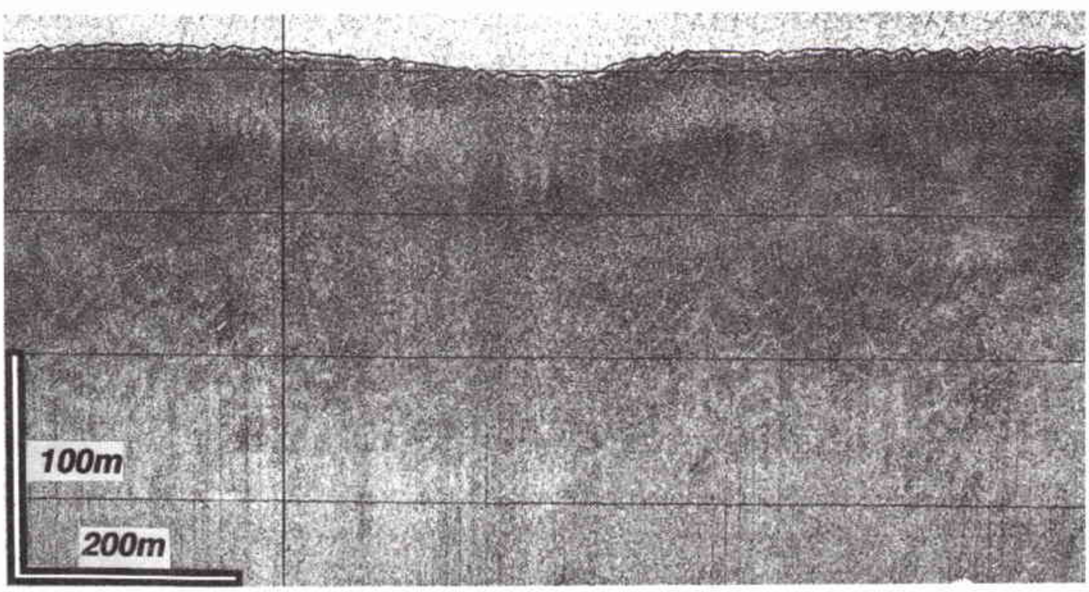

Figure 30 *Side-scan. Less well-defined ripple field.*

4.3.6. Bottom samples

Only one core was successfully obtained (Table 4). Similarly to Cores 264 and 265 from Site 2, there is a strong downward coarsening sequence. The core bottomed in fragments of angular shell hash and clastic detritus with a largely silica sand fraction.

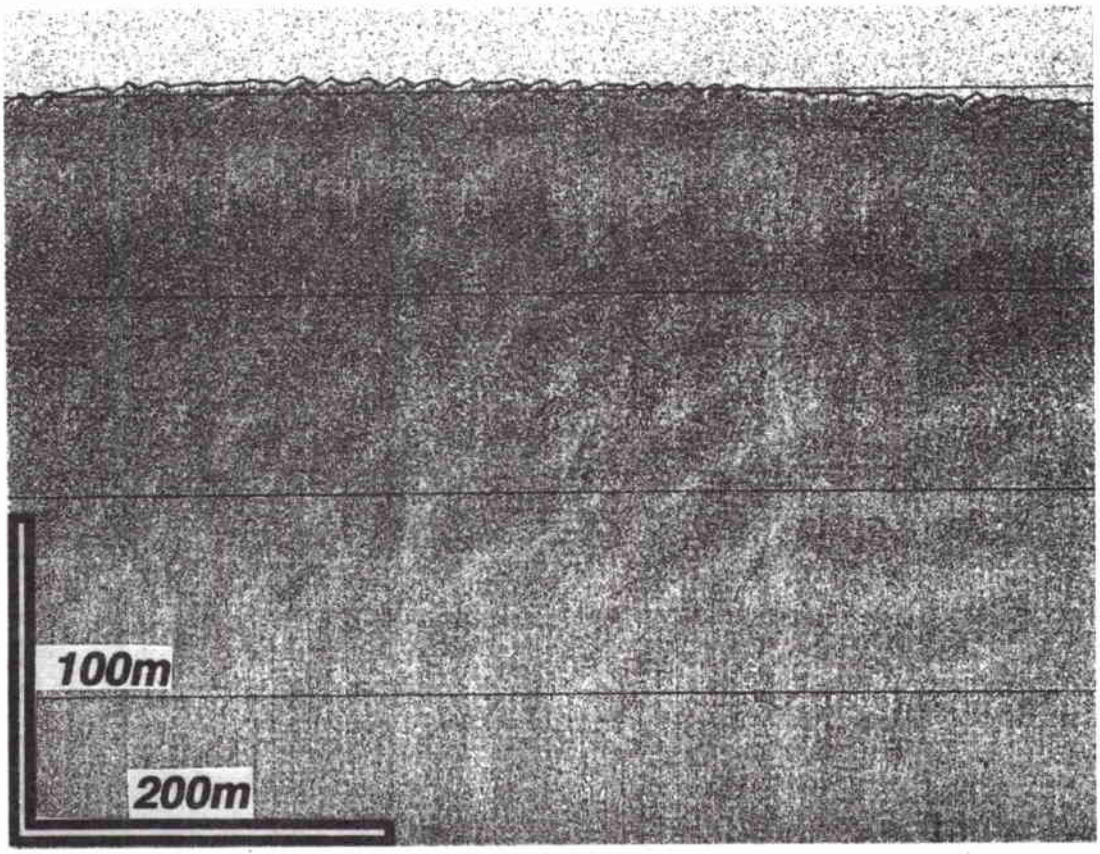

Figure 31 *Side-scan. Mottled ripple pattern.*

Shallow reflection seismics (Fig. 25) showed a flat bottom underlain by a complex but weakly acoustically differentiated Recent or Quaternary sediments. Side-scan sonar showed the bottom to be sediment covered, with moderate mottled-appearing small cresentic ripples (Fig. 30).

Grab sampling only was carried out in this area after two cores were unsuccessful because of the hard bottom. Little penetration was achieved and the core barrel nose and stability fin assembly was damaged by impact with the bottom.

The bottom sands are dominated by coarse sand shell detritus, with over 30% clastic debris. Quartz and feldspathic clasts are reworked terrigenous material. Gravel is dominent below the surface, with some gravelly patches and weak banks on the surface. Cherty grains, probably derived from the chalk horizon also occur, but no mineralogical analysis of the non-carbonate sediment residue (Table 5) were carried out. Sediments are probably no more than a few centimeters thick over most of the area, and are probably no more than a metre thick where ripple fields occur.

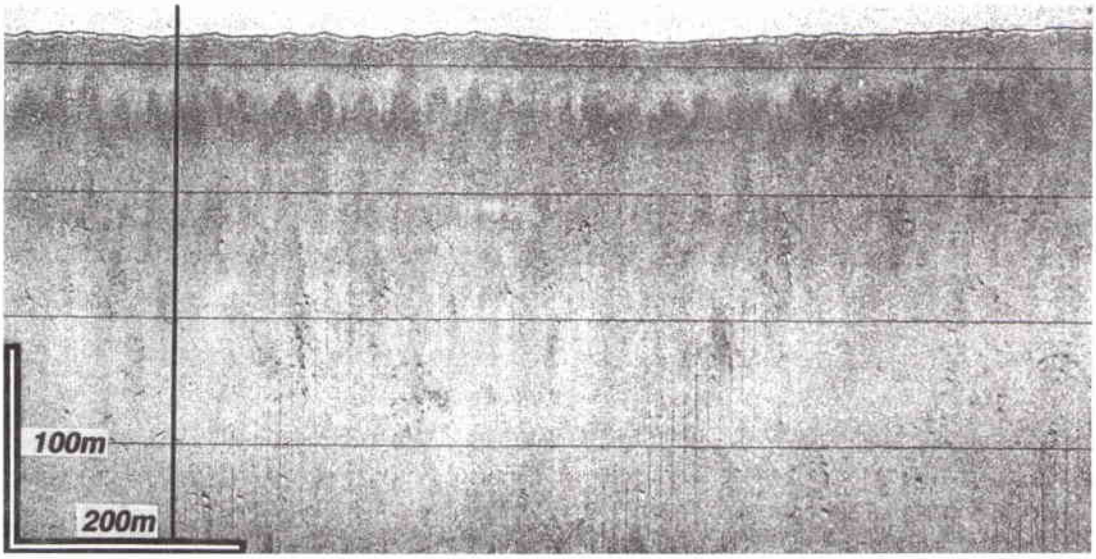

Figure 32 *Side-scan. Stony bottom.*

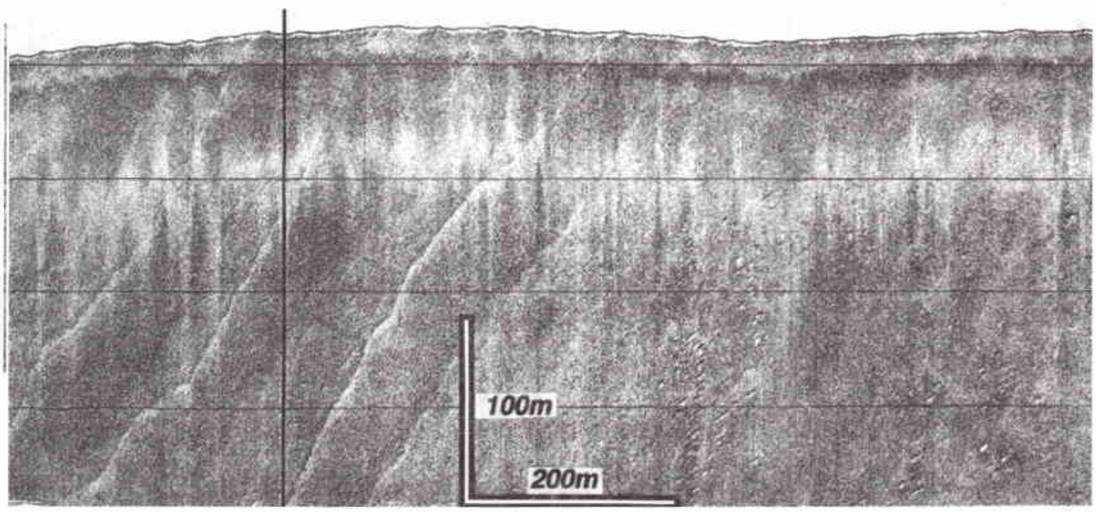

Figure 33 *Side-scan. Broad, low sandwaves on stony bottom.*

4.3.7. Physical properties and velocity structure

Regional velocity structure has been established for the Western Approaches Basin by Avedik (1975). This velocity structure combines rock of various ages (Fig. 3; Table 6), where there is a natural relationship of velocities.

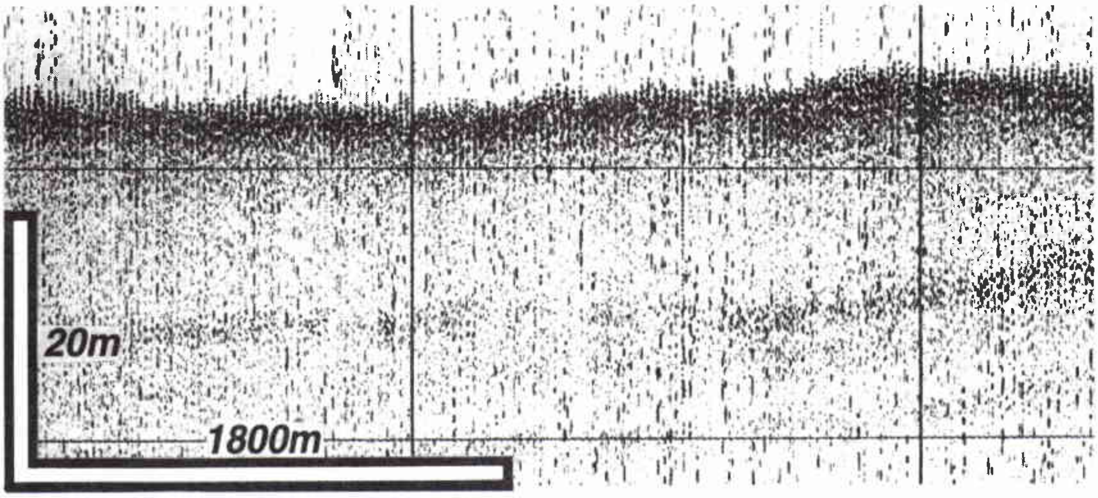

Figure 34 *Uniboom record showing virtually no relief associated with rippled surface (Fig. 33).*

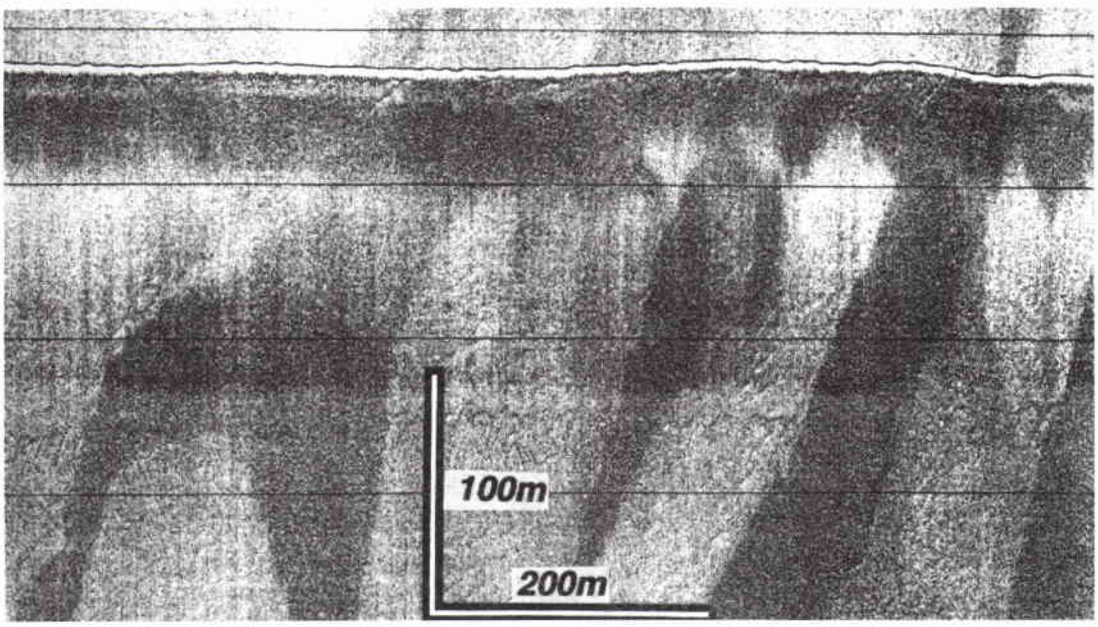

Figure 35 *Side-scan. Thin rippled sediment on rocky gravel on ridge.*

Pleistocene deposits have a mean velocity of about 1.85 km/s (Wingfield, 1985). The greater part of the shelf of the SWAP is not veneered with 'raw' Pleistocene deposits, but with highly reworked sediments derived from nearby land masses with generally lower velocity rock as provenance. Rock flours are often recrystallized to lower velocity clay minerals and these are intermixed with pelagic and carbonate sediments of lower velocity. Pleistocene sediments show shallow areas of acoustic blanking that is attributed to the presence of gas

Recent coarse calcareous sandy sediments in the northern Irish Sea have mean velocities of about 1.65 (Wingfield, 1985), but because the only cores gained by us

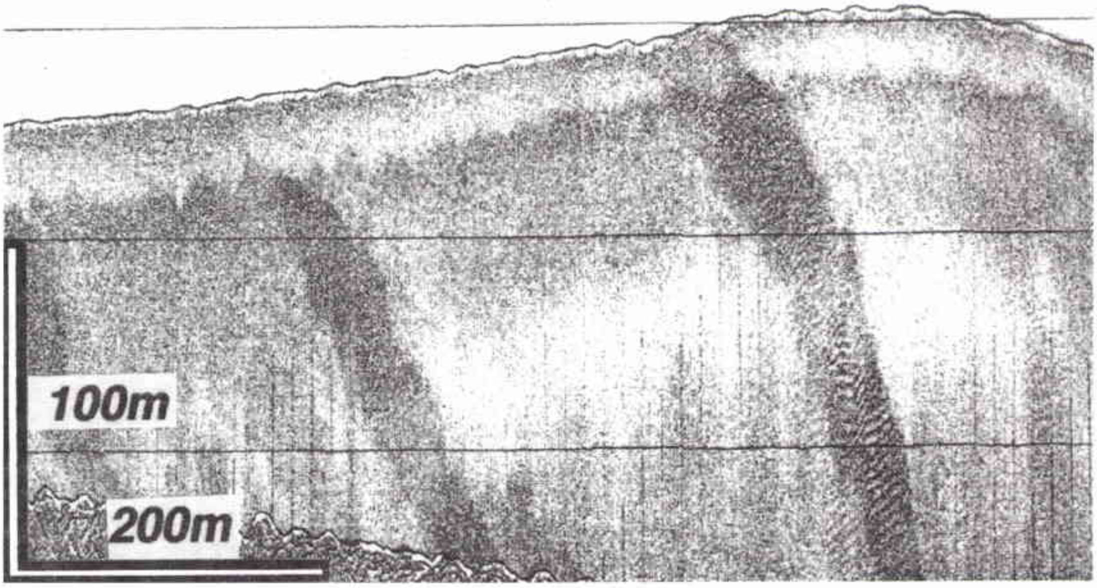

Figure 36 *Side-scan. Ripple marked gravel banks on eroded ridge surface.*

Table 4 *Generalized analyses of Core 266.*

Core 266

Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt.	$CaCO_3$ (%)
03	00.0	77.2	16.9	05.9	03.54	01.90	00.68	01.83	00.65	69.1
10	19.8	73.8	03.9	02.4	01.01	02.10	−0.34	01.10	00.52	59.6
20	16.8	72.9	06.1	04.3	01.21	02.65	−0.22	02.18	00.69	55.9
30	49.4	47.3	01.8	01.4	−0.47	02.40	00.16	00.78	00.44	55.4
40	70.7	28.3	00.4	00.6	−1.01	02.07	00.45	01.16	00.54	55.4

Table 5 *Analyses of recent sediment from Site 1 grab samples.*

Grab	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt.	$CaCO_3$ (%)
Site 2 (C)										
2534	35.9	53.3	06.7	04.1	00.44	02.63	00.52	01.12	00.53	45.2
2536	01.8	88.3	05.3	04.6	01.73	01.88	00.30	01.67	00.63	59.0
2537	16.3	82.2	00.4	01.1	00.50	01.22	−0.41	00.72	00.42	44.9
2538	12.3	71.7	10.0	06.0	01.99	02.81	−0.11	02.76	00.73	68.8
2539	04.1	81.1	09.7	05.0	02.73	01.89	00.17	03.14	00.76	73.9
2540	01.1	87.2	06.4	05.3	02.56	01.67	00.26	03.64	00.78	72.6
2541	02.9	90.9	03.5	02.8	02.27	01.22	−0.01	02.47	00.71	44.4

were short and highly disturbed coarse-grained material, we measured no velocities. This reflects the presence of a terrigenous component derived from rocks of no great acoustic velocities. In the SWAP the thin, mobile, water-supported surface sediments have velocities only slightly greater than water and are effectively transparent to acoustic propagation in the 25–300 Hz range.

The physical properties of the different rock and sediment materials vary considerably. The occurrence of different materials at the seafloor (Fig. 2) strongly influences acoustic response at those lower frequencies where sound penetrates the seafloor. Thus from place to place acoustic response and physical properties can be generally predicted. There is also a variation with depth (Caiti and Max, 1994), even in fully lithified materials that is probably a response to weathering, uplift and erosion. Table 6 shows a number of physical and acoustical properties of the lithified materials on the shelf in this region. However, geological mapping of the seafloor has been extensive and the distribution of materials is known with confidence, as is the nature of the sea bottom itself. Because there are a limited number of rocks and lithified sediments in the area, which have undergone a related sedimentological and structural history, the physical properties of individual materials are similar, wherever they occur on the shelf. This is particularly important in the SWAP area because Recent sediment is very thin to absent. Where sediment does occur, it is composed of a coarse carbonate sand overlying patchy sands and lag gravels that has an acoustic velocity similar to the acoustic velocities of the chalk. Therefore, above acoustic frequencies where significant acoustic energy passes through the bottom and returns into the water, the strong to moderately strong reflection and backscatter can be anticipated. Because the solid geological materials forming the upper shelf occur at or very nearly at the sea bottom with virtually no sediment cover, they are available to interact with plunging acoustic energy.

Table 6 *Chalk data from Ellis and Chapman (1985), recalculated to dB/λ by A. Caiti, SACLANTCEN.*

Material	Seismic char	V_p (m/s)	V_s (m/s)	A_p dB/λ	A_s dB/λ	Den.[1] gm/cc
Recent calcareous sand	thin, turbid layer, no internal structure	1650	30–60	high	high	01.3
Ave. Pleistocene	transparent in tills to highly structured	1850	200	00.25	01.0	02.0
Consolidated sed. terrane. Wedges of W-dipping strata	sandy and limy, areas of strong internal reflections, lag gravel surface[3]	1800–2000 2800[4]	400–600 950[4]	mod	mod	01.1–01.5
Chalk[2] (a) surface (b) 60 m depth	weak, wide-spaced reflections	1720 (a) 2,000 (b)	930 1050	00.6	00.3	02.2
Chalk < 100 m	weak, wide-spaced internal reflections	2400	1000	00.24	01.0	02.2
Basement terrane[5]	very weak internal reflections	3,000–4,000	1300–1800	low	low	02.4

[1] Den. is dry density.
[2] Chalk calculated values from Caiti and Max (1994).
[3] Because of the lag gravel along the surface, there may be a slight negative velocity gradient.
[4] Limestone locally developed at base of succession in contact with chalks.
[5] Strong variations in P and S velocities in this terrane, but these single values taken as appropriate average values for modeling because granite comprises a large part of the terrane outlier to the WNW of Lands End.

5
Conclusions

The strongly acoustically banded P–N terrane occurs everywhere in the area beneath the acoustically transparent younger sediment ridges. Usually dips are very shallow and relatively simple, except nearest the shelf edge. Thus, the sub-striate here have a nearly acoustically range-independent character. Near the shelf edge significant range dependence may occur, but this is well away from the site and is atypical for the area.

The morphological ridges are internally transparent and probably formed from poorly sorted and bedded sands and gravels. They are internally range independent, but their external form may be important for both backscatter and transmission loss.

The sea bottom is formed essentially from eroded P–N terrane and deflated younger sand and gravel ridges now having lag or armored surfaces. The bottom is thus very hard. The roughness will also be high on the small scale, with the ridges providing possible larger facets. There are no smooth areas dominated by thick Recent sediment and for modeling purposes, sediment virtually does not exist at this site. Because the lags layer is composed of resistant material locally derived, and from other detritus that has survived transport into this area, it may be a higher velocity layer than the beds immediately below it.

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Appendix A

Descriptions and analyses of cores and grab samples

Core and grab samples referenced to SACLANTCEN numbering system.

Sites 2-3/(B). The sea bottom in Areas 1, 2 and 3 is very hard with only a very thin scum of recoverable sediment over a hard bottom armored with lag gravels. The three cores recovered are not so much cores as large grab samples that show an increasing coarseness toward their base. Cores penetrated only with difficulty: The site in Area 1, which showed mottled sediment pattern on the side-scan, was the best core, but had only a very small muddy fraction.

Core 264. Bottom pictures taken at this site. Hard bottom, no penetration by the camera weight with only a little very fine material thrown up. Noticeable current cleared view relatively quickly. Core: 17 cm medium to coarse sand in core with some gravel in the lower 5 cm. Gravel is composed of Terrane 3 clasts and chart and flint fragments and pebbles. Gravel is highly immature, and shows little sign of current working. Nose of core penetrator was skimmed with a paste of white to weathered chalk.

Grab 2528. Grab was coarse to medium sand similar to that in the core, but containing no pebbles.

Core 265 Core: 32 cm core with mostly very coarse sand to gravel formed mainly from angular shell hash. Many smaller unbroken shells and this year's spat very prominent. Some suggestion of sedimentary bedding with a sand layer amidst the coarse fraction, but the fine layer at the top of the core is entirely settled material that may have been largely unmixed during disturbance and settling afterward. Coarse gravel in the lower 5 cm composed of Terrane 3 very immature clasts and chert fragments. Nose of core penetrator was skimmed with a paste of white to gray weathered chalk. Mud in upper part of core is undoubtedly more common toward the surface but may not form a discrete layer as could be suggested from the rest position in the core.

Grab 2529 Coarse to medium sand with prominent mud fraction.

Grab 2530 On basement terrane, smooth area. Very coarse gravely sand composed almost entirely of shell hash. Some large gravel clasts are coarse sand or fine gravel.

Grab 2531 On basement terrane, rough area. Coarse sand, not as coarse as site 266. Same general composition as before.

Grab 2532 On basement terrane, rough area. Medium to coarse sand, same composition as before.

Grab 2533 On basement terrane, smooth area. Very coarse sand to fine gravel shell hash and some tectosilicate grains.

SITE 1/B
Core 266 42 cm coarse sand with coarse gravel in the core catcher and the bottom several cm of the core. Second bag of stones picked up off deck after core extraction. Not so much a core as a large grab sample. Suitable for granulometry only.

Grab 2534 Failed Core 257. On ridge. Coarse sand with unbroken shells and angular shell hash. Also some medium to coarse sand tectosilicate grains. Core did not penetrate and damage was sustained to the penetrator, which was dented, and to the stability fin assembly, which was bent after after toppling over and falling to the bottom.

Grab 2535 Ridge. Very small specimen after three tries with the grab. Medium sand only. Not analyzed

Grab 2536 Trough. Medium to coarse sand, mostly shell fragments with some tectosilicate grains.

Grab 2537 Ridge. Very coarse sand to gravel composed largely of angular shell fragments. No pebbles.

Grab 2538 Coarse sand fraction similar to the upper half of the sample in the core. Sand appears to be largely angular shell fragments with some tectosilicate grains which are rounded but of irregular dimensional shape.

Grab 2539 Trough (propagation path offset). Very small specimen after a number of tries with the grab. Mostly medium sand of shell hash with some tectosilicate grains.

Grab 2540 Trough (propagation path offset). Small specimen combining the results of two grabs. Mostly fine sand of shell hash with some tectosilicate grains.

Grab 2541 Top of low ridge. Very small specimen from combining the results of three grabs. Mostly medium sand with prominent angular black grains.

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M.D. Max, E. Michelozzi, F. Turgutcan and B. Tonarelli

Title

Geoenvironmental characterization of selected shallow-water sites on the western European continental shelf (SWAP)

Abstract

Geoenvironmental analyses for four experiment sites on the continental shelf to the west of Britain and the English Channel have utilized two modes of shallow reflection seismic profiling, side-scan sonar, and bottom and sub-bottom sampling to derive environmental information relevant to predicting bottom-acoustic interaction. Because of the geological development of the shelf and the history of sea-level rise and fall over the past 1,000,000 years, and especially over the last 15,000 years, solid rock and sediment materials having very different physical properties and frequency-dependent acoustic response are located at or very close to the sea bottom. Recent sediment is very thin to absent both on the inner and outer shelves, and features characterized as being products of recent sedimentation will respond, at higher frequencies, as solid rock materials. Bottom-acoustic interaction, therefore, is strongly dependent on the type of rock and sediment material in the bottom at any particular place. These have been grouped into a number of geoacoustic terranes, based on their physical properties and some transmission loss data from earlier acoustic experiments, which could be related to individual bottom materials. Acoustic response for individual materials can be expected to remain constant everywhere on this shelf, and thus characterization of response, at a number of selected sites through acoustic experiments, can theoretically be used to predict general response elsewhere where geologic conditions are similar.

Keywords

Southwestern Approaches, bottom properties

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Part A
Core samples

Report no. changed (Mar 2006): SM-288-UU

Detailed sediment analyses from selected shallow-water sites on the western European continental shelf (SWAP). Unpublished data report.

Tonarelli, B., Max, M.D., Michelozzi, E. & Turgutcan, F.
1994.

This unpublished data report contains data and graphics that suppliment SACLANTCEN SM-288: Max et al. 1995. Geoenvironmental characterization of selected shallow-water sites on the western European continental shelf (SWAP). This data report contains the detailed analyses from every level of all cores and is an external, but supporting document to that memorandum.

Sediment grain size analyses and diagrams of core and grab samples.
Analyses and graphics of particle size 'fill' shown from most coarse to fines.

A. Core samples

B. Grab samples

Sound velocity analyses were not carried out on the ship at sea following coring because they were short and filled with highly disturbed gravels and loose sands that were regarding as not reflecting the in-situ position of the sediments. Some physical properties, however, were measured, and these are shown in the summary tables in SM-288 and in Parts A and B of this data report.

Core sediment stratigraphy and size fraction analyses.

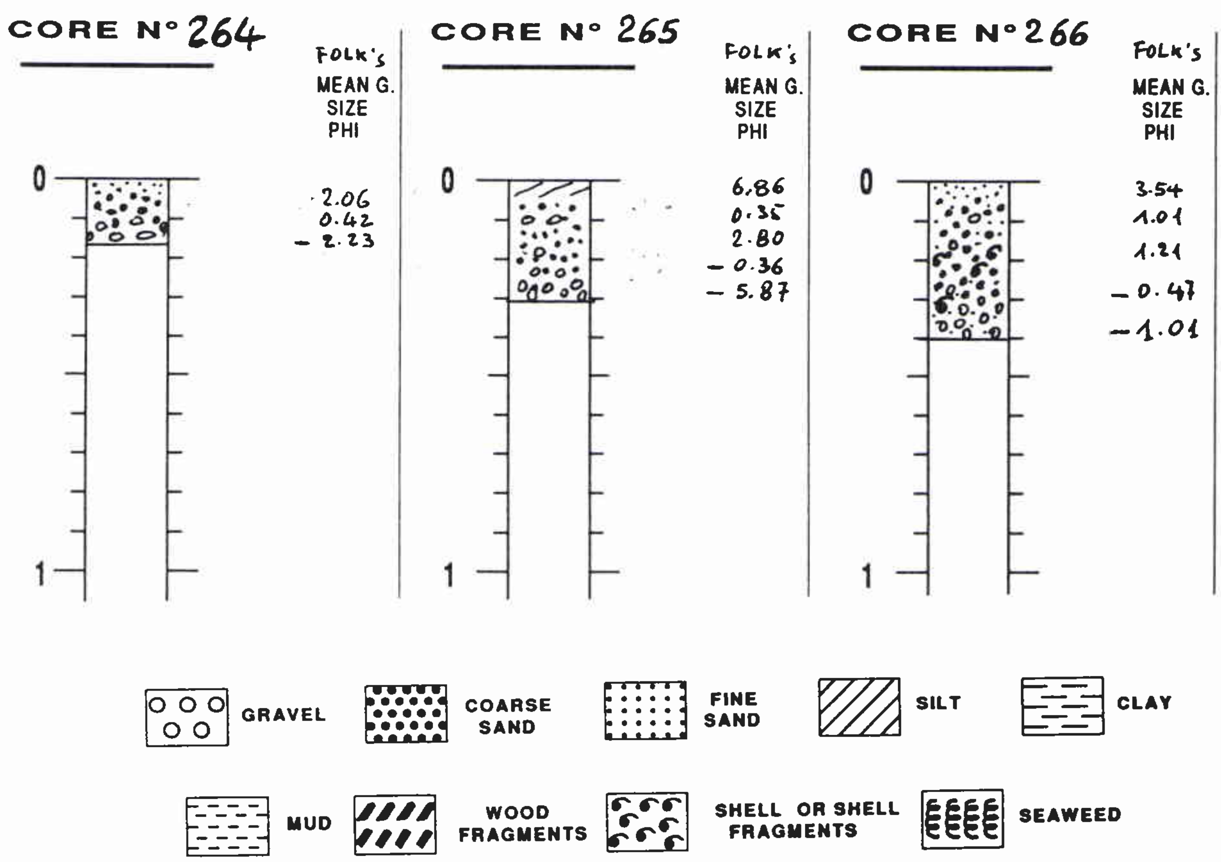
Only three short cores were taken because of the lack of sediment in the area and the hardness of the bottom. Analyses are summarized in table A2-1. Graphics show accumulated sediment fraction of individual analyses. Data may be available separately by request through NATO channels.

Core/ depth	Gravel %	Sand %	Silt %	Clay %	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt	CaCO3 %
264										
05	0.3	91.0	5.8	2.9	2.06	1.38	0.45	2.49	0.71	69.5
10	19.9	75.8	2.2	2.2	0.42	1.96	-0.29	1.37	0.58	81.0
15	62.6	35.9	1.0	0.6	-2.23	3.13	-0.04	-.76	0.43	68.8
265										
05	0.0	19.5	53.3	27.2	6.86	3.24	0.26	1.05	0.51	58.5
10	24.6	66.6	5.6	3.1	0.35	2.53	0.13	1.46	0.59	58.1
15	9.3	65.5	16.3	8.9	2.80	3.47	0.34	1.67	0.62	43.7
20	42.4	48.4	5.6	3.6	-0.36	2.88	0.25	1.17	0.54	59.9
25	67.4	29.3	1.9	1.4	-5.87	7.67	-0.61	0.85	0.46	56.5
266										
03	0.0	77.2	16.9	5.9	3.54	1.90	0.68	1.83	0.65	69.1
10	19.8	73.8	3.9	2.4	1.01	2.10	-0.34	1.10	0.52	59.6
20	16.8	72.9	6.1	4.3	1.21	2.65	-0.22	2.18	0.69	55.9
30	49.4	47.3	1.8	1.4	-0.47	2.40	0.16	0.78	0.44	55.4
40	70.7	28.3	0.4	0.6	-1.01	2.07	0.45	1.16	0.54	55.4

Table 1. Generalized analyses of cores.
Depth levels in the three cores are in centimetres.

max 6

STRATIGRAPHY



Cruise : CORE Station : 00264 Sample : 00005
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-1.25	0.05	0.15	0.15
-1.00	0.06	0.18	0.33
-0.75	0.05	0.15	0.49
-0.50	0.06	0.19	0.68
-0.25	0.10	0.30	0.98
0.00	0.11	0.33	1.32
0.25	0.29	0.88	2.20
0.50	0.29	0.88	3.08
0.75	1.17	3.56	6.65
1.00	1.17	3.57	10.21
1.25	2.63	8.00	18.21
1.50	2.63	8.00	26.21
1.75	5.43	16.53	42.74
2.00	5.43	16.53	59.27
2.25	2.98	9.08	68.35
2.50	2.98	9.08	77.44
2.75	0.88	2.69	80.13
3.00	0.88	2.69	82.82
3.25	0.65	1.98	84.80
3.50	0.65	1.98	86.77
3.75	0.75	2.29	89.07
4.00	0.75	2.29	91.36
4.50	0.24	0.72	92.08
5.00	0.24	0.72	92.80
5.50	0.24	0.72	93.52
6.00	0.24	0.72	94.24
6.50	0.24	0.72	94.97
7.00	0.24	0.72	95.69
7.50	0.24	0.72	96.41
8.00	0.24	0.72	97.13
9.00	0.16	0.48	97.61
10.00	0.16	0.48	98.09
11.00	0.16	0.48	98.57
12.00	0.16	0.48	99.04
13.00	0.16	0.48	99.52
14.00	0.16	0.48	100.00

Post Analytical Weight : 32.84

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
0.63	1.18	1.46	1.86	2.43	3.15	6.52

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.33	91.02	5.77	2.87

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.06	1.38	0.45	2.49	0.71

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.86	2.17	0.98	0.31	1.75	1.99

Cruise : CORE Station : 00264 Sample : 00010
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.75	1.25	2.92	2.92
-3.50	1.25	2.92	5.84
-3.25	1.25	2.92	8.76
-3.00	1.25	2.92	11.67
-2.75	0.19	0.44	12.11
-2.50	0.19	0.44	12.55
-2.25	0.19	0.44	12.99
-2.00	0.19	0.44	13.43
-1.75	0.59	1.39	14.82
-1.50	0.59	1.39	16.21
-1.25	0.78	1.82	18.04
-1.00	0.78	1.82	19.86
-0.75	1.00	2.33	22.19
-0.50	1.00	2.33	24.53
-0.25	1.64	3.84	28.36
0.00	1.64	3.84	32.20
0.25	2.00	4.68	36.88
0.50	2.00	4.68	41.57
0.75	2.73	6.40	47.97
1.00	2.73	6.40	54.37
1.25	3.37	7.91	62.27
1.50	3.37	7.91	70.18
1.75	3.19	7.48	77.66
2.00	3.19	7.48	85.14
2.25	1.48	3.47	88.60
2.50	1.48	3.47	92.07
2.75	0.41	0.97	93.04
3.00	0.41	0.97	94.02
3.25	0.19	0.45	94.46
3.50	0.19	0.45	94.91
3.75	0.16	0.36	95.27
4.00	0.16	0.36	95.63
4.50	0.12	0.28	95.91
5.00	0.12	0.28	96.19
5.50	0.12	0.28	96.46
6.00	0.12	0.28	96.74
6.50	0.12	0.28	97.02
7.00	0.12	0.28	97.29
7.50	0.12	0.28	97.57
8.00	0.12	0.28	97.85
9.00	0.15	0.36	98.21
10.00	0.15	0.36	98.57
11.00	0.15	0.36	98.92
12.00	0.15	0.36	99.28
13.00	0.15	0.36	99.64
14.00	0.15	0.36	100.00

Post Analytical Weight : 42.66

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.57	-1.54	-0.47	0.83	1.66	1.96	3.56

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
19.86	75.77	2.21	2.15

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
0.42	1.96	-0.29	1.37	0.58

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
0.83	0.21	1.75	-0.35	-0.48	1.04

Cruise : CORE Station : 00264 Sample : 00015
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	19.75	30.20	30.20
-3.75	1.36	2.08	32.27
-3.50	1.36	2.07	34.35
-3.25	1.36	2.07	36.42
-3.00	1.36	2.07	38.50
-2.75	2.28	3.48	41.98
-2.50	2.28	3.48	45.46
-2.25	2.28	3.48	48.94
-2.00	2.28	3.48	52.42
-1.75	1.73	2.65	55.07
-1.50	1.73	2.65	57.72
-1.25	1.58	2.42	60.14
-1.00	1.58	2.42	62.56
-0.75	1.48	2.26	64.82
-0.50	1.48	2.26	67.08
-0.25	1.63	2.50	69.58
0.00	1.63	2.50	72.08
0.25	1.36	2.09	74.16
0.50	1.36	2.09	76.25
0.75	1.87	2.85	79.10
1.00	1.87	2.85	81.95
1.25	1.82	2.79	84.74
1.50	1.82	2.79	87.53
1.75	1.98	3.03	90.57
2.00	1.98	3.03	93.60
2.25	1.05	1.60	95.21
2.50	1.05	1.61	96.81
2.75	0.29	0.45	97.26
3.00	0.29	0.45	97.71
3.25	0.13	0.20	97.91
3.50	0.13	0.20	98.10
3.75	0.11	0.17	98.27
4.00	0.11	0.17	98.43
4.50	0.08	0.13	98.56
5.00	0.08	0.13	98.69
5.50	0.08	0.13	98.81
6.00	0.08	0.13	98.94
6.50	0.08	0.13	99.07
7.00	0.08	0.13	99.20
7.50	0.08	0.13	99.32
8.00	0.08	0.13	99.45
9.00	0.06	0.09	99.54
10.00	0.06	0.09	99.63
11.00	0.06	0.09	99.72
12.00	0.06	0.09	99.82
13.00	0.06	0.09	99.91
14.00	0.06	0.09	100.00

Post Analytical Weight : 65.39

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-7.04	-5.71	-4.63	-2.17	0.35	1.18	2.22

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
62.56	35.87	1.02	0.55

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-2.23	3.13	-0.04	0.76	0.43

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-2.17	-2.26	3.45	-0.03	-0.07	0.34

Cruise : CORE Station : 00265 Sample : 00005
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
1.75	0.09	0.99	0.99
2.00	0.10	1.00	2.00
2.25	0.15	1.59	3.59
2.50	0.15	1.59	5.18
2.75	0.13	1.31	6.49
3.00	0.13	1.31	7.80
3.25	0.13	1.36	9.16
3.50	0.20	2.14	11.29
3.75	0.30	3.14	14.44
4.00	0.48	5.02	19.46
4.50	0.64	6.67	26.13
5.00	0.64	6.67	32.80
5.50	0.64	6.67	39.46
6.00	0.64	6.67	46.13
6.50	0.64	6.67	52.80
7.00	0.64	6.67	59.47
7.50	0.64	6.67	66.14
8.00	0.64	6.67	72.80
9.00	0.43	4.53	77.34
10.00	0.43	4.53	81.87
11.00	0.43	4.53	86.40
12.00	0.43	4.53	90.93
13.00	0.43	4.53	95.47
14.00	0.43	4.53	100.00

Post Analytical Weight : 9.55

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
2.47	3.83	4.42	6.29	8.48	10.47	12.90

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.00	19.46	53.34	27.20

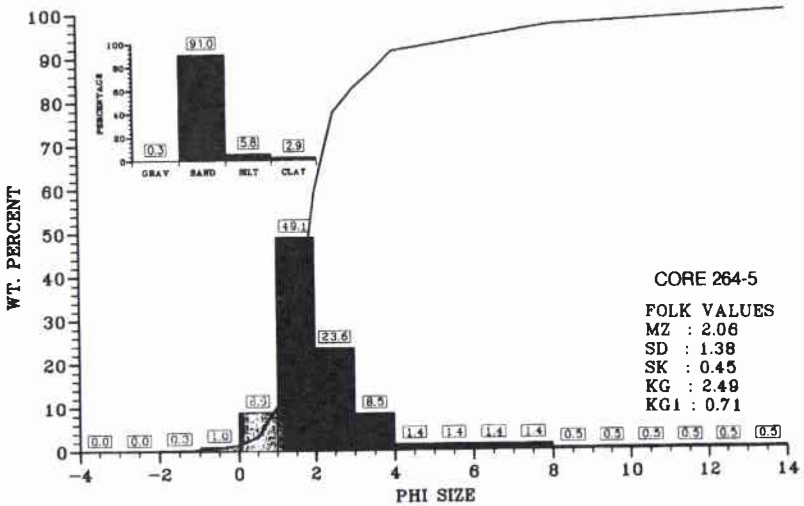
FOLK VALUES :

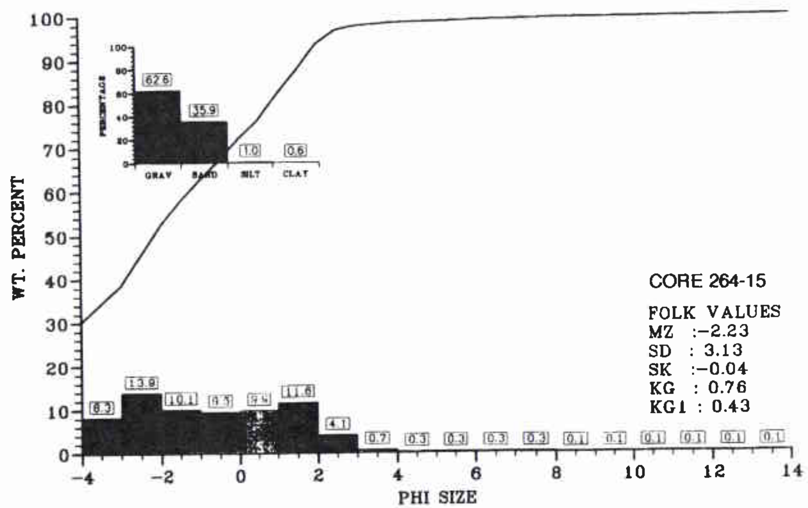
MEAN	ST.DEV	SKEW	KURT	N.KURT
6.86	3.24	0.26	1.05	0.51

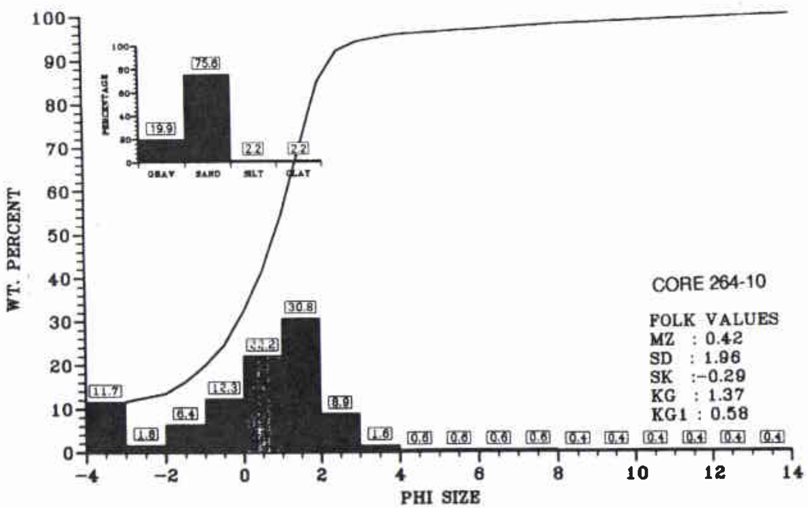
INMAN VALUES :

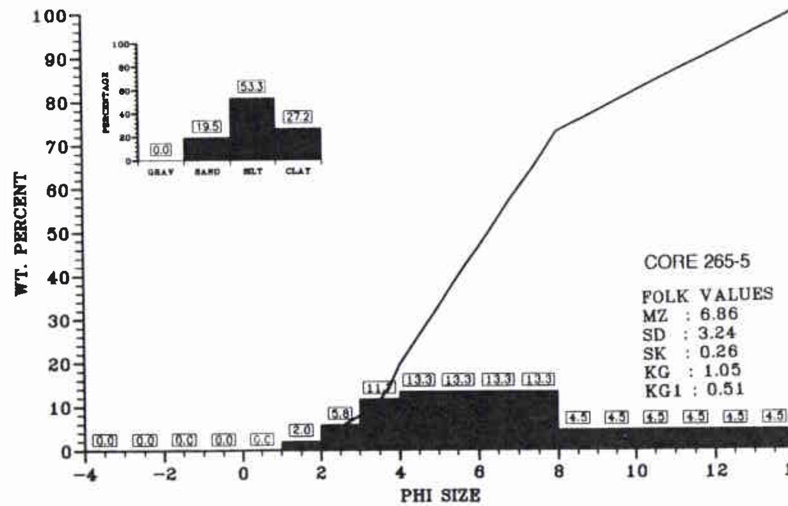
MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
6.29	7.15	3.32	0.26	0.42	0.57

GRAIN SIZE ANALYSIS









Cruise : CORE   Station : 00265   Sample : 00010
Date :   Latitude :   Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.75	0.74	1.86	1.86
-3.50	0.74	1.86	3.71
-3.25	0.74	1.86	5.57
-3.00	0.74	1.86	7.42
-2.75	0.57	1.44	8.86
-2.50	0.57	1.44	10.30
-2.25	0.57	1.43	11.73
-2.00	0.57	1.43	13.17
-1.75	0.92	2.31	15.48
-1.50	0.92	2.31	17.79
-1.25	1.36	3.42	21.21
-1.00	1.36	3.42	24.62
-0.75	1.78	4.49	29.11
-0.50	1.78	4.49	33.60
-0.25	2.04	5.14	38.73
0.00	2.04	5.14	43.87
0.25	1.77	4.47	48.33
0.50	1.77	4.47	52.80
0.75	1.69	4.25	57.05
1.00	1.69	4.25	61.30
1.25	1.59	3.99	65.29
1.50	1.59	3.99	69.28
1.75	1.79	4.51	73.79
2.00	1.79	4.51	78.30
2.25	1.47	3.69	81.99
2.50	1.47	3.69	85.68
2.75	0.44	1.10	86.78
3.00	0.44	1.10	87.88
3.25	0.28	0.70	88.59
3.50	0.28	0.70	89.29
3.75	0.39	0.98	90.27
4.00	0.39	0.98	91.26
4.50	0.28	0.70	91.96
5.00	0.28	0.70	92.66
5.50	0.28	0.70	93.36
6.00	0.28	0.70	94.06
6.50	0.28	0.70	94.77
7.00	0.28	0.70	95.47
7.50	0.28	0.70	96.17
8.00	0.28	0.70	96.87
9.00	0.21	0.52	97.39
10.00	0.21	0.52	97.92
11.00	0.21	0.52	98.44
12.00	0.21	0.52	98.96
13.00	0.21	0.52	99.48
14.00	0.21	0.52	100.00

Post Analytical Weight : 39.73

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.33	-1.69	-0.98	0.34	1.82	2.39	6.67

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
24.62	66.63	5.62	3.13

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
0.35	2.53	0.13	1.46	0.59

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
0.34	0.35	2.04	0.00	0.65	1.45

Cruise : CORE   Station : 00265   Sample : 00020
Date :   Latitude :   Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	0.33	0.68	0.68
-3.75	1.54	3.17	3.85
-3.50	1.54	3.17	7.01
-3.25	1.54	3.17	10.18
-3.00	1.54	3.17	13.35
-2.75	1.85	3.80	17.15
-2.50	1.85	3.80	20.95
-2.25	1.85	3.80	24.76
-2.00	1.85	3.80	28.56
-1.75	1.82	3.75	32.31
-1.50	1.82	3.75	36.06
-1.25	1.54	3.17	39.23
-1.00	1.54	3.17	42.40
-0.75	1.88	3.88	46.28
-0.50	1.88	3.88	50.16
-0.25	1.77	3.65	53.81
0.00	1.77	3.65	57.46
0.25	1.34	2.77	60.23
0.50	1.34	2.77	63.00
0.75	1.30	2.68	65.68
1.00	1.30	2.68	68.36
1.25	1.60	3.29	71.65
1.50	1.60	3.29	74.94
1.75	1.63	3.35	78.29
2.00	1.63	3.35	81.64
2.25	1.18	2.43	84.06
2.50	1.18	2.43	86.49
2.75	0.34	0.71	87.20
3.00	0.34	0.71	87.91
3.25	0.28	0.58	88.48
3.50	0.28	0.58	89.06
3.75	0.42	0.87	89.93
4.00	0.42	0.87	90.80
4.50	0.34	0.70	91.50
5.00	0.34	0.70	92.20
5.50	0.34	0.70	92.90
6.00	0.34	0.70	93.60
6.50	0.34	0.70	94.29
7.00	0.34	0.70	94.99
7.50	0.34	0.70	95.69
8.00	0.34	0.70	96.39
9.00	0.29	0.60	96.99
10.00	0.29	0.60	97.59
11.00	0.29	0.60	98.20
12.00	0.29	0.60	98.80
13.00	0.29	0.60	99.40
14.00	0.29	0.60	100.00

Post Analytical Weight : 48.53

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.66	-2.83	-2.23	-0.51	1.50	2.24	7.00

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
42.40	48.41	5.59	3.61

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-0.36	2.88	0.25	1.17	0.54

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-0.51	-0.29	2.53	0.09	0.86	1.10

Cruise : CORE   Station : 00265   Sample : 00015
Date :   Latitude :   Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.75	0.40	1.20	1.20
-2.50	0.40	1.20	2.39
-2.25	0.40	1.20	3.59
-2.00	0.40	1.20	4.79
-1.75	0.36	1.08	5.87
-1.50	0.36	1.08	6.95
-1.25	0.38	1.15	8.11
-1.00	0.38	1.15	9.26
-0.75	0.53	1.60	10.86
-0.50	0.53	1.60	12.45
-0.25	0.57	1.73	14.18
0.00	0.57	1.73	15.90
0.25	0.60	1.81	17.72
0.50	0.60	1.81	19.53
0.75	0.98	2.95	22.48
1.00	0.98	2.95	25.43
1.25	1.48	4.44	29.87
1.50	1.48	4.44	34.30
1.75	2.13	6.39	40.69
2.00	2.13	6.39	47.08
2.25	2.05	6.16	53.24
2.50	2.05	6.16	59.40
2.75	0.59	1.78	61.17
3.00	0.59	1.78	62.95
3.25	0.65	1.96	64.92
3.50	0.65	1.96	66.88
3.75	1.31	3.94	70.82
4.00	1.31	3.94	74.76
4.50	0.68	2.04	76.80
5.00	0.68	2.04	78.84
5.50	0.68	2.04	80.88
6.00	0.68	2.04	82.92
6.50	0.68	2.04	84.96
7.00	0.68	2.04	87.01
7.50	0.68	2.04	89.05
8.00	0.68	2.04	91.09
9.00	0.49	1.49	92.57
10.00	0.49	1.49	94.06
11.00	0.49	1.49	95.54
12.00	0.49	1.49	97.03
13.00	0.49	1.49	98.51
14.00	0.49	1.49	100.00

Post Analytical Weight : 33.26

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-1.95	0.01	0.96	2.12	4.06	6.26	10.63

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
9.26	65.50	16.33	8.91

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.80	3.47	0.34	1.67	0.62

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.12	3.14	3.13	0.33	0.71	1.01

Cruise : CORE   Station : 00265   Sample : 00025
Date :   Latitude :   Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	33.62	41.29	41.29
-3.75	0.44	0.53	41.83
-3.50	0.44	0.53	42.36
-3.25	0.44	0.53	42.90
-3.00	0.44	0.53	43.43
-2.75	2.36	2.90	46.33
-2.50	2.36	2.90	49.24
-2.25	2.36	2.90	52.14
-2.00	2.36	2.90	55.04
-1.75	2.67	3.28	58.32
-1.50	2.67	3.28	61.60
-1.25	2.38	2.92	64.52
-1.00	2.38	2.92	67.45
-0.75	2.39	2.93	70.38
-0.50	2.39	2.93	73.31
-0.25	2.19	2.69	76.00
0.00	2.19	2.69	78.69
0.25	1.71	2.10	80.79
0.50	1.71	2.10	82.89
0.75	1.48	1.82	84.70
1.00	1.48	1.82	86.52
1.25	1.47	1.80	88.32
1.50	1.47	1.80	90.12
1.75	1.34	1.64	91.77
2.00	1.34	1.64	93.41
2.25	0.79	0.98	94.38
2.50	0.79	0.98	95.36
2.75	0.20	0.25	95.61
3.00	0.20	0.25	95.86
3.25	0.13	0.16	96.02
3.50	0.13	0.16	96.18
3.75	0.22	0.27	96.45
4.00	0.22	0.27	96.73
4.50	0.19	0.23	96.96
5.00	0.19	0.23	97.19
5.50	0.19	0.23	97.43
6.00	0.19	0.23	97.66
6.50	0.19	0.23	97.89
7.00	0.19	0.23	98.13
7.50	0.19	0.23	98.36
8.00	0.19	0.23	98.59
9.00	0.19	0.23	98.83
10.00	0.19	0.23	99.06
11.00	0.19	0.23	99.30
12.00	0.19	0.23	99.53
13.00	0.19	0.23	99.77
14.00	0.19	0.23	100.00

Post Analytical Weight : 81.42

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
*****	*****	*****	-2.43	-0.34	0.65	2.41

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
67.45	29.28	1.87	1.41

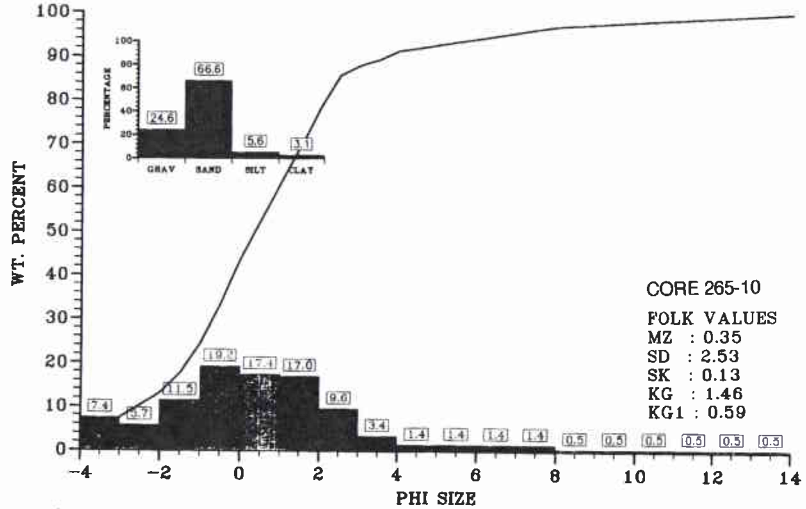
FOLK VALUES :

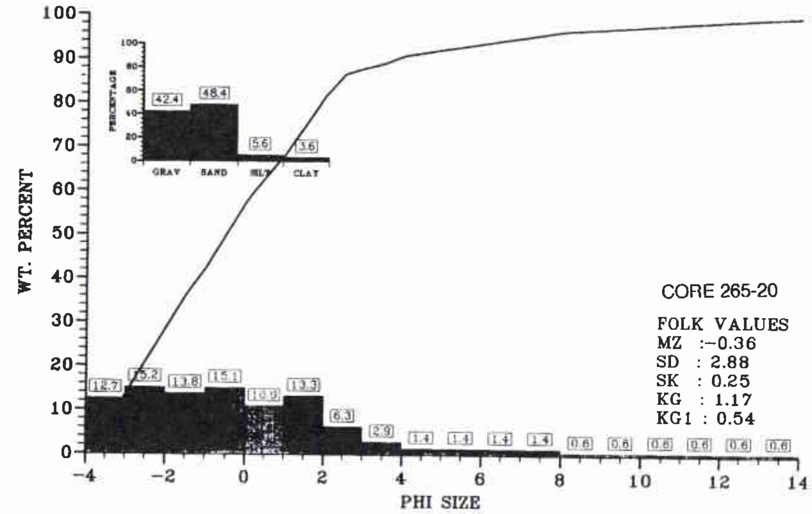
MEAN	ST.DEV	SKEW	KURT	N.KURT
-5.87	7.67	-0.61	0.85	0.46

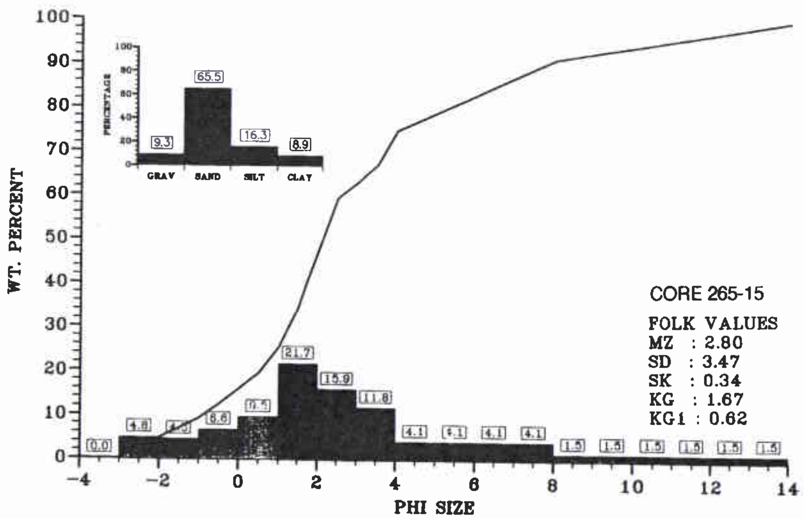
INMAN VALUES :

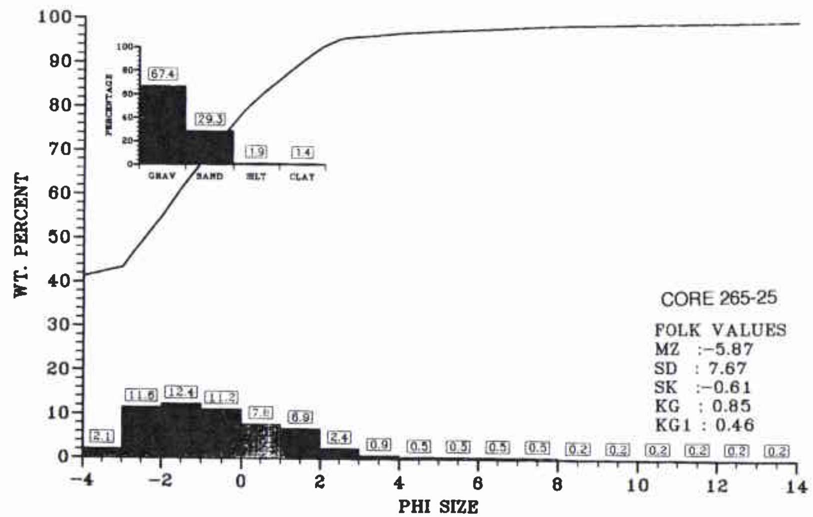
MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-2.43	-7.59	8.24	-0.63	-0.83	0.42

GRAIN SIZE ANALYSIS









Report no. changed (Mar 2006): SM-288-UU

Cruise : CORE Station : 00266 Sample : 00003
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
0.75	0.05	0.24	0.24
1.00	0.05	0.24	0.47
1.25	0.05	0.19	0.67
1.50	0.05	0.19	0.86
1.75	0.51	2.22	3.08
2.00	0.51	2.22	5.30
2.25	3.50	15.08	20.38
2.50	3.50	15.08	35.45
2.75	2.48	10.68	46.14
3.00	2.48	10.68	56.82
3.25	1.30	5.60	62.42
3.50	1.35	5.83	68.25
3.75	1.04	4.50	72.75
4.00	1.04	4.50	77.25
4.50	0.49	2.11	79.36
5.00	0.49	2.11	81.47
5.50	0.49	2.11	83.58
6.00	0.49	2.11	85.69
6.50	0.49	2.11	87.80
7.00	0.49	2.11	89.91
7.50	0.49	2.11	92.02
8.00	0.49	2.11	94.13
9.00	0.23	0.98	95.11
10.00	0.23	0.98	96.09
11.00	0.23	0.98	97.07
12.00	0.23	0.98	98.04
13.00	0.23	0.98	99.02
14.00	0.23	0.98	100.00

Post Analytical Weight : 23.21

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
1.97	2.18	2.33	2.84	3.88	5.60	8.89

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.00	77.25	16.89	5.87

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
3.54	1.90	0.68	1.83	0.65

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.84	3.89	1.71	0.61	1.51	1.02

Cruise : CORE Station : 00266 Sample : 00010
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.75	0.41	1.44	1.44
-2.50	0.41	1.44	2.88
-2.25	0.41	1.44	4.32
-2.00	0.41	1.44	5.76
-1.75	1.21	4.24	10.00
-1.50	1.21	4.24	14.25
-1.25	0.80	2.80	17.04
-1.00	0.80	2.80	19.84
-0.75	0.68	2.39	22.24
-0.50	0.68	2.39	24.63
-0.25	0.51	1.78	26.41
0.00	0.51	1.78	28.20
0.25	0.32	1.13	29.33
0.50	0.32	1.13	30.46
0.75	0.22	0.79	31.25
1.00	0.26	0.90	32.16
1.25	0.47	1.67	33.83
1.50	0.47	1.67	35.50
1.75	3.26	11.48	46.98
2.00	3.26	11.46	58.44
2.25	3.55	12.49	70.93
2.50	3.55	12.49	83.42
2.75	0.95	3.36	86.79
3.00	0.95	3.36	90.15
3.25	0.33	1.15	91.30
3.50	0.33	1.15	92.46
3.75	0.17	0.62	93.07
4.00	0.17	0.62	93.69
4.50	0.14	0.49	94.18
5.00	0.14	0.49	94.68
5.50	0.14	0.49	95.17
6.00	0.14	0.49	95.66
6.50	0.14	0.49	96.16
7.00	0.14	0.49	96.65
7.50	0.14	0.49	97.14
8.00	0.14	0.49	97.63
9.00	0.11	0.39	98.03
10.00	0.11	0.39	98.42
11.00	0.11	0.39	98.82
12.00	0.11	0.39	99.21
13.00	0.11	0.39	99.61
14.00	0.11	0.39	100.00

Post Analytical Weight : 28.40

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-2.13	-1.34	-0.45	1.82	2.33	2.54	5.33

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
19.84	73.85	3.94	2.37

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
1.01	2.10	-0.34	1.10	0.52

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.82	0.60	1.94	-0.63	-0.11	0.92

Cruise : CORE Station : 00266 Sample : 00020
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	1.18	3.30	3.30
-3.75	0.22	0.61	3.90
-3.50	0.22	0.61	4.51
-3.25	0.22	0.61	5.12
-3.00	0.22	0.61	5.73
-2.75	0.26	0.72	6.45
-2.50	0.26	0.72	7.16
-2.25	0.26	0.72	7.88
-2.00	0.26	0.72	8.60
-1.75	1.01	2.83	11.42
-1.50	1.01	2.83	14.25
-1.25	0.46	1.28	15.53
-1.00	0.46	1.28	16.81
-0.75	0.56	1.56	18.38
-0.50	0.56	1.56	19.94
-0.25	0.51	1.43	21.37
0.00	0.51	1.43	22.80
0.25	0.47	1.32	24.12
0.50	0.47	1.32	25.44
0.75	0.68	1.88	27.32
1.00	0.68	1.88	29.20
1.25	0.70	1.96	31.16
1.50	0.70	1.96	33.13
1.75	4.11	11.44	44.57
2.00	4.11	11.44	56.02
2.25	3.81	10.61	66.62
2.50	3.81	10.61	77.23
2.75	1.49	4.15	81.38
3.00	1.49	4.15	85.53
3.25	0.46	1.27	86.80
3.50	0.46	1.27	88.07
3.75	0.29	0.81	88.87
4.00	0.29	0.81	89.68
4.50	0.27	0.76	90.44
5.00	0.27	0.76	91.20
5.50	0.27	0.76	91.95
6.00	0.27	0.76	92.71
6.50	0.27	0.76	93.47
7.00	0.27	0.76	94.22
7.50	0.27	0.76	94.98
8.00	0.27	0.76	95.74
9.00	0.25	0.71	96.45
10.00	0.25	0.71	97.16
11.00	0.25	0.71	97.87
12.00	0.25	0.71	98.58
13.00	0.25	0.71	99.29
14.00	0.25	0.71	100.00

Post Analytical Weight : 35.91

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.30	-1.16	0.42	1.87	2.45	2.91	7.51

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
16.81	72.87	6.06	4.26

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
1.21	2.65	-0.22	2.18	0.69

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.87	0.87	2.03	-0.49	0.12	1.66

Cruise : CORE Station : 00266 Sample : 00030
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	6.62	7.36	7.36
-3.75	0.76	0.85	8.21
-3.50	0.76	0.85	9.05
-3.25	0.76	0.85	9.90
-3.00	0.76	0.85	10.74
-2.75	3.75	4.17	14.92
-2.50	3.75	4.17	19.09
-2.25	3.75	4.17	23.26
-2.00	3.75	4.17	27.44
-1.75	6.14	6.83	34.27
-1.50	6.14	6.83	41.11
-1.25	3.74	4.16	45.27
-1.00	3.74	4.16	49.43
-0.75	2.04	2.27	51.70
-0.50	2.04	2.27	53.98
-0.25	1.30	1.45	55.43
0.00	1.30	1.45	56.88
0.25	0.81	0.90	57.78
0.50	0.81	0.90	58.68
0.75	0.59	0.66	59.34
1.00	0.59	0.66	60.00
1.25	1.13	1.25	61.25
1.50	1.13	1.25	62.50
1.75	7.14	7.93	70.43
2.00	7.14	7.93	78.37
2.25	5.77	6.42	84.79
2.50	5.77	6.42	91.21
2.75	1.68	1.87	93.08
3.00	1.68	1.87	94.96
3.25	0.50	0.56	95.51
3.50	0.50	0.56	96.07
3.75	0.31	0.34	96.41
4.00	0.31	0.34	96.76
4.50	0.20	0.23	96.98
5.00	0.20	0.23	97.21
5.50	0.20	0.23	97.44
6.00	0.20	0.23	97.66
6.50	0.20	0.23	97.89
7.00	0.20	0.23	98.12
7.50	0.20	0.23	98.35
8.00	0.20	0.23	98.57
9.00	0.21	0.24	98.81
10.00	0.21	0.24	99.05
11.00	0.21	0.24	99.29
12.00	0.21	0.24	99.52
13.00	0.21	0.24	99.76
14.00	0.21	0.24	100.00

Post Analytical Weight : 89.92

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-4.70	-2.69	-2.15	-0.94	1.89	2.22	3.02

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
49.43	47.33	1.81	1.43

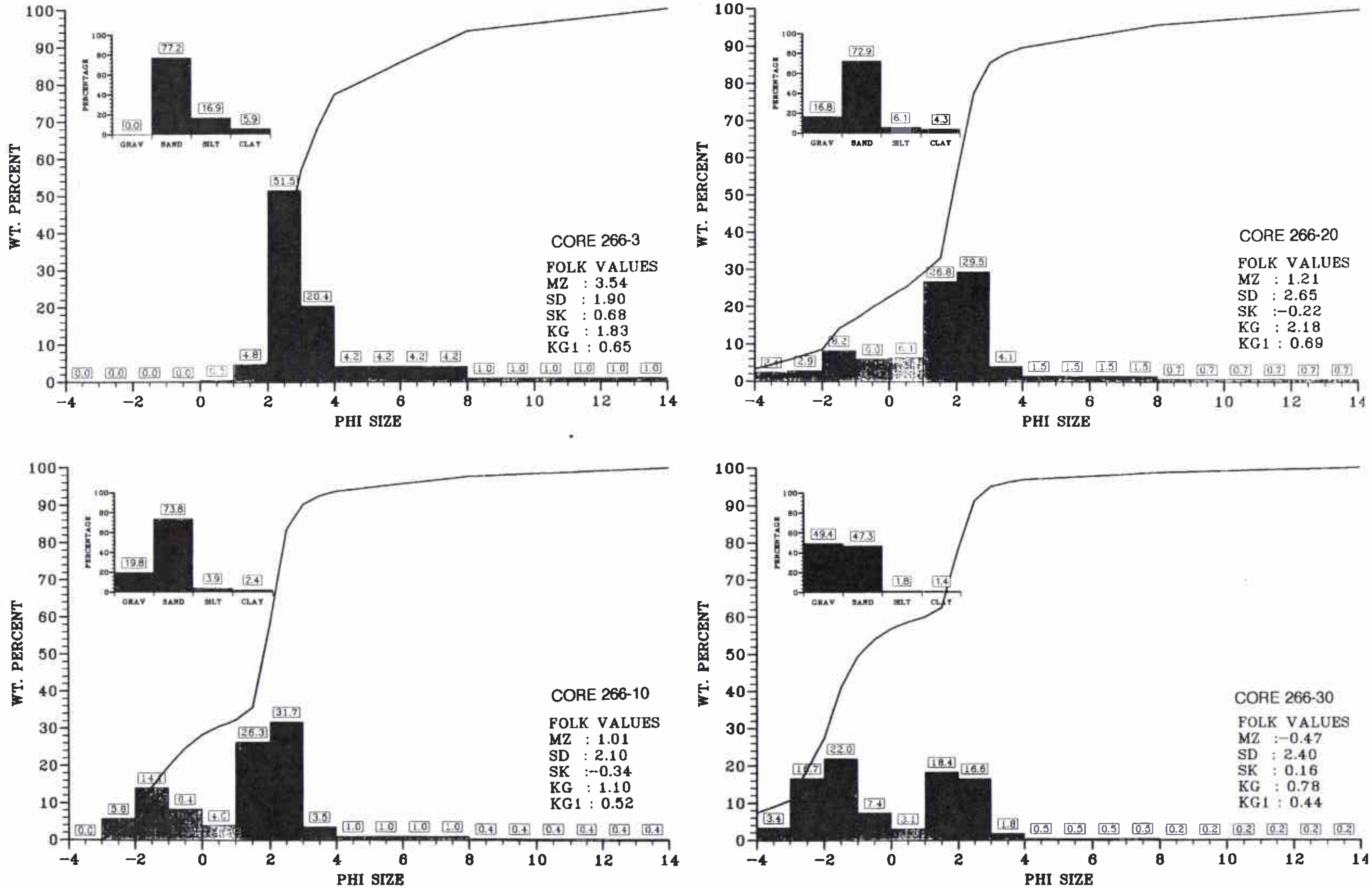
FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-0.47	2.40	0.16	0.78	0.44

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-0.94	-0.23	2.45	0.29	0.04	0.57

GRAIN SIZE ANALYSIS



Report no. changed (Mar 2006): SM-288-UU

Cruise : CORE   Station : 00266   Sample : 00040
Date :   Latitude :   Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-4.00	1.22	1.15	1.15
-3.75	3.18	3.00	4.16
-3.50	3.18	3.00	7.16
-3.25	3.18	3.00	10.17
-3.00	3.18	3.00	13.17
-2.75	7.61	7.19	20.36
-2.50	7.61	7.19	27.54
-2.25	7.61	7.19	34.73
-2.00	7.61	7.19	41.92
-1.75	10.52	9.94	51.86
-1.50	10.52	9.94	61.80
-1.25	4.72	4.46	66.26
-1.00	4.72	4.46	70.71
-0.75	2.14	2.02	72.74
-0.50	2.14	2.02	74.76
-0.25	1.14	1.08	75.84
0.00	1.14	1.08	76.92
0.25	0.62	0.59	77.51
0.50	0.62	0.59	78.09
0.75	0.46	0.44	78.53
1.00	0.46	0.44	78.97
1.25	0.88	0.84	79.80
1.50	0.88	0.84	80.64
1.75	5.03	4.75	85.39
2.00	5.03	4.75	90.14
2.25	3.22	3.04	93.19
2.50	3.22	3.04	96.23
2.75	1.10	1.04	97.27
3.00	1.10	1.04	98.30
3.25	0.23	0.22	98.53
3.50	0.23	0.22	98.75
3.75	0.13	0.12	98.87
4.00	0.13	0.12	98.99
4.50	0.06	0.05	99.05
5.00	0.06	0.05	99.10
5.50	0.06	0.05	99.16
6.00	0.06	0.05	99.21
6.50	0.06	0.05	99.27
7.00	0.06	0.05	99.32
7.50	0.06	0.05	99.38
8.00	0.06	0.05	99.43
9.00	0.10	0.09	99.53
10.00	0.10	0.09	99.62
11.00	0.10	0.09	99.72
12.00	0.10	0.09	99.81
13.00	0.10	0.09	99.91
14.00	0.10	0.09	100.00

Post Analytical Weight : 105.83

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.68	-2.90	-2.59	-1.80	-0.44	1.68	2.40

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
70.71	28.28	0.44	0.57

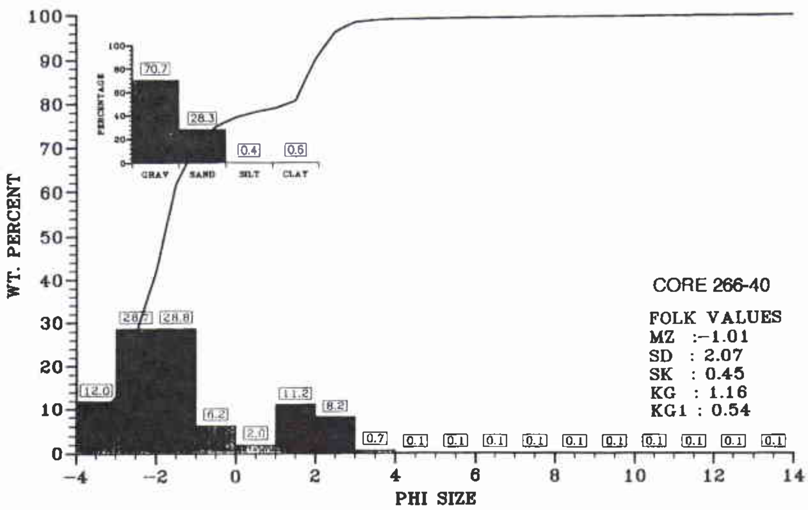
FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-1.01	2.07	0.45	1.16	0.54

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-1.80	-0.61	2.29	0.52	0.51	0.33

GRAIN SIZE ANALYSIS



Part B
Grab samples

Grab sample size fraction analyses of grab samples.
Grabs were taken from the western two sites only.

Grab	Gravel %	Sand %	Silt %	Clay %	Mean phi	Stand. Dev.	Skew.	Kurt.	N. Kurt	CaCO3 %
Site 3 (C)										
2528	0.4	90.8	4.4	4.4	1.84	1.61	0.43	2.37	0.70	71.5
2529	1.2	73.9	16.0	8.9	2.96	2.98	0.62	1.53	0.61	50.3
2530	22.9	71.2	3.3	2.6	-0.12	1.96	0.05	1.99	0.67	71.5
2531	0.0	92.0	4.2	3.8	1.83	1.32	0.29	2.88	0.74	58.8
2532	0.0	85.5	8.8	5.7	2.51	1.80	0.50	3.04	0.75	74.0
2533	37.4	55.7	4.1	2.9	-0.41	2.84	0.15	1.00	0.50	45.2
Site 1 (B)										
2534	35.9	53.3	6.7	4.1	0.44	2.63	0.52	1.12	0.53	45.2
2535										29.0
2536	1.8	88.3	5.3	4.6	1.73	1.88	0.30	1.67	0.63	59.0
2537	16.3	82.2	0.4	1.1	0.50	1.22	-0.41	0.72	0.42	44.9
2538	12.3	71,7	10.0	6.0	1.99	2.81	-0.11	2.76	0.73	68.8
2539	4.1	81.1	9.7	5.0	2.73	1.89	0.17	3.14	0.76	73.9
2540	1.1	87.2	6.4	5.3	2.56	1.67	0.26	3.64	0.78	72.6
2541	2.9	90.9	3.5	2.8	2.27	1.22	-0.01	2.47	0.71	44.4

Table 1. Generalalized analyses of recent sediment from grab samples.

Cruise : GRAB Station : 02528 Sample : 02528
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-1.50	0.05	0.12	0.12
-1.25	0.06	0.13	0.25
-1.00	0.06	0.13	0.39
-0.75	0.15	0.34	0.73
-0.50	0.15	0.34	1.08
-0.25	0.38	0.88	1.96
0.00	0.38	0.88	2.84
0.25	0.91	2.15	5.00
0.50	0.91	2.15	7.15
0.75	2.39	5.64	12.80
1.00	2.39	5.64	18.44
1.25	5.08	11.99	30.43
1.50	5.08	11.99	42.42
1.75	4.81	11.34	53.77
2.00	4.81	11.34	65.11
2.25	2.71	6.40	71.52
2.50	2.71	6.40	77.92
2.75	1.40	3.30	81.22
3.00	1.40	3.30	84.51
3.25	0.76	1.79	86.30
3.50	0.76	1.79	88.09
3.75	0.66	1.56	89.65
4.00	0.66	1.56	91.21
4.50	0.23	0.54	91.76
5.00	0.23	0.54	92.30
5.50	0.23	0.54	92.85
6.00	0.23	0.54	93.39
6.50	0.23	0.54	93.94
7.00	0.23	0.54	94.48
7.50	0.23	0.54	95.02
8.00	0.23	0.54	95.57
9.00	0.31	0.74	96.31
10.00	0.31	0.74	97.05
11.00	0.31	0.74	97.78
12.00	0.31	0.74	98.52
13.00	0.31	0.74	99.26
14.00	0.31	0.74	100.00

Post Analytical Weight : 42.39

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
0.25	0.89	1.14	1.67	2.39	2.96	7.48

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.39	90.82	4.36	4.43

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
1.84	1.61	0.43	2.37	0.70

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.67	1.93	1.03	0.25	2.12	2.49

Cruise : GRAB Station : 02530 Sample : 02530
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.75	0.75	1.57	1.57
-3.50	0.75	1.57	3.14
-3.25	0.75	1.57	4.71
-3.00	0.75	1.57	6.29
-2.75	0.86	1.81	8.10
-2.50	0.86	1.81	9.91
-2.25	0.86	1.81	11.72
-2.00	0.86	1.81	13.53
-1.75	0.75	1.58	15.11
-1.50	0.75	1.58	16.70
-1.25	1.48	3.11	19.80
-1.00	1.48	3.11	22.91
-0.75	2.68	5.66	28.57
-0.50	2.68	5.66	34.22
-0.25	3.76	7.93	42.15
0.00	3.76	7.93	50.07
0.25	3.79	7.99	58.06
0.50	3.79	7.99	66.04
0.75	3.60	7.59	73.63
1.00	3.60	7.59	81.22
1.25	1.36	2.87	84.09
1.50	1.36	2.87	86.97
1.75	0.77	1.63	88.59
2.00	0.77	1.63	90.22
2.25	0.33	0.69	90.90
2.50	0.33	0.69	91.59
2.75	0.13	0.28	91.87
3.00	0.13	0.28	92.15
3.25	0.14	0.29	92.44
3.50	0.14	0.29	92.72
3.75	0.33	0.70	93.43
4.00	0.33	0.70	94.13
4.50	0.20	0.41	94.54
5.00	0.20	0.41	94.96
5.50	0.20	0.41	95.37
6.00	0.20	0.41	95.78
6.50	0.20	0.41	96.20
7.00	0.20	0.41	96.61
7.50	0.20	0.41	97.02
8.00	0.20	0.41	97.43
9.00	0.20	0.43	97.86
10.00	0.20	0.43	98.29
11.00	0.20	0.43	98.72
12.00	0.20	0.43	99.14
13.00	0.20	0.43	99.57
14.00	0.20	0.43	100.00

Post Analytical Weight : 47.47

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.20	-1.61	-0.91	0.00	0.80	1.24	5.05

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
22.91	71.22	3.30	2.57

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-0.12	1.96	0.05	1.99	0.67

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
0.00	-0.18	1.43	-0.13	0.65	1.90

Cruise : GRAB Station : 02529 Sample : 02529
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-1.50	0.10	0.34	0.34
-1.25	0.12	0.41	0.75
-1.00	0.12	0.41	1.16
-0.75	0.16	0.57	1.73
-0.50	0.16	0.57	2.31
-0.25	0.40	1.40	3.71
0.00	0.40	1.40	5.11
0.25	0.73	2.57	7.68
0.50	0.73	2.57	10.25
0.75	1.53	5.37	15.63
1.00	1.53	5.37	21.00
1.25	2.00	7.02	28.02
1.50	2.00	7.02	35.04
1.75	2.76	9.66	44.70
2.00	2.76	9.66	54.36
2.25	1.11	3.88	58.24
2.50	1.11	3.88	62.12
2.75	0.33	1.17	63.29
3.00	0.33	1.17	64.46
3.25	0.56	1.98	66.44
3.50	0.56	1.98	68.42
3.75	0.95	3.34	71.76
4.00	0.95	3.34	75.09
4.50	0.57	2.00	77.09
5.00	0.57	2.00	79.09
5.50	0.57	2.00	81.09
6.00	0.57	2.00	83.09
6.50	0.57	2.00	85.09
7.00	0.57	2.00	87.08
7.50	0.57	2.00	89.08
8.00	0.57	2.00	91.08
9.00	0.42	1.49	92.57
10.00	0.42	1.49	94.05
11.00	0.42	1.49	95.54
12.00	0.42	1.49	97.03
13.00	0.42	1.49	98.51
14.00	0.42	1.49	100.00

Post Analytical Weight : 28.52

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-0.02	0.77	1.14	1.89	3.99	6.23	10.64

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
1.16	73.94	15.99	8.92

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.96	2.98	0.62	1.53	0.61

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.89	3.50	2.73	0.59	1.25	0.95

Cruise : GRAB Station : 02531 Sample : 02531
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-0.50	0.14	0.37	0.37
-0.25	0.18	0.46	0.83
0.00	0.18	0.46	1.29
0.25	0.51	1.32	2.60
0.50	0.51	1.32	3.92
0.75	1.82	4.72	8.64
1.00	1.82	4.72	13.36
1.25	2.69	6.98	20.33
1.50	2.69	6.98	27.31
1.75	6.52	16.91	44.22
2.00	6.52	16.91	61.12
2.25	4.29	11.13	72.25
2.50	4.29	11.13	83.38
2.75	0.88	2.29	85.67
3.00	0.88	2.29	87.96
3.25	0.40	1.04	89.00
3.50	0.40	1.04	90.05
3.75	0.38	0.97	91.02
4.00	0.38	0.97	91.99
4.50	0.20	0.53	92.52
5.00	0.20	0.53	93.05
5.50	0.20	0.53	93.58
6.00	0.20	0.53	94.10
6.50	0.20	0.53	94.63
7.00	0.20	0.53	95.16
7.50	0.20	0.53	95.69
8.00	0.20	0.53	96.22
9.00	0.24	0.63	96.85
10.00	0.24	0.63	97.48
11.00	0.24	0.63	98.11
12.00	0.24	0.63	98.74
13.00	0.24	0.63	99.37
14.00	0.24	0.63	100.00

Post Analytical Weight : 38.57

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
0.56	1.09	1.42	1.84	2.31	2.57	6.85

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.00	91.99	4.23	3.78

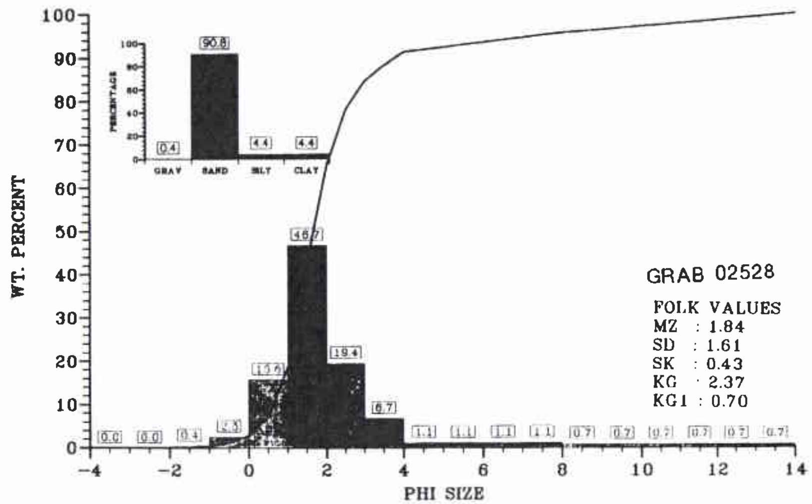
FOLK VALUES :

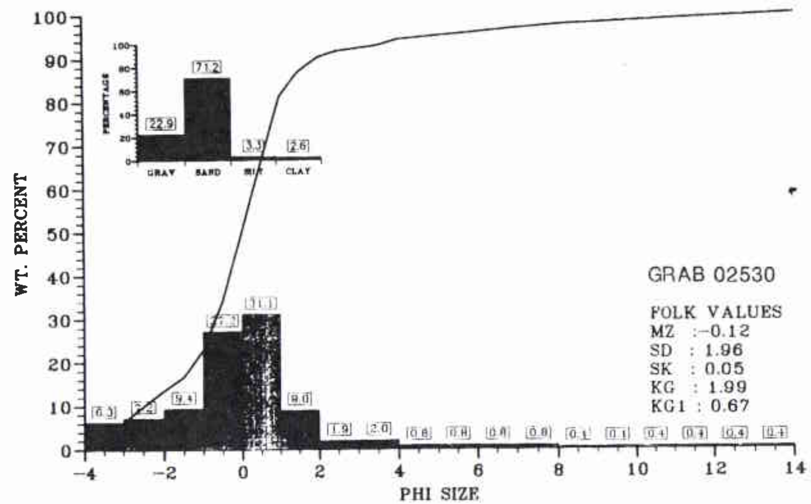
MEAN	ST.DEV	SKEW	KURT	N.KURT
1.83	1.32	0.29	2.88	0.74

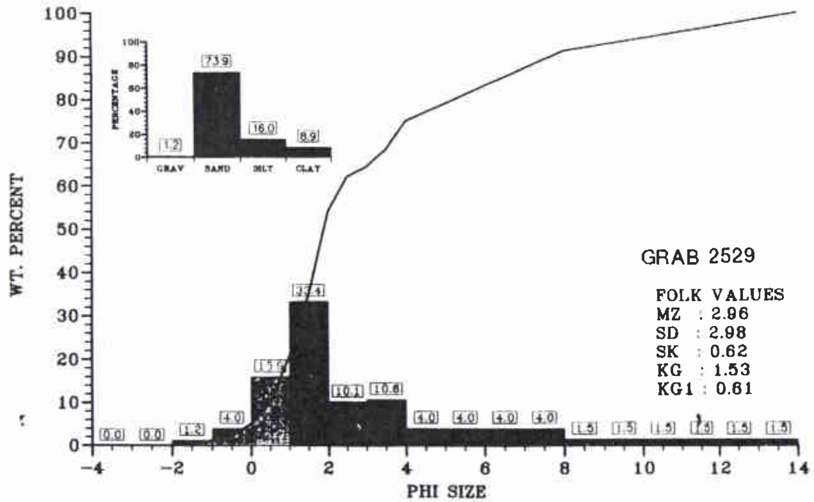
INMAN VALUES :

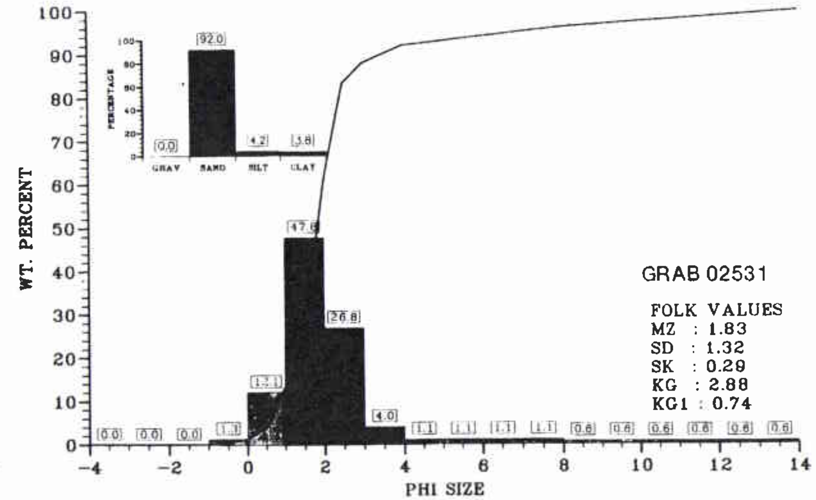
MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.84	1.83	0.74	-0.01	2.53	3.27

GRAIN SIZE ANALYSIS









Cruise : GRAB Station : 02532 Sample : 02532
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-0.75	0.20	0.54	0.54
-0.50	0.21	0.56	1.10
-0.25	0.31	0.84	1.94
0.00	0.31	0.83	2.77
0.25	0.41	1.10	3.87
0.50	0.40	1.08	4.95
0.75	0.50	1.35	6.30
1.00	0.50	1.35	7.66
1.25	1.20	3.24	10.90
1.50	1.20	3.24	14.14
1.75	4.34	11.76	25.90
2.00	4.34	11.76	37.66
2.25	5.83	15.80	53.46
2.50	5.83	15.80	69.26
2.75	1.58	4.29	73.55
3.00	1.58	4.29	77.83
3.25	0.75	2.04	79.88
3.50	0.75	2.04	81.92
3.75	0.67	1.81	83.74
4.00	0.67	1.81	85.55
4.50	0.41	1.10	86.65
5.00	0.41	1.10	87.75
5.50	0.41	1.10	88.85
6.00	0.41	1.10	89.95
6.50	0.41	1.10	91.05
7.00	0.41	1.10	92.15
7.50	0.41	1.10	93.24
8.00	0.41	1.10	94.34
9.00	0.35	0.94	95.29
10.00	0.35	0.94	96.23
11.00	0.35	0.94	97.17
12.00	0.35	0.94	98.11
13.00	0.35	0.94	99.06
14.00	0.35	0.94	100.00

Post Analytical Weight : 36.92

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
0.51	1.54	1.73	2.20	2.83	3.79	8.70

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
0.00	85.55	8.80	5.66

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.51	1.80	0.50	3.04	0.75

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.20	2.66	1.12	0.42	2.14	2.64

Cruise : GRAB Station : 02534 Sample : 02534
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.75	0.61	1.35	1.35
-2.50	0.61	1.35	2.69
-2.25	0.61	1.35	4.04
-2.00	0.61	1.35	5.38
-1.75	3.00	6.62	12.00
-1.50	3.00	6.62	18.63
-1.25	3.92	8.65	27.28
-1.00	3.92	8.65	35.93
-0.75	2.60	5.73	41.66
-0.50	2.60	5.73	47.39
-0.25	1.13	2.49	49.87
0.00	1.13	2.49	52.36
0.25	0.67	1.47	53.83
0.50	0.67	1.47	55.30
0.75	0.96	2.11	57.41
1.00	0.96	2.11	59.52
1.25	1.63	3.60	63.12
1.50	1.63	3.60	66.72
1.75	1.67	3.68	70.40
2.00	1.67	3.68	74.07
2.25	0.58	1.28	75.35
2.50	0.58	1.28	76.63
2.75	1.38	3.05	79.68
3.00	1.38	3.05	82.74
3.25	0.86	1.89	84.63
3.50	0.86	1.89	86.52
3.75	0.61	1.35	87.87
4.00	0.61	1.35	89.22
4.50	0.38	0.84	90.06
5.00	0.38	0.84	90.89
5.50	0.38	0.84	91.73
6.00	0.38	0.84	92.57
6.50	0.38	0.84	93.40
7.00	0.38	0.84	94.24
7.50	0.38	0.84	95.07
8.00	0.38	0.84	95.91
9.00	0.31	0.68	96.59
10.00	0.31	0.68	97.27
11.00	0.31	0.68	97.96
12.00	0.31	0.68	98.64
13.00	0.31	0.68	99.32
14.00	0.31	0.68	100.00

Post Analytical Weight : 45.33

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-2.07	-1.60	-1.32	-0.24	2.18	3.17	7.46

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
35.93	53.29	6.69	4.09

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
0.44	2.63	0.52	1.12	0.53

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-0.24	0.78	2.38	0.43	1.23	1.00

Cruise : GRAB Station : 02533 Sample : 02533
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.75	2.45	4.79	4.79
-3.50	2.45	4.79	9.59
-3.25	2.45	4.79	14.38
-3.00	2.45	4.79	19.18
-2.75	1.00	1.97	21.14
-2.50	1.00	1.97	23.11
-2.25	1.00	1.97	25.08
-2.00	1.00	1.97	27.04
-1.75	1.08	2.12	29.17
-1.50	1.08	2.12	31.29
-1.25	1.55	3.04	34.33
-1.00	1.55	3.04	37.36
-0.75	2.67	5.22	42.59
-0.50	2.67	5.22	47.81
-0.25	2.84	5.55	53.36
0.00	2.84	5.55	58.92
0.25	1.70	3.33	62.25
0.50	1.70	3.33	65.58
0.75	1.02	2.00	67.57
1.00	1.02	2.00	69.57
1.25	0.70	1.37	70.95
1.50	0.70	1.37	72.32
1.75	1.80	3.53	75.85
2.00	1.80	3.53	79.38
2.25	1.70	3.34	82.71
2.50	1.70	3.34	86.05
2.75	0.69	1.36	87.40
3.00	0.69	1.36	88.76
3.25	0.42	0.81	89.57
3.50	0.42	0.81	90.39
3.75	0.67	1.32	91.71
4.00	0.67	1.32	93.02
4.50	0.26	0.51	93.53
5.00	0.26	0.51	94.05
5.50	0.26	0.51	94.56
6.00	0.26	0.51	95.07
6.50	0.26	0.51	95.58
7.00	0.26	0.51	96.09
7.50	0.26	0.51	96.60
8.00	0.26	0.51	97.11
9.00	0.25	0.48	97.59
10.00	0.25	0.48	98.07
11.00	0.25	0.48	98.56
12.00	0.25	0.48	99.04
13.00	0.25	0.48	99.52
14.00	0.25	0.48	100.00

Post Analytical Weight : 51.09

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-3.74	-3.17	-2.26	-0.40	1.69	2.35	5.93

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
37.36	55.66	4.09	2.89

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
-0.41	2.84	0.15	1.00	0.50

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
-0.40	-0.41	2.76	0.00	0.54	0.75

Cruise : GRAB Station : 02536 Sample : 02536
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.50	0.07	0.18	0.18
-2.25	0.07	0.18	0.37
-2.00	0.07	0.18	0.55
-1.75	0.08	0.22	0.78
-1.50	0.08	0.22	1.00
-1.25	0.16	0.42	1.42
-1.00	0.16	0.42	1.84
-0.75	0.47	1.23	3.07
-0.50	0.47	1.23	4.31
-0.25	0.83	2.20	6.51
0.00	0.83	2.20	8.71
0.25	1.48	3.90	12.61
0.50	1.48	3.90	16.51
0.75	3.96	10.46	26.98
1.00	3.96	10.46	37.44
1.25	1.90	5.03	42.47
1.50	1.90	5.03	47.49
1.75	1.88	4.97	52.46
2.00	1.88	4.97	57.43
2.25	2.38	6.27	63.71
2.50	2.38	6.27	69.98
2.75	2.51	6.63	76.61
3.00	2.51	6.63	83.24
3.25	0.82	2.16	85.40
3.50	0.82	2.16	87.56
3.75	0.49	1.28	88.84
4.00	0.49	1.28	90.12
4.50	0.25	0.67	90.78
5.00	0.25	0.67	91.45
5.50	0.25	0.67	92.11
6.00	0.25	0.67	92.78
6.50	0.25	0.67	93.44
7.00	0.25	0.67	94.11
7.50	0.25	0.67	94.77
8.00	0.25	0.67	95.44
9.00	0.29	0.76	96.20
10.00	0.29	0.76	96.96
11.00	0.29	0.76	97.72
12.00	0.29	0.76	98.48
13.00	0.29	0.76	99.24
14.00	0.29	0.76	100.00

Post Analytical Weight : 37.89

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-0.42	0.47	0.70	1.63	2.69	3.09	7.67

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
1.84	88.28	5.32	4.56

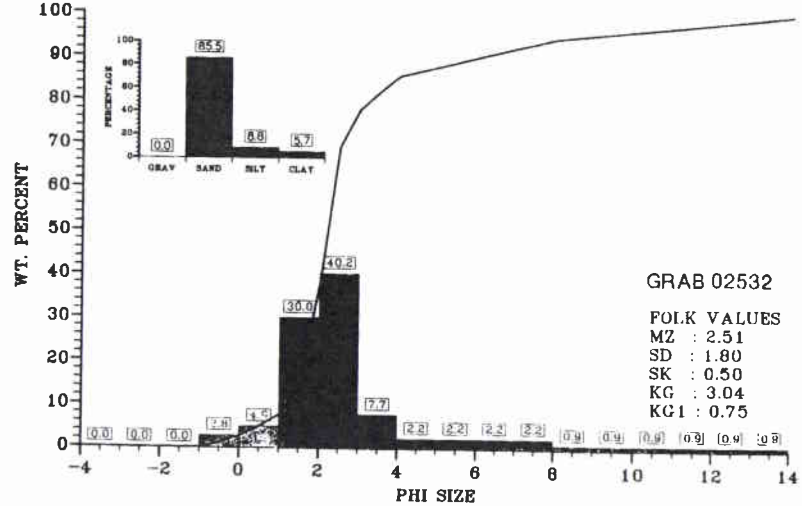
FOLK VALUES :

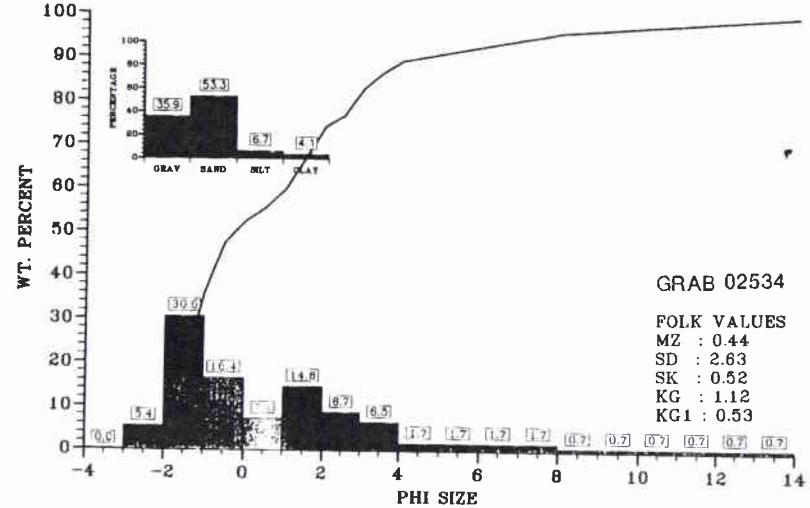
MEAN	ST.DEV	SKEW	KURT	N.KURT
1.73	1.88	0.30	1.67	0.63

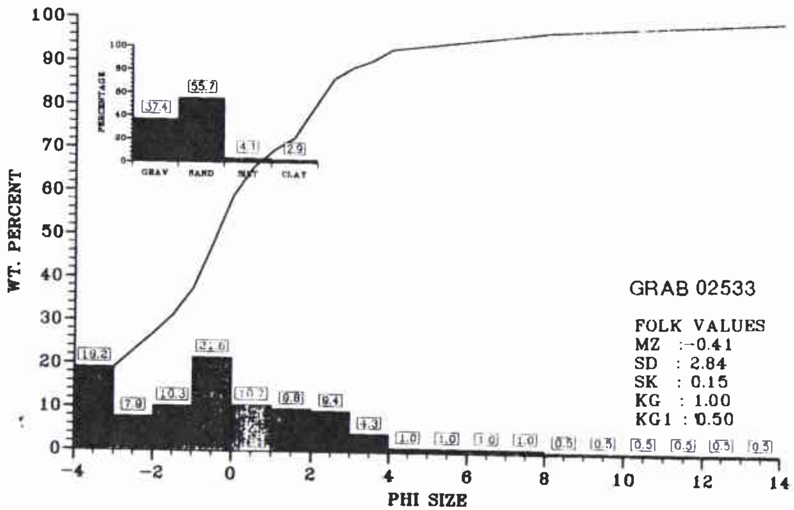
INMAN VALUES :

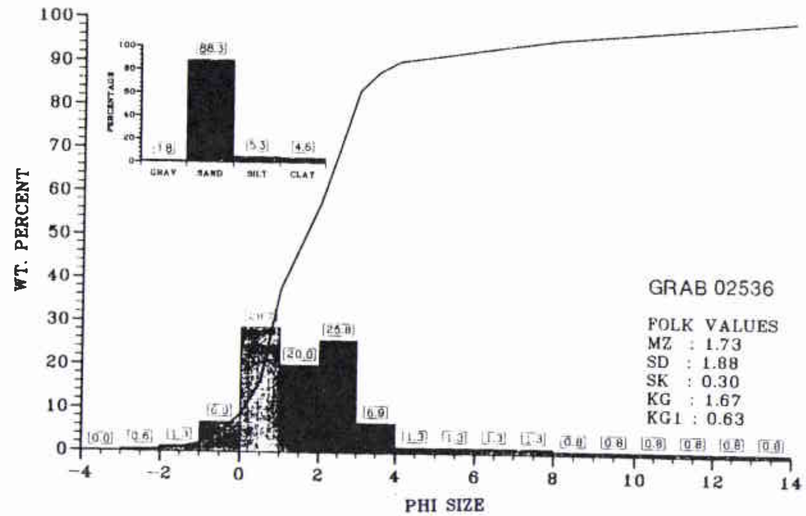
MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
1.63	1.78	1.31	0.12	1.52	2.09

GRAIN SIZE ANALYSIS









Report no. changed (Mar 2006): SM-288-UU

Cruise : GRAB Station : 02537 Sample : 02537
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.75	0.17	0.28	0.28
-2.50	0.17	0.28	0.56
-2.25	0.17	0.28	0.84
-2.00	0.17	0.28	1.13
-1.75	1.73	2.82	3.94
-1.50	1.73	2.82	6.76
-1.25	2.93	4.76	11.52
-1.00	2.93	4.76	16.29
-0.75	3.81	6.20	22.49
-0.50	3.81	6.20	28.68
-0.25	2.57	4.17	32.86
0.00	2.57	4.17	37.03
0.25	1.29	2.11	39.14
0.50	1.29	2.11	41.24
0.75	3.62	5.88	47.12
1.00	3.62	5.88	53.00
1.25	8.09	13.15	66.16
1.50	8.09	13.15	79.31
1.75	5.04	8.20	87.51
2.00	5.04	8.20	95.71
2.25	0.41	0.67	96.38
2.50	0.41	0.67	97.06
2.75	0.24	0.40	97.45
3.00	0.24	0.40	97.85
3.25	0.12	0.20	98.05
3.50	0.12	0.20	98.24
3.75	0.07	0.11	98.35
4.00	0.07	0.11	98.46
4.50	0.03	0.05	98.51
5.00	0.03	0.05	98.57
5.50	0.03	0.05	98.62
6.00	0.03	0.05	98.67
6.50	0.03	0.05	98.73
7.00	0.03	0.05	98.78
7.50	0.03	0.05	98.83
8.00	0.03	0.05	98.89
9.00	0.11	0.19	99.07
10.00	0.11	0.19	99.26
11.00	0.11	0.19	99.44
12.00	0.11	0.19	99.63
13.00	0.11	0.19	99.81
14.00	0.11	0.19	100.00

Post Analytical Weight : 61.50

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-1.66	-1.02	-0.65	0.87	1.42	1.64	1.98

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
16.29	82.17	0.43	1.11

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
0.50	1.22	-0.41	0.72	0.42

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
0.87	0.31	1.33	-0.42	-0.54	0.37

Cruise : GRAB Station : 02539 Sample : 02539
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.75	0.12	0.65	0.65
-2.50	0.12	0.65	1.30
-2.25	0.12	0.65	1.96
-2.00	0.12	0.65	2.60
-1.75	0.07	0.38	2.98
-1.50	0.07	0.38	3.36
-1.25	0.07	0.36	3.73
-1.00	0.07	0.36	4.09
-0.75	0.19	1.01	5.10
-0.50	0.19	1.01	6.10
-0.25	0.17	0.93	7.04
0.00	0.18	0.96	8.00
0.25	0.15	0.82	8.81
0.50	0.15	0.82	9.63
0.75	0.17	0.95	10.57
1.00	0.17	0.95	11.52
1.25	0.22	1.17	12.69
1.50	0.22	1.17	13.86
1.75	0.64	3.48	17.34
2.00	0.64	3.48	20.82
2.25	1.93	10.52	31.34
2.50	1.93	10.52	41.85
2.75	2.62	14.24	56.09
3.00	2.62	14.24	70.33
3.25	0.86	4.68	75.01
3.50	0.86	4.68	79.69
3.75	0.51	2.78	82.46
4.00	0.51	2.78	85.24
4.50	0.22	1.22	86.46
5.00	0.22	1.22	87.68
5.50	0.22	1.22	88.89
6.00	0.22	1.22	90.11
6.50	0.22	1.22	91.33
7.00	0.22	1.22	92.54
7.50	0.22	1.22	93.76
8.00	0.22	1.22	94.98
9.00	0.15	0.84	95.82
10.00	0.15	0.84	96.65
11.00	0.15	0.84	97.49
12.00	0.15	0.84	98.33
13.00	0.15	0.84	99.16
14.00	0.15	0.84	100.00

Post Analytical Weight : 18.40

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-0.77	1.65	2.10	2.64	3.25	3.89	8.03

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
4.09	81.15	9.74	5.02

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.73	1.89	0.17	3.14	0.76

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.64	2.77	1.12	0.11	0.88	2.94

Cruise : GRAB Station : 02538 Sample : 02538
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-2.50	0.48	1.48	1.48
-2.25	0.48	1.48	2.97
-2.00	0.48	1.48	4.45
-1.75	0.60	1.85	6.31
-1.50	0.60	1.85	8.16
-1.25	0.67	2.06	10.22
-1.00	0.67	2.06	12.27
-0.75	0.76	2.35	14.63
-0.50	0.76	2.35	16.98
-0.25	0.45	1.39	18.37
0.00	0.45	1.39	19.75
0.25	0.21	0.63	20.39
0.50	0.21	0.63	21.02
0.75	0.19	0.59	21.61
1.00	0.19	0.59	22.19
1.25	0.18	0.57	22.76
1.50	0.19	0.57	23.33
1.75	0.93	2.87	26.21
2.00	0.93	2.87	29.08
2.25	2.69	8.29	37.37
2.50	2.69	8.29	45.65
2.75	4.00	12.32	57.97
3.00	4.00	12.32	70.29
3.25	1.40	4.30	74.59
3.50	1.40	4.30	78.89
3.75	0.83	2.55	81.44
4.00	0.83	2.55	84.00
4.50	0.40	1.24	85.24
5.00	0.40	1.24	86.49
5.50	0.40	1.24	87.73
6.00	0.40	1.24	88.98
6.50	0.40	1.24	90.22
7.00	0.40	1.24	91.47
7.50	0.40	1.24	92.71
8.00	0.40	1.24	93.96
9.00	0.33	1.01	94.96
10.00	0.33	1.01	95.97
11.00	0.33	1.01	96.98
12.00	0.33	1.01	97.99
13.00	0.33	1.01	98.99
14.00	0.33	1.01	100.00

Post Analytical Weight : 32.46

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-1.93	-0.60	1.65	2.59	3.27	4.00	9.04

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
12.27	71.72	9.96	6.04

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
1.99	2.81	-0.11	2.76	0.73

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.59	1.70	2.30	-0.39	0.42	1.38

Cruise : GRAB Station : 02540 Sample : 02540
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-1.75	0.07	0.22	0.22
-1.50	0.07	0.22	0.45
-1.25	0.11	0.34	0.79
-1.00	0.11	0.34	1.14
-0.75	0.23	0.71	1.84
-0.50	0.23	0.71	2.55
-0.25	0.25	0.77	3.32
0.00	0.25	0.77	4.09
0.25	0.28	0.87	4.96
0.50	0.28	0.87	5.83
0.75	0.43	1.32	7.15
1.00	0.43	1.32	8.47
1.25	0.55	1.69	10.17
1.50	0.55	1.69	11.86
1.75	1.72	5.29	17.15
2.00	1.72	5.29	22.43
2.25	4.36	13.41	35.84
2.50	4.36	13.41	49.26
2.75	4.60	14.13	63.38
3.00	4.60	14.13	77.51
3.25	1.13	3.48	80.99
3.50	1.13	3.48	84.46
3.75	0.62	1.91	86.38
4.00	0.62	1.91	88.29
4.50	0.26	0.80	89.09
5.00	0.26	0.80	89.89
5.50	0.26	0.80	90.70
6.00	0.26	0.80	91.50
6.50	0.26	0.80	92.30
7.00	0.26	0.80	93.10
7.50	0.26	0.80	93.90
8.00	0.26	0.80	94.71
9.00	0.29	0.88	95.59
10.00	0.29	0.88	96.47
11.00	0.29	0.88	97.35
12.00	0.29	0.88	98.24
13.00	0.29	0.88	99.12
14.00	0.29	0.88	100.00

Post Analytical Weight : 32.53

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
0.26	1.70	2.05	2.51	2.96	3.47	8.33

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
1.14	87.15	6.42	5.29

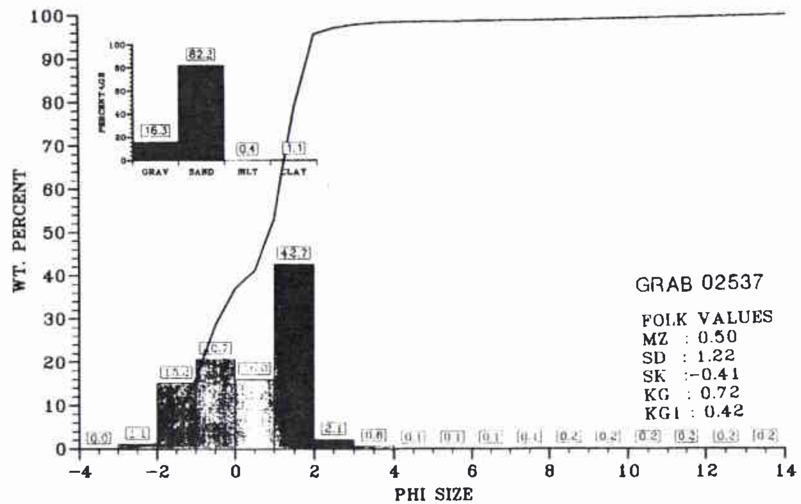
FOLK VALUES :

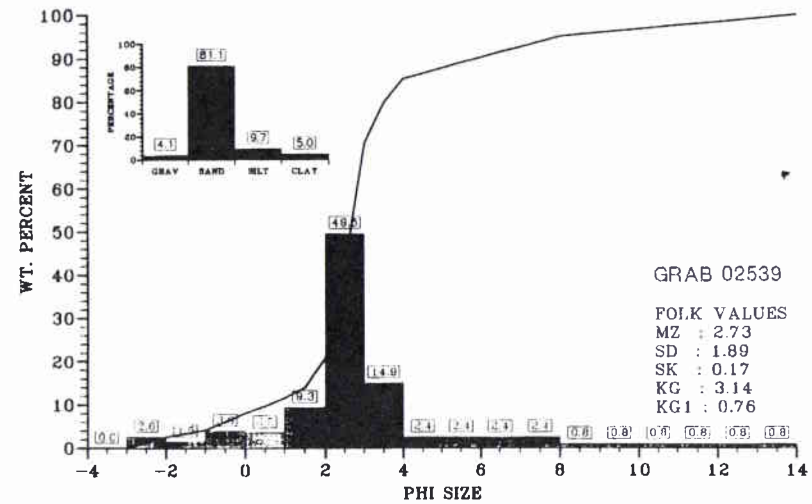
MEAN	ST.DEV	SKEW	KURT	N.KURT
2.56	1.67	0.26	3.64	0.78

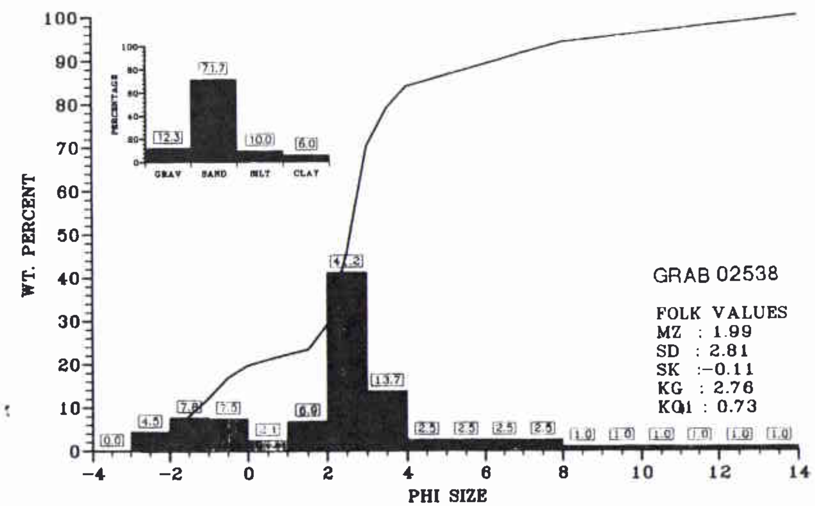
INMAN VALUES :

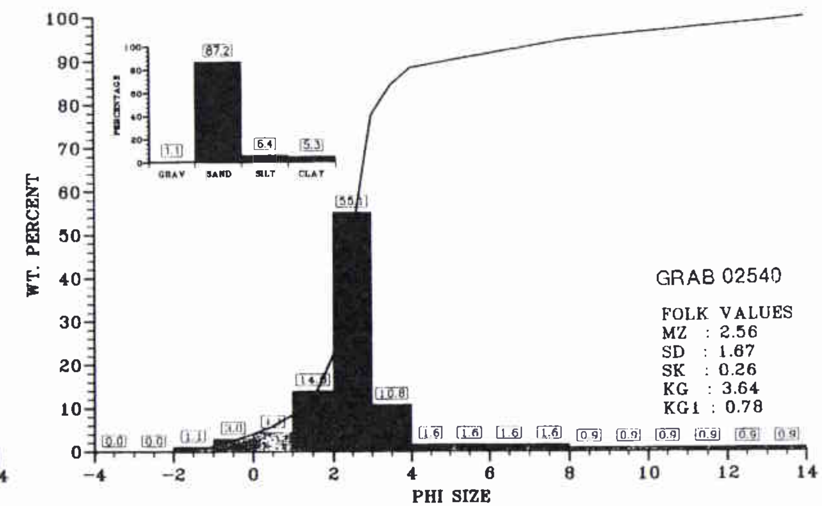
MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.51	2.58	0.89	0.08	2.01	3.56

GRAIN SIZE ANALYSIS









Cruise : GRAB Station : 02541 Sample : 02541
Date : Latitude : Longitude :

PHI SIZE	FRACTION WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.75	0.06	0.21	0.21
-3.50	0.06	0.21	0.42
-3.25	0.06	0.21	0.64
-3.00	0.06	0.21	0.85
-2.75	0.04	0.15	1.00
-2.50	0.04	0.16	1.16
-2.25	0.04	0.16	1.31
-2.00	0.04	0.16	1.47
-1.75	0.08	0.29	1.76
-1.50	0.08	0.29	2.04
-1.25	0.11	0.42	2.47
-1.00	0.11	0.42	2.89
-0.75	0.21	0.79	3.69
-0.50	0.21	0.79	4.48
-0.25	0.21	0.79	5.27
0.00	0.21	0.79	6.07
0.25	0.24	0.88	6.94
0.50	0.23	0.87	7.82
0.75	0.21	0.79	8.61
1.00	0.21	0.80	9.41
1.25	0.70	2.61	12.02
1.50	0.70	2.61	14.64
1.75	2.21	8.22	22.86
2.00	2.21	8.22	31.08
2.25	4.04	15.03	46.11
2.50	4.04	15.03	61.15
2.75	3.43	12.77	73.91
3.00	3.43	12.77	86.68
3.25	0.67	2.48	89.16
3.50	0.67	2.48	91.65
3.75	0.29	1.06	92.71
4.00	0.29	1.06	93.77
4.50	0.12	0.43	94.21
5.00	0.12	0.43	94.64
5.50	0.12	0.43	95.07
6.00	0.12	0.43	95.50
6.50	0.12	0.43	95.93
7.00	0.12	0.43	96.37
7.50	0.12	0.43	96.80
8.00	0.12	0.43	97.23
9.00	0.12	0.46	97.69
10.00	0.12	0.46	98.15
11.00	0.12	0.46	98.61
12.00	0.12	0.46	99.08
13.00	0.12	0.46	99.54
14.00	0.12	0.46	100.00

Post Analytical Weight : 26.86

PHI SIZE AT PERCENTAGE LEVELS :

5	16	25	50	75	84	95
-0.34	1.54	1.82	2.31	2.77	2.95	5.42

PERCENTAGE OF :

GRAVEL	SAND	SILT	CLAY
2.89	90.88	3.46	2.77

FOLK VALUES :

MEAN	ST.DEV	SKEW	KURT	N.KURT
2.27	1.22	-0.01	2.47	0.71

INMAN VALUES :

MEDIAN	MEAN	ST.DEV	SKEW	SKEW.2	KURT
2.31	2.24	0.70	-0.10	0.32	3.09

GRAIN SIZE ANALYSIS