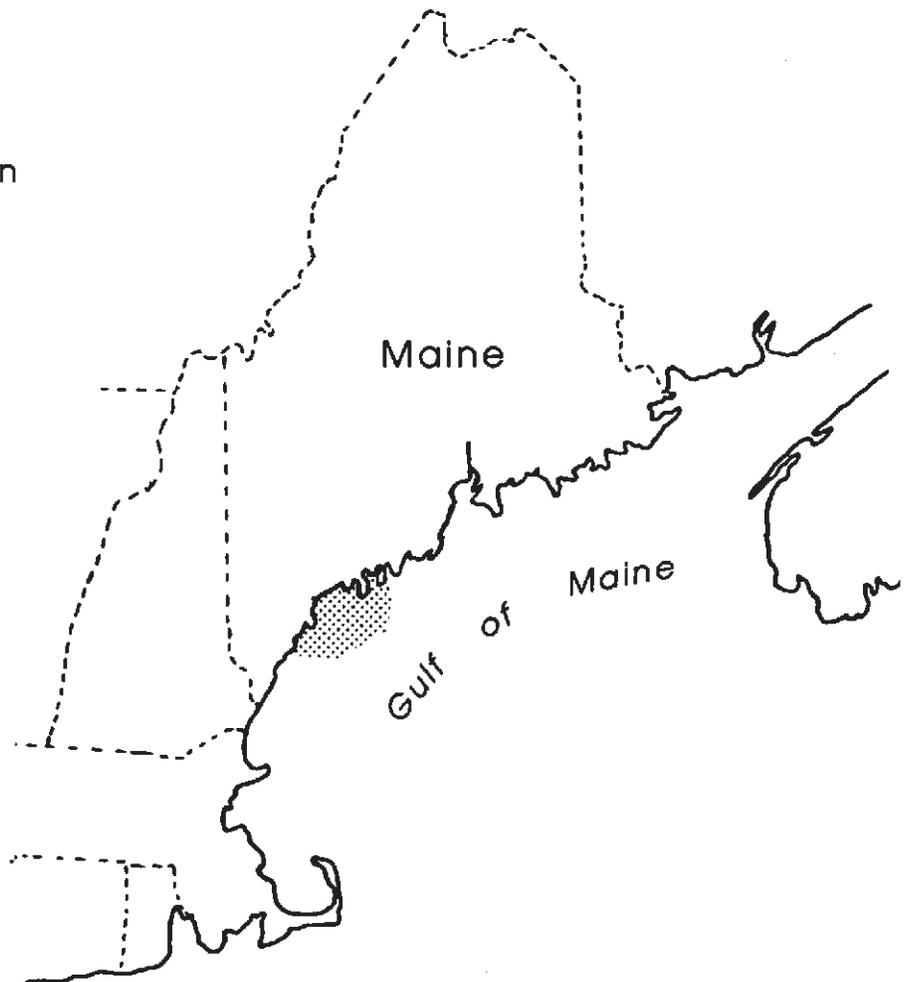


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Sedimentary Framework of the Southern Maine Inner Continental Shelf: Preliminary Results from Vibracores

by

Joseph T. Kelley
Stephen M. Dickson
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Walter A. Anderson, State Geologist
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***Joseph T. Kelley
Stephen M. Dickson***
*Maine Geological Survey
State House Station #22
Augusta, ME 04333*

and

***Daniel F. Belknap
Julie K. Friez***
*Department of Geological Sciences
University of Maine
Orono, ME 04469*

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INTRODUCTION

Within the past 14,000 years the inner continental shelf of Maine has experienced deglaciation accompanied by a marine transgression, a period of emergence (for at least some of the shelf), followed by the on-going marine transgression. This brief history has resulted in a thin, but complex, Quaternary stratigraphic column. Deposits resulting from glacial activity are often internally heterogeneous and unevenly distributed across the regionally-variable, crystalline bedrock of the western Gulf of Maine. As a consequence of sea-level changes, much of this glacial sediment has been reworked twice by nearshore processes, and overlain by new material introduced from local rivers. On the basis of bottom sampling, seismic reflection and side scan sonar profiling, models for the timing of sea-level changes and the resulting late Quaternary stratigraphy of the inner shelf have been presented and are discussed below. These models strongly rely on interpretations of seismic reflection data, which can be ambiguous in such a complex depositional setting. For example, the seismic data is often of insufficient resolution to recognize individual beds of differing grain size which would be useful for paleo-environmental interpretation. Furthermore, seismic data alone allows only qualitative understanding of the chronology of late Quaternary events, particularly with respect to the time and depth of the early Holocene lowstand of sea level. To confirm and improve previous interpretations of the seismic data, and provide samples of sediment for grain-size analyses and fossils for age determinations, cores were collected from areas where significant seismic reflectors are found near the modern seafloor. The purpose of this report is to summarize existing core data from the inner shelf and

nearshore zone, and to describe the sediment from 13 new vibracores collected from the inner shelf in 1988.

LOCATION

Along the Atlantic Coastal Plain, abrupt geographic and bathymetric boundaries clearly separate estuaries from the inner continental shelf. Along the highly irregular shoreline of Maine, however, it is difficult to clearly demark the boundaries between estuaries and the inner continental shelf, or between the inner and mid-shelf, since abrupt geographic and bathymetric terminations do not occur. For this reason we have arbitrarily defined the inner shelf as the area seaward of the zone of significant mixing of river and sea water (estuaries) out to the 100 meter isobath (Figure 1). This excludes constricted embayments, especially in the central portion of the coast (Kelley, 1987), but includes more open embayments to the south with better connections to the open ocean.

PREVIOUS WORK

Although he did not work offshore, Bloom (1963) was the first to define the emergent glaciomarine sediment of southwestern Maine as the Presumpscot Formation, estimate its time of deposition in relation to the disappearance of glacial ice, and recognize that portions of the unit that were once emergent, are presently underwater. Shortly thereafter, Borns and Hagar (1965) established the Embden and North Anson Formations as (regressive) fluvial sand and gravel deposits that unconformably

overlie the Presumpscot Formation in terrace deposits of the Kennebec River valley. Stuiver and Borns (1975) later clarified the timing of deposition of the Presumpscot Formation with many radiocarbon dates.

Slightly north of the study area, Ostericher (1965) collected the first seismic reflection records from Penobscot Bay, along the central Maine shelf. He clearly identified the Presumpscot Formation, as well as glacial till and modern fluvial and marine deposits, from seismic records, and collected numerous cores to confirm his interpretations. He interpreted a coherent and widespread seismic reflector as the regressive unconformity on the surface of the Presumpscot Formation, and in one core, collected a wood fragment from its surface at a depth of 18 meters. The wood sample yielded a radiocarbon date of 7390 +/- 500 BP, and has been subsequently cited by Knebel and Scanlon (1985) as conclusive evidence for a minimum depth and age of the lowstand of sea level for the western Gulf of Maine. On the basis of further mapping of the seismic reflector interpreted as the transgressive unconformity, Knebel (1986) proposed that the lowstand of sea level in the area occurred around 40 meters depth.

Schnitker (1974) had earlier inferred, on the basis of seismic reflection profiles, that the "ultimate" lowstand off the mouth of the Kennebec River was at 65 m depth. At this depth he tentatively identified a "berm" on a seismic profile, and landward of 65 m depth he interpreted (subaerially) "dissected till", as opposed to the "undissected till" seaward of 65 m. While Schnitker's "dissected till" and "undissected till" deposits have subsequently been re-interpreted as stratified sand and gravel and natural gas, respectively, his suggestion of a shoreline at around 65 m depth has garnered some support (Belknap et al., 1989; Shipp, 1989, Shipp et al., 1989). The shoreline at the 65 m isobath has not been cored and dated, however, and its position is in conflict with theoretical studies (Peltier, 1986; Quinlan and Beaumont, 1982).

In the past few years, on the basis of extensive, reconnaissance-level, seismic mapping (Belknap et al., 1986, 1987, 1989; Kelley et al., 1986; 1987b; 1989a,b,c; Kelley and Belknap 1988, 1989, 1990; Shipp, 1989; Shipp et al., 1987, 1989), Quaternary seismic stratigraphic models were developed for the inner shelf (Belknap et al., 1989; Belknap and Shipp, 1990; Kelley et al., 1987a, 1989c; Shipp, 1989). Central to creation of these models is a classification and interpretation of seismic facies based on the acoustic contrast of bounding surfaces, as well as on the internal configuration, external shape, and setting or frequency of occurrence of the seismic facies (Table 1) (Belknap et al., 1989; Belknap and Shipp, 1990; Shipp, 1989).

Crystalline bedrock (BR) of Precambrian to Mesozoic age forms the base of the section (Osberg et al., 1985). Our seismic equipment rarely penetrates the bedrock, which yields an intense, high-relief surface return that is often correlated with outcrops on land (Belknap et al., 1986, 1987b; Kelley et al., 1986) and recognized by other workers in the region (Birch, 1984a,b; 1989). Presumed Triassic-Jurassic synrift basin rocks and Cre-

taceous-Tertiary coastal plain deposits have been interpreted from seismic records offshore of Maine and nearby (Belknap and Shipp, 1990; Birch, 1984a,b; Fader et al., 1977; Oldale et al., 1973; Shipp, 1989), but were not found in the present study area.

Unconformably overlying bedrock, a seismic unit (T) with an intense surface return and variable thickness is usually observed (Table 1). Chaotic internal reflections are often recognized within the unit, which typically is thin and lens or sheet-shaped (Tb), but is found occasionally as an irregular mound (Tm). This unit is interpreted as glacial till on the basis of its association with nearby outcrops on land (Shipp, 1989), and it correlates with Birch's (1984a,b; 1989) Unit 1 and King and Fader's (1986) Scotian Shelf Drift in adjacent New Hampshire and Canada, respectively. The mounded unit, Tm, is interpreted as a moraine, and closely-spaced seismic lines indicate the moraines often have lateral continuity of hundreds of meters (Kelley, et al., 1987b; Knebel, 1986; Shipp, 1989). On land, stratified drift is often found in intimate association with moraine deposits (Smith, 1985; Thompson and Borns, 1985), but it is very rarely interpreted from seismic records (Belknap and Shipp, 1990). No varieties of till like King and Fader's (1986) "till tongues" or Birch's (1989) drumlins were recognized along the Maine inner shelf.

Most commonly overlying bedrock or till are seismic facies with a weak to moderate acoustical contrast with adjacent units. The lower of these often has few or no coherent internal reflectors, and is draped on the underlying surface. It has been interpreted as a massive, glaciomarine diamicton (GM-M), and often forms a deposit more than 10 m thick (Table 1)(Belknap et al., 1989). Above this unit, or resting directly on bedrock or till is a seismic unit (GM-D) with laterally coherent, parallel, internal reflectors that are always draped over the underlying material. This is interpreted as ice-proximal, glaciomarine sediment, and is observed in almost every seismic profile in the study area. The surface of the draped glaciomarine sediment yields a weak acoustic return when overlain by a similar seismic facies with weak internal reflectors. When observed, the layers of this seismic unit (GM-P) are nearly horizontal and appear to form ponds within the greater relief of the underlying draped material. The ponded unit is interpreted as an ice-distal deposit, laid down by turbidity currents or formed by reworking of older material (Belknap and Shipp, 1990). The draped and ponded glaciomarine material are believed to correlate with outcrops on land (Belknap et al., 1986; Kelley and Hay, 1986; Kelley et al., 1986) and with nearby seismic records in Canada (facies A, B, C of King and Fader's Emerald Silt) and New Hampshire (Unit 2 and possibly part of Unit 3 of Birch, 1989).

Above 60-70 m depth, the surface of what is interpreted as glaciomarine sediment, either GM-D or GM-P, is usually marked by a strong, laterally continuous seismic reflector that has been recognized as an unconformity (Belknap et al., 1989; Kelley et al., 1986; Ostericher, 1965). Often this surface is exposed at the present seafloor and truncates reflectors of the underlying material. Where it is overlain by an acoustically

transparent unit, M, interpreted as modern mud, the reflector is very pronounced and usually truncates underlying reflectors. Where the overlying material itself produces a strong acoustic return, such as modern sand and gravel, SG, the unconformity surface is sometimes less distinct. In the absence of cores it is sometimes unclear whether the unconformity is regressive or transgressive. Often the transgression obliterates all traces of the prior regression. In one example from near the mouth of the Penobscot River, however, Knebel (1986) interpreted a regressive unconformity to a depth of 40 m, and used this depth to support his estimate of the maximum lowstand of sea level. The reason for preservation of the regressive unconformity in Penobscot Bay is that a thick section of Holocene fluvial sediment covered the unconformity and protected it during the following transgression.

On the basis of early interpretation of the seismic units an ideal stratigraphic cross-section was prepared for southwestern Maine (Figure 2)(Kelley et al., 1987b; 1989c). In this depiction, which was based on reconnaissance work in Saco Bay (Kelley et al., 1986) as well as terrestrial mapping (Smith, 1985), the glaciomarine units (GM) were labeled Presumpscot Formation. The intention of the illustration was partly to suggest that the major time of sediment introduction to the shelf was during deglaciation. Relatively thick deposits of modern sand were inferred to exist seaward of major beaches (Nearshore Ramps), but no regressive sand deposits were recognized offshore as they had been along the river valleys (Emden and North Anson Formations; Borns and Hager, 1965).

More recently, the seismic facies were put into a sequence model for the west central inner shelf seaward of the Kennebec River (Figure 3) (Belknap et al., 1989). An important emphasis in this illustration is on the location of unconformities. In relatively deep water (> 65 m) there is conformity between the glaciomarine sediment and modern mud. In water depths less than 65 m an unconformity separates the inferred Holocene paleodelta sand and gravel from the underlying glaciomarine units. The paleodelta is interpreted to be a lowstand and subsequent Holocene transgression. Modern sands on the shelf and nearby beaches are inferred to be reworked from the Pleistocene sediment. Although little dynamical data exist for the Kennebec River, FitzGerald and Fink (1987) believe that the river does contribute modern sand at least to the beaches at its mouth, if not to the shelf. Recent unpublished observations of the Maine Geological Survey, however, support the concept of sand transport into the river, at least during normal flow.

METHODS

Our previous work referred to above was based on seismic reflection data derived from both a 3.5 kHz Ratheon RTT 1000a profiler and an Ocean Research Equipment (ORE) Geopulse boomer system. More than 3,000 km of data was collected, much of it in conjunction with an EG&G SMS model 960 or 260 side-scan sonar. More than 1,000 bottom samples were gathered

from the study area to confirm the side-scan and seismic interpretations of the nature of the seafloor, and more than 40 submersible dives were made to further ground truth the remotely-sensed geophysical observations (Belknap et al., 1988). All navigation in the offshore areas was based on LORAN-C.

Approximate core locations were based on previous seismic data, and confirmed with additional data gathered aboard the coring vessel, the R/V Atlantic Twin. The coring was performed by Alpine Ocean Seismic Survey, Inc. between October 14 and 16, 1988. The vibracorer used a pneumatic impacting piston vibrator over a 12 m (40 foot) long, 10 cm (4 inch) diameter steel pipe fitted with a 9 cm (3.5 inch) diameter plastic liner. An aluminum H-beam supported by 4 legs rested on the seafloor as a vertical guide for the corer during operation, and compressed air from the vessel drove the vibrator. A penetrometer continuously recorded depth of core penetration as a function of time to aid in understanding the mass properties of the cored material.

After returning to the deck of the vessel the plastic liner was removed from the steel barrel, cut into 1.5 m (5 foot) lengths, labelled and stored upright. Upon return to the laboratory, the core was cut lengthwise, logged, photographed, and subsampled for grain-size analyses. Fossils were subsequently removed for identification and possible dating. The grain-size analyses were performed on sieves (gravel fraction), in a settling tube (sand fraction) and Micromeritics Sedigraph (mud fraction).

RESULTS

Casco Bay

Casco Bay is the largest embayment along the southern Maine coast. Its inner region is sheltered from the open sea by chains of islands and peninsulas (Figures 1, 4). An elongate Nearshore Basin separates its landward margin from a prominent series of large islands in the central part of the bay. Most of the seafloor in the basin is muddy and smooth except near channels between islands where deepening, presumably by tidal currents, has occurred. The outer bay, in contrast, has a more irregular bottom, with numerous bedrock exposures (Kelley et al., 1986; 1987b). A series of seismic profiles across the bay (Figure 9 in Belknap et al., 1987b) depicts the greater amount of sediment in the inner bay as opposed to the rocky outer region.

Vibracore CBVC88-1 was collected in 15 m of water (Figure 4) where previous work indicated a relatively thin cover of inferred Holocene mud overlying glaciomarine sediment (Figures 4a and 7a in Kelley et al., 1986; Figure 9 in Belknap et al., 1987b). New seismic records over the core site were similar to the previous work, although a great deal of acoustic noise was present (Figure 5). The glaciomarine sediment is interpreted as GM-D because of the large number of parallel reflectors which are draped over the underlying bedrock throughout the area (Figure 4; Figure 7a in Kelley et al., 1986).

This core nicely matches the seismic record (Figures 5, 6). The upper 5 m contains gray (5Y5/1) relatively uniform, very

fine-grained mud, as might be expected from acoustically transparent material (Table 2). While the modal size varies between 3 and 4 phi, most of the samples in the upper 5 m average clay size (>9 phi) and are very poorly sorted because of the tail of fine sediment (Figures 7, 8). Few macrofossil remains were observed in the upper 5 m, and sedimentary structures consisted of only a single shell horizon (Figure 6). At 522 cm depth, the same depth that the strong acoustic reflector occurs in the seismic record, an abrupt coarsening of the texture occurs and better sorted, dark gray (5Y4/1) medium to fine sand extends to the bottom of the core (Figures 6, 7, 8; Table 2). The modal size of the sand ranges from 1.2-2.0 phi, and several laminae of coarse sand and a few thin laminae of burned wood fragments were recognized.

Saco Bay

Saco Bay is more exposed than Casco Bay, with sandy onshore and offshore environments (Kelley et al., 1986, 1987a). Cores were collected along Shelf Valleys, in the Nearshore Ramp, and in a Rocky Zone (Figures 1, 9). Two cores (SCVC88-1, and 2) were gathered from the same approximate location in about 50 m of water near what has been interpreted as a lowstand shoreline at the terminus of a Shelf Valley bordering an Outer Basin (Kelley et al., 1986, 1987a, Shipp et al., 1989). A submersible dive across this shoreline revealed extremely turbid near-bottom water with a muddy substrate (Kelley, unpublished field notes, 1985).

Because of depth limitations on the coring apparatus, the shoreline itself could not be sampled directly, but cores were taken less than 500 m from the shoreline (Figure 10). The seismic line shows a prominent ridge of bedrock outcropping around 50 m depth and then descending into deeper water. In a seaward direction the rock is buried beneath more than 30 m of mostly glaciomarine sediment. Because of the way the glaciomarine reflectors mimic the underlying bedrock bathymetry it is interpreted as GM-D near the bottom with more ponded GM-P overlying it. An especially prominent reflector appears to mark the boundary between the two glaciomarine units before it melds into a more complex set of reflectors in the area of the shoreline. In an earlier interpretation this reflector was interpreted as the transgressive unconformity (Kelley et al., 1986, 1987a), and where it existed below the inferred depth of sea-level lowstand, it was thought to represent "paleo-wave base". The present interpretation more closely conforms to that of Shipp et al. (1989, their Figure 2).

The sediment from cores SCVC88-1, and SCVC88-2 are very similar and consist largely of light yellow (10YR8/1) to gray (2.5 Y5/0), moderately to moderately well-sorted medium sand (Figures 8, 11). The modal size of the sediment ranged from 0.7 to 2.0 phi, with coarser material near the core top and no bimodal samples (Figure 12). Several large *Artica islandica* fragments were noted near the core tops, and a 2 cm diameter clast was observed in a muddy seam at 50 cm depth in SC-2. Bedding consisted of many laminae of coarse or fine sand, gen-

erally with gradational contacts. Owing to the relatively shallow penetration of the cores and the strong ringing of the bubble pulse near the surface of the seismic record, no acoustic reflectors were correlated with the cores. Both cores appear to have met refusal against coarse sediment in the uppermost seismic unit, SG.

Cores SCVC88-3 and SCVC88-4 were also located near an inferred shoreline feature (Figures 9, 13). The seismic record shows a buried bedrock ridge descending to greater than 80 m depth beneath the shoreline, and similar to that observed near the previous shoreline (Figure 10). Greater than 25 m of glaciomarine sediment overlies bedrock in a seaward direction, with variable thicknesses occurring landward of the ridge. A previous interpretation of this record (Figures 6a, 8a in Kelley et al., 1986) suggested that the material above GM-D was Holocene mud; the present interpretation follows Shipp et al. (1989, his Figure 2) and labels this material as GM-P (Figure 13). The thickness of the Holocene mud seaward of the shoreline is not known. Of the two cores, only SCVC88-4 appears to penetrate the uppermost unit labeled SG? or GM-P? (Figure 13) into GM-D.

Core SCVC88-3 met refusal in an olive gray (10YR6/1) sandy mud with pebbles. The penetrometer log indicates that refusal was abrupt against a hard surface. Sediment from SC-3 was poorly sorted medium sand (Figures 8, 12) with only a single *Astarte sp.* shell and other fragments near the top (Figure 11). The modal size was near 2 phi for all samples analyzed from SCVC88-3, but several muddy laminae occurred within the core (Figure 12).

Core SCVC88-4 is relatively coarse grained near the top, with fine-grained sediment increasing abruptly below 50 cm (Figure 11). Below 1 m the number of bluish clay layers (2.5Y6/0) increases, and laminae of black mud appear beneath 3 m. Sand occurs as lenses and layers throughout the lower 3 m of the core, and 1-4 cm pebbles are common beneath 2.5 m (Figure 11). While the layers of sand appear intact, some of the sand lenses may have migrated from elsewhere in the core during drilling or handling. Sorting is very poor or extremely poor for all samples from SCVC88-4 (Figure 8). The upper samples are bimodal with a gravel mode between -1 and -2 phi, and a sand mode near 2 phi (Figure 12). Sediment from the lower part of the core displays a prominent mode between 3 and 4 phi, with a relatively large mud fraction (Figure 12). Shell fragments are common throughout the core, with an articulated *Hiattella arctica* at 265 cm. It appears that SCVC88-4 penetrated a seismic reflector between 0.5 and 1 m below the seafloor (Figure 13) where the mud content increases significantly (Figure 11).

One vibracore for this project (SCVC88-5) was collected from the upper part of the major Shelf Valley of Saco Bay (Figure 9) near where 5 cores were previously collected by the U.S. Army Corps of Engineers/USGS (Kelley et al., 1987a; Luepke and Grosz, 1986). All the cores are relatively short, but reveal a common stratigraphy with muddy material beneath a thin surficial sand bed. In recent seismic data from near the Army

core sites, glaciomarine units, GM-D and GM-P, appear to exist at or near the seafloor throughout the area (Figure 14). Core 1241 appears to penetrate the relatively acoustically transparent material beneath the surficial sand unit and meet refusal at a strong seismic reflector in GM-P (Figure 14). On the basis of lithology the muddy lower three meters of core 1241 was previously interpreted as glaciomarine (Kelley et al., 1987a, Figure 45).

Core SCVC88-5 was taken from near the axis of the Shelf Valley, about 1 km from Army core 1241. Seismic data above the core site is poor because a dense field of lobster traps necessitated tight maneuvering during data collection, deleteriously influencing the towing configuration of the seismic gear. Nevertheless, extrapolation from nearby suggests that GM-P is very near the seafloor, and was reached by at least the lower portion of the core (Figure 15).

The upper part of the core is complex, and contains numerous alternating beds of grayish brown (2.5Y5/2), well sorted shelly sand with laminae of gray (2.5Y6/0) silty sand (Figure 11). Several 2-3 cm diameter pebbles occur near broken shells in the upper half meter. The thin nature of the beds precluded easy sampling of individual beds, and the resulting grain size analyses are of very poorly sorted silty clays with mean grain sizes often in the clay size range (Figure 8). Samples from generally sandy beds in the the upper 1.8 m have modes around 2 phi, with prominent fine-grained tails to the particle size distributions (Figure 12). Samples from below 1.8 m in the core all lack the medium sand mode, but possess a small mode at 4 phi with an important amount of very fine-grained mud (Figure 12).

The final area cored in Saco Bay is in a Rocky Zone between Prouts Neck and Bluff Island (Figure 9). Each of several cores gathered nearby by the U.S. Army Corps of Engineers/USGS was short and penetrated mostly gravelly sediment (Figure 44 in Kelley et al., 1987b; Luepke and Grosz, 1986). Seismic reflection data from over a typical Army/USGS core 1220 shows that bedrock is very close to the seafloor beneath the core site, and crops out nearby (Figure 16). The GM-D and GM-P glaciomarine units are interpreted above the rock, and may have been just reached at the bottom of the core (as the silty sand unit).

Nearby, at the site of SCVC88-6, the seismic data is more complex (Figure 17). Bedrock is easily traced from outcrops at Prouts Neck into the subsurface where it is buried beneath a relatively thick, non-stratified seismic unit interpreted as till (Figure 17). The seafloor above this area is covered by a complex assemblage of mud, sand, gravel, including large boulders up to 5 m in diameter (Kelley et al., 1987b; 1989a). Dipping to the south of the till deposit is a strongly reflecting, well-stratified unit interpreted as draped glaciomarine sediment (GM-D). Above this material is a poorly layered seismic unit that may be GM-P. In the middle of this unit is a small, strongly-reflecting seismic unit with abrupt edges. This may be of glacial origin, or represent a tidal channel or fluvial channel deposit. The lack of clinof orm reflectors filling the possible channel suggest a glacial origin.

Above this feature, and extending from near the seafloor towards Bluff Island, is a seismic unit with a strong surface return and a few inclined reflectors. It remains unclear whether this is a sand and gravel deposit of Holocene age that was derived from the underlying till, or a feature of glacial origin.

Vibracore SCVC88-6 was gathered from near the boulder-strewn seafloor adjacent to the till deposit (Figure 17). It contains extremely-poorly sorted, gray (10YR5/1), gravelly, sandy mud (Figures 8, 11). The modal size for all samples analyzed narrowly ranges between 2.5 and 2.8 phi (Table 2), with a smaller mode occasionally seen in the gravel fraction (Figure 12). Mud comprises from 25 to 55 percent of each sediment sample, but is without a mode (Table 2). Despite the poor sorting, the core is well stratified, with abrupt contacts between beds at 39 and 233 cm. The upper contact is marked by shell fragments and 2 cm diameter clasts, and separates sandy mud above from muddy gravelly sand below. The muddy gravelly sand is separated from an underlying sandy mud deposit by a layer with 5 cm diameter pebbles. Shell fragments are common throughout the core, but pebbles are restricted to the middle unit (Figure 16). Intact specimens of *Macoma baltica* and large fragments of *Ensis sp.* and *Mya sp.* and *Balanus sp.* attached to pebbles were common between 40 and 240 cm. The seismic record suggests the core terminates at the till unit. This inference is supported by the sudden refusal of the corer against a hard object (bedrock or a boulder, unpublished penetrometer log notes).

Cape Small

The Cape Small area is the most exposed portion of the study area. Seguin Island, seaward of the Kennebec River mouth, offers some shelter from waves to the nearby beach, but all core sites were in more exposed water (Figure 18). Previous mapping (Kelley et al., 1987b) has demonstrated that the seafloor in the Cape Small region is part of an extensive Nearshore Ramp, interpreted as the paleodelta of the Kennebec River (Belknap et al., 1986) and is mantled with sand and gravel between occasional outcrops of bedrock (Figures 1, 18).

Cores SBVC88-1 and 2 were collected from the same location west of Seguin Island in 19 m of water (Figure 18). Seismic profiles across the core site reveal a 30-40 m thick unit with numerous coherent reflectors, interpreted as glaciomarine sediment, over bedrock (Figures 19, 20). The upper portion of the glaciomarine unit appears as GM-P or GM-D, and its reflectors are truncated by a seismic reflector which is strong and relatively flat on the 3.5 kHz record (Figure 19), but appears to be channeled on the Geopulse data (Figure 20). On the 3.5 kHz record this reflector is overlain by a strongly reflecting unit lacking internal reflectors which pinches out in a seaward direction; the reflector is not easily distinguished on the Geopulse record.

Since the two cores were collected at the same site, and are internally very similar (Figure 21), only SBVC88-2, the longer core, will be discussed in detail. The upper 2 m of sediment from this core are poorly sorted, dark gray (5Y4/1), muddy sands with

a mean size ranging from 1.5 to 3.5 phi, but possessing a clear mode around 2 phi (Figures 22, 23). Between 2 and 5 m there is a gradual coarsening of the sand, which has a mean size ranging from 0.7 to -0.4 phi (Table 2). The modal size also coarsens to about 1 phi, with a minor gravel mode at -1 phi occasionally recognized. Beds, defined by layers of *Mytilus edulis* fragments, or small laminae of fine micaceous or coarse sand, are common. Between 220 and 240 cm several *Mya arenaria* in life position were observed and tentatively radiocarbon dated to between 9090 +/- 95 and 9250 +/- 110 BP (R. Stuckenrath, University of Pittsburgh, personal communication). An additional date of 7270 +/- 105 was also produced, however, so additional dates are being obtained through cooperation with Dr. Stuckenrath.

An abrupt change from gravelly sand above to sandy mud below occurs at 5 m depth in the core, and corresponds with the hard, flat reflector in the seismic profile (Figures 19, 20, 21). Between 5 and 6.5 m depth the sandy mud is very poorly sorted with mean grain sizes ranging from 5.9 to 7.1 phi (Table 2; Figure 23), with a mode at 3.0-3.5 phi (Figure 22). Below 6.5 m depth the proportion of mud declines to less than 10%, (except in rare muddy laminae) and the mean grain size generally coarsens to between 2.0 and 3.0 phi, with an accompanying increase in the sorting. The modal size also coarsens slightly to 2.0 phi and becomes very pronounced (Figure 22). Numerous micaceous, fine sandy laminae occur in the lower portion of the core as well as more than 10 small laminae of wood fragments.

Vibracores SBVC88-3, 4, and 5 were collected west of Cape Small on the margin of what is interpreted as a deltaic lobe (Figure 18) by Belknap et al. (1989; their Figure 7). SBVC88-3 was gathered on the seaward margin of the lobe where clinoform reflectors are thought to represent deltaic foresets (SG; Figure 24). A bedrock outcrop separates this core from cores SBVC88-4 and 5, which came from the same location and are also positioned over clinoform reflectors. If horizontal reflectors, representing topset beds, are present at the site of SBVC88-4 and 5, they cannot be recognized through the acoustic bubblepulse.

Core SBVC88-3 is almost uniformly light brownish gray (2.5Y6/2), fine, muddy sand (Figure 21). The sand is micaceous with many angular fragments of *Arctica islandica* and *Mya sp.* Despite the relatively poor sorting of most of the samples (Figure 23), all size analyses show a solitary sand mode around 3.0-3.5 phi (Figure 22). Between 3.0 and 3.5 m depth there are many 1 cm thick laminae of mud with shell fragments.

Cores SBVC88-4 and 5 are from the same location and internally very similar (Figure 21), so only number 5, the longer core is discussed. Its sediment is largely medium to coarse, very dark gray (7.5Y3/0), well sorted sand and gravel (Figure 23). Coarser sediment occurs in the upper portion of the core, with a modal size at 0.0 or 1.5 phi (Figure 23). The lower 2 m of the core contain sand with modal sizes ranging from 2.75 to 3 phi. Alternating beds of sand with varying grain size form the only structures within the core, and shell matter is rare. Although interpretation of the seismic line is difficult near the surface due to

the bubble pulse, it is possible that the change from coarse to finer sand at 1.0 m corresponds to the upper reflector in SB89-7 (Figure 24).

Core SBVC88-6 was collected from the southern border of the paleodelta, near an inferred lowstand shoreline (Figure 18; Belknap et al., 1989, his Figure 5). Bedrock ridges crop out near the core site, as does a strongly reflecting seismic unit interpreted as till (Figure 25). The till exists beneath the core site but is overlain by 10 m of a weakly layered unit interpreted as glaciomarine sediment (GM-P). Above the glaciomarine sediment about 10 m of weakly layered sediment extends to the seafloor. This unit is interpreted as deltaic sand (SG).

Core SBVC88-6 contains poorly layered coarse to fine-grained, brownish gray (2.5Y5/2) sand. The upper 1.5 m is distinctly coarser-grained and better sorted than the remainder of the core (Figure 21; Table 2). Modal sizes in the upper core range from 2 to 3 phi, while the lower portion of the core is bimodal, with modes at 3.5 and 5.5 phi (Figure 22). A few muddy laminae and shell horizons form the only structures in the core.

DISCUSSION

Interpretation of Seismic Reflectors

One of the most important goals of this coring project was to verify and improve interpretation of seismic reflectors along the inner shelf. Of the seismic reflectors previously recognized, unconformities at the surface of the glaciomarine sediment are the most important to confirm. In all, 4 cores, SCVC88-4, and 6; SBVC88-2; and CBVC88-1, penetrated reflectors previously inferred to be unconformities.

Interpretation of the Casco Bay core was the least ambiguous. The acoustically transparent material in the upper 5 meters was correctly interpreted as mud of apparent Holocene age. The strong acoustic reflector around 5 meters depth correlates with an abrupt change in the sediment texture of the core from mud above to sand and muddy sand below (Figures 5, 6). Such an abundance of sand is commonly found nearby in exposures near the top of the glaciomarine sequence. A problem with this interpretation is that there are few beds within the sandy part of the core to correlate with reflectors in the seismic profile (Figures 5, 6). This may be a result of the distance of the core site from the seismic profile line (200 meters), although other seismic lines in the area are identical (Kelley et al., 1987b). A further difficulty with this interpretation as GM-D is the presence of wood and charcoal in the sandy material. As defined, the interpreted depositional environment of the draped unit is "glaciomarine, at least in part under an ice shelf near the ice grounding line" (Belknap et al., 1989, p 12). It is most likely that the sandy material in the lower part of the core is glaciomarine sediment that was reworked during the transgression. The depositional environment of the sand may have been a low-energy beach formed from sandy glaciomarine material at an eroding bluff. Many bluffs are eroding in Casco Bay today as a result of the on-going

transgression, and muddy sands with wood fragments at the base of such bluffs are an appropriate analogue for the cores (Smith, 1990).

Vibracore SBVC88-2 also penetrated a strong seismic reflector that has been considered a transgressive unconformity (Belknap et al., 1989). As with the Casco Bay core, a good correlation exists between the depth of the strong seismic reflector and a textural change in the core (Figures 19, 20, 21). The sand and gravel of the upper 5 meters of the core was correctly interpreted as SG on the seismic records, just as muddy sediment was recognized below the reflector. As in Casco Bay, however, the interpretation of glaciomarine mud in the lower portion of the core is constrained by the presence of numerous laminae of wood fragments. As indicated in Figure 20, the upper part of the glaciomarine sediment may be GM-P, which is a distal facies of glaciomarine sediment that could have been deposited long after the local retreat of ice. Indeed, the upper part of the GM-P is probably an estuarine or shallow marine deposit similar to sediment accumulating in modern coastal embayments. Radiocarbon dates on the *Mya arenaria* which were in life position at 2 meters depth in the core raise questions over our earlier sea-level curve interpretations.

In order to fairly interpret these dates and the seismic data, we must employ the method of multiple working hypotheses. The dates on the fossil *Mya*, which have a generally intertidal, estuarine ecology, imply that at approximately 9170 BP local relative sea level was 21 m below present. These dates may require revision of the existing sea-level curve for the Gulf of Maine (Figure 26). Also, the abundant wood fragments in the lower portion of the core require a relatively late, ice-distal interpretation for the glaciomarine mud. In one working hypothesis (1), the shell dates are incorrect or reworked (the coexisting 7270 \pm 105 date raises some questions). We think that this is unlikely, since two dates are close together and from articulated clams, while the younger date is from a small, questionable shell analysis. The second hypothesis (2) is that the 9170 date is accurate, and that the underlying unconformity is transgressive unconformity. The unconformity is smooth and flat, truncating draped glaciomarine reflectors in a manner similar to those produced by bluff erosion in Casco Bay, or by a meandering channel thalweg. The overlying sandy sediments demonstrate a clear fining upward sequence, as would be expected in a transgression, with progressively deepening shoreface environments. In addition, an estuarine environment would be expected during transgression, analogous to today's settings. This interpretation requires revision of the sea-level curve, requiring a rapid early Holocene rise from a lowstand at about 60 m depth about 10,000 BP, and a rapid slowing to intercept Ostericher's (1965) date at -20 m 7390 \pm 500 BP, and the Damariscotta River date of 6295 \pm 55 BP at -15 m (Belknap et al., 1989b). Hypothesis (3) suggests that the strong seismic reflector is the regressive unconformity, and that deltaic sand and gravel, including the *Mya arenaria* fossils, were deposited during the fall to lowstand. Channels correlative to this surface occur farther offshore (Belknap et al., 1989). The

erosional unconformity would be created by scour from a migrating channel thalweg analogous to that reported from Penobscot Bay (Knebel and Scanlon, 1985). The later transgressive ravinement unconformity would either be found within the upper sandy sequence or would be at the present seafloor. The present seafloor is inferred to be actively eroding and supplying sand to local beaches (Belknap et al., 1981). This interpretation raises even more serious problems with the existing sea-level curve, leaving little room for a deep lowstand, and conflicts seriously with other sea-level interpretations nearby (e.g., Oldale et al., 1983). Hypothesis (4) is that the deep sea-level lowstand is incorrect, and that the local lowstand would only have been at 30 (?) m. This interpretation is in conflict with a number of published interpretations based on numerous independent data (Belknap et al., 1987a; Belknap and Shipp, 1990; Knebel and Scanlon, 1985; Oldale et al., 1983; Shipp, 1989). We prefer either hypothesis (2) or (3) at the present time, although hypotheses 2 and 3 can be combined if the seismic unconformity is the regressive surface, and the gravelly sand between 3.6 and 4.8 m represents regressive deltaic deposits, overlain by a transgressive ravinement surface, followed by fossiliferous estuarine and shoreface deposits. More dating is being done to clarify these relationships.

In Saco Bay vibracore SCVC88-4 appeared to penetrate a seismic reflector at about 1-1.5 meters beneath the seafloor (Figure 13). In the core this reflector is manifested as a change from gravelly sand above to sandy mud below (Figure 11). This change may represent regressive Holocene sand over GM-P. The inferred glaciomarine sediment contains numerous black, organic-rich bands, sand laminae, and occasional pebbles (dropstones?), similar to outcrops of the Presumpscot Formation on land. Alternatively, the upper sand may not be Holocene regressive material introduced by the ancestral Saco River, but rather a lag deposit of glaciomarine sediment reworked during the transgression. This would mean that the regressive unconformity was obliterated by the on-going formation of the transgressive unconformity. The different sand modes in the upper and lower parts of the core suggest that the upper sand was derived from a sand population distinct from glaciomarine sediment, however, and supports the idea of early Holocene fluvial sand input (Figure 12).

SCVC88-5 as well as the many U. S. Army Corps of Engineer/USGS cores nearby encountered a stratigraphic sequence similar to SCVC88-4, with sand over generally muddy sediment. Although it was earlier anticipated that the upper sand would be thicker and of Holocene age (Kelley et al., 1986, 1987a), it is possible that it is simply reworked glaciomarine sediment, and that no unconformity exists in the seismic record. The coarse sand mode in the upper part of the core again suggests a different source for the upper, presumably fluvial sand than for the lower, presumably glaciomarine sand (Figure 12), and that an unconformity separates the sandy sediment from the muddy material. This is further supported by comparison of the mineralogy of sand from the upper (sandy) and lower (muddy) portions of

cores analyzed by Luepke and Grosz (1986; Table 3). The upper (fluvial?) sand is significantly enriched in the proportion of heavy minerals, as well as in the abundance of several mineral species.

Vibracores SBVC88-3, 4, 5, 6, and SCVC88-1, 2, 3, and 6 appear to have encountered no Holocene sediment. All samples from SCVC88-6 possess a fine sand mode around 3 phi, consistent with that observed in all other presumed glaciomarine units (Figure 12). This observation supports earlier inferences that the Prouts Neck area from which the core was gathered is one of non-deposition, or erosion, and may be a source of fine sand to nearby beaches (Farrell, 1972; Kelley et al., 1987a). Thus, it is not surprising that no unconformity was encountered in the core from this area (Figures 16, 17).

SBVC88-3, 4, and 5 each met refusal in deltaic sand and gravel (SG). Textural variations in these coarse-grained cores may correlate with clinoform seismic reflectors interpreted as foreset beds (Figures 21, 24). Reworking of the seafloor sediment off Cape Small is apparently on-going, and so the transgressive unconformity may now be forming at the sea floor. Alternatively, the ravinement surface may occur at approximately 1 m depth in cores SB-4, 5 and 6 (?).

Recognition of the Lowstand Shoreline

Five cores, SBVC88-3, 6; and SCVC88-1, 2, and 3, were gathered on or near inferred shorelines. None of the cores yielded unambiguous evidence for or against the hypothesized shorelines. In Saco Bay the three cores near the shoreline terraces contained the best sorted, coarsest sediment examined from the bay (Figure 4). Coarse sand modes are present in only these cores and the upper parts of cores discussed above (Figure 12). This suggests a common source and time of deposition consistent with the hypothesis of fluvial input during a time of sea-level lowering. No alternative explanation can reasonably account for such well-sorted sandy sediment in such deep water, so far from modern sources. Although we cannot rule out the possibility that the sand in these cores is glaciomarine, it does not appear very plausible that glaciomarine sand has remained exposed at the seafloor since the Pleistocene.

Vibracore SBVC88-3 was collected from a shallow shoreline terrace. Sand from the core was strongly unimodal at 3.0-3.5 phi (Figure 22), but the overall sediment was poorly sorted from all samples (Figure 23). The reason for the poor sorting is a significant proportion of mud in the samples. This observation does not correspond with a shoreline deposit, deltaic foresets. Further seaward of Cape Small, SBVC88-6 was also gathered from near a shoreline terrace. The sediment of this core contains well sorted coarse-grained sand near the top of the core, and finer-grained, poorly sorted material at depth (Figures 21, 22, 23). Although the contact between the well sorted and poorly sorted sediment is gradational, and no seismic reflector separating the two units was recognized, it is plausible that the upper

sand was reworked from fluvial, deltaic, or glaciomarine sediment by littoral processes.

IMPLICATIONS FOR SAND VOLUMES AND FURTHER RESEARCH

One of the most surprising observations resulting from this work is the scarcity of sand offshore of Old Orchard Beach in Saco Bay. Large quantities of well-sorted sand were recognized only in deeper water near the inferred lowstand shoreline. While large volumes of sand exist near the present mouths of the Saco and Scarborough Rivers, it appears that the Shelf Valleys are not important depositional sites today. More seismic work would probably be useful to inventory sand volumes near the large river mouths, and samples of sand from the rivers might be useful to further compare grain size and mineralogical trends with sand from the glaciomarine sediment. On the basis of the preliminary comparison here (Table 3) the Saco River has contributed a coarser grained, enriched heavy mineral suite to Saco Bay compared to the glaciomarine sediment.

Owing to budget constraints detailed radiocarbon dating of fossils was not possible. However dates on the many fossils present throughout most of the cores will provide a firmer answer to questions regarding the presence or absence of an unconformity, the age of the shorelines, and whether or not a particular seismic unit is Pleistocene glaciomarine or Holocene sediment.

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TABLE 1. CHARACTERISTICS OF SEISMIC DEPOSITIONAL SEQUENCES AND FACIES, MAINE INNER SHELF

DEPOSITIONAL SEQUENCE		SEISMIC FACIES UNIT	CHARACTERISTICS	INTERPRETATION
H	7	NG	Strong return, convex upward shape, fuzzy upper surface	Natural gas acoustic wipeout
	6	SG	Strong, ringing return well stratified, channels and foresets	Holocene sand and gravel
	5	M	Weak to transparent, flat, ponded in basins, basin mud	Holocene marine
G	4c	GM-P	Strong to moderate surface return, weak to transparent internal reflections, ponded	Glaciomarine mud distal from grounding line, minor effects of ice rafting
	4b	GM-D	Strong, rhythmic bedding, draped	Glaciomarine: interbedded mud, silt and sand
	4a	GM-M	Weak to transparent, faintly bedded, draped	Glaciomarine sediment or diamicton: grounding line deposit
	3	SD	Strong return, wedge shape, stratified, interfingers with 2 & 4	Stratified drift
	2b	Tm	Strong return, chaotic internal reflections, mound shape	Till, moraine ridge
	2a	Tb	Strong return, indistinct interior reflections	Till, thin drift
Pz	1	BR	Very strong, sharp return, no internal reflections, steep slopes and peaks	Paleozoic bedrock

(modified from Belknap et al., 1989a)

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TABLE 2: VIBRACORE LOCATIONS AND TEXTURAL PROPERTIES OF SEDIMENT SAMPLES

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
CB 1	814	15	43° 38.8' N 69° 51.1' W	13243.3 26036.4

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20		31	69	8.0	3.0	4.0
50		54	46	5.9	3.0	3.7
100		9	91	10.0	4.0	2.9
144		3	97	10.3	10.2	2.4
203		3	97	10.6	8.8	2.4
250		12	88	9.5	4.0	3.2
300		8	92	9.9	4.0	2.9
340		10	90	9.9	4.0	2.9
400		2	98	10.1	8.2	2.4
440		3	97	10.2	10.5	2.4
500		40	60	7.2	2.5	4.7
540	5	89	6	1.3	1.2	1.9
600		84	16	2.4	2.2	2.2
640	1	90	9	2.0	2.2	1.8
706		95	5	2.0	2.2	1.1
740		88	12	2.4	2.5	1.9
800		62	38	5.0	2.5	2.5

TABLE 2: CONTINUED.

CORE:	LENGTH (CM)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 1	299	52	43°29.4' N 70°13.3' W	13349.5 25981.3

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20	2	97	3	0.9	1.0	0.7
40		95	3	0.7	0.7	0.6
80		97	3	1.0	0.8	0.7
120		96	4	1.5	1.8	0.7
140		97	3	1.3	1.5	0.8
160		97	3	1.2	1.2	0.8
240		95	5	1.9	2.0	0.9
260		97	3	1.1	1.2	0.9
280		96	4	1.6	1.2	0.9

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 2	205	51	43°29.4' N 70°13.3' W	13349.5 25981.3

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20		97	3	1.6	1.8	0.7
60		98	2	1.6	1.5	0.7
80		83	17	3.2	1.8	3.2
140		98	2	1.2	1.5	0.6
160		98	2	1.2	1.2	0.7
180		94	6	1.6	1.5	1.2

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TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 3	75	49	43° 30.8' N 70° 13.2' W	25988.1 13339.3

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20		93	7	2.1	2.2	1.4
40	1	92	7	1.9	1.8	1.5
60	1	90	9	1.6	1.8	1.6

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 4	440	46	43° 30.8 N 70° 13.2 W	25991.9 13339.3

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
56		1	99	10.1	11.8	2.5
57	9	58	33	4.4	2.2	4.8
58	6	74	20	3.5	2.0	3.8
94	4	55	41	4.8	2.0	4.5
96	2	49	49	5.7	2.0	4.5
99		2	98	10.3	10.0	2.4
116	5	62	33	4.6	2.0	4.6
219		1	99	9.4		2.9
330	1	56	43	6.0	3.2	3.8
360	1	24	75	8.5	3.8	3.8
371		50	50	6.2	3.2	3.7
419		36	64	7.5	3.8	3.8

TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 5	752	20	43° 29.8' N 70° 20.1 W	26015.3 13389.9

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
60		7	93	9.5	4.0	2.9
80		64	36	4.5	1.8	3.8
120		24	76	7.3	7.2	4.1
140		2	98	9.9	9.5	2.4
180		48	52	5.8	1.8	4.0
200		2	98	9.9	10.2	2.4
240		4	96	9.4	10.0	2.5
280		4	96	9.5	10.5	2.6
310		4	96	9.6	10.0	2.9
340		6	94	9.1	10.0	2.8
380		3	97	9.7	10.5	2.5
400		3	97	9.5	10.2	2.4
440		2	98	9.7	10.5	2.4
480		2	98	9.8	10.5	2.5
500		5	95	9.4	10.0	2.7
540		3	97	9.8	10.2	2.6
580		2	98	10.1	10.5	2.4
600		3	97	9.6	10.5	2.7
640		11	89	8.6	4.0	3.1
680		6	94	9.4	4.0	2.9
700		11	89	9.0	10.8	3.2
740		5	95	9.5	10.2	3.0

Sedimentary Framework of the Southern Maine Inner Continental Shelf

TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SC 6	330	21	43° 31.4' N 70° 19.4' W	26021.3 13375.6

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20	1	54	45	5.6	2.8	3.8
60	2	63	35	5.3	2.5	3.9
80	1	73	26	5.1	2.5	3.6
120	2	73	25	4.6	2.8	3.3
154		57	43	5.6	2.8	3.8
180	2	53	45	5.6	2.8	3.7
220		45	55	6.8	2.8	3.9
260		48	52	6.7	2.8	3.9
280		48	52	6.6	2.8	3.9
320		65	35	5.4	2.8	3.6

TABLE 2: CONTINUED.

<i>CORE:</i>	<i>LENGTH (cm)</i>	<i>WATER DEPTH (MHW, m)</i>	LAT./LON.	<i>LORAN POSITION</i>
SB1	275	19	43° 42.2 N 69° 46' W	25927.2 13095.2

<i>CORE</i>	<i>GRAIN SIZE DISTRIBUTION</i>			<i>MEAN</i>	<i>MODE</i>	<i>SORTING</i>
<i>Sample Depth (cm)</i>	% Gravel	% Sand	% Mud	<i>(phi)</i>	<i>(phi)</i>	<i>(dimensionless)</i>
9	3	60	37	4.9	2.8	3.6
40	3	61	36	5.1	3.5	3.4
80	4	53	43	5.5	2.8	3.9
100		60	40	5.2	2.8	3.5
145		78	22	3.8	2.5	2.6
180		79	21	3.7	2.5	2.6
200		46	54	6.2	2.8	3.6
225	26	66	8	0.4	0.2	2.7
240		91	9	2.1	2.2	1.7
260	7	85	2	1.6	1.5	2.0

Sedimentary Framework of the Southern Maine Inner Continental Shelf

TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SB 2	870	19	43° 42.2' N 69° 46' W	25927.2 13095.2

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
40		84	16	2.9	2.5	1.9
80	4	76	20	3.9	2.0	2.9
100		84	16	2.5	2.0	2.0
140	1	81	17	3.1	2.0	2.8
180	14	78	8	1.5	1.8	2.4
200		90	10	1.8	1.2	2.1
240	7	90	3	0.7	1.2	0.9
280	24	75	1	-0.1	1.2	1.7
300	4	95	1	0.7	1.0	0.6
340	18	81	1	0.3	1.2	1.3
380	12	88	0	0.6	1.2	1.2
400	33	67	0	-0.4	1.2	1.6
440	35	62	3	-0.4	-1.0	1.0
480	9	90	1	0.6	1.0	0.9
500		40	60	6.5	3.0	3.3
540		32	68	7.0	3.2	3.4
570		27	73	7.1	3.2	3.4
600		25	75	7.0		3.6
640		39	61	5.9	3.0	2.8
680		89	11	2.8	2.2	1.4
700		97	3	2.3	2.2	0.4
734		95	5	2.5	2.5	0.4
780		23	77	7.4	2.5	3.5
800		94	6	3.1	3.5	1.0
840		66	34	5.1	2.5	3.1
880		70	30	5.0	3.0	3.0

TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SB 3	630	34	43° 41.8' N 69° 54.7' W	25962.2 13151.6

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% mud	(phi)	(phi)	(dimensionless)
18	1	83	17	3.3	2.5	2.1
58		84	16	3.0	2.8	1.9
98		82	17	3.5	2.8	2.0
118		82	18	3.5	3.0	1.8
158		82	18	3.5	3.0	2.0
198		74	26	5.1	3.0	3.7
218		78	22	4.0	3.0	2.6
258		73	27	5.5	3.0	3.5
298		69	31	5.5	3.0	3.3
318		70	30	5.6	3.0	3.5
338		70	30	5.5	3.2	3.2
398		77	23	5.0	3.0	3.3
418		66	34	4.5	3.2	2.3
458		60	40	5.9	3.2	3.6
478		64	36	5.9	3.2	3.7
518		66	34	5.6	3.2	3.5
558		65	35	5.8	3.0	3.6
598		59	41	5.9	3.0	3.6
618		60	40	5.6	3.0	3.5

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SB 4	160	26	43° 41.8' N 69° 53.8' W	25958.2 13146.2

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20	1	97	2	1.2	1.2	0.5
40	3	91	6	1.9	1.8	1.2
57		52	48	5.4	2.0	4.1
80	4	97	1	0.8	0.5	0.7
100		97	3	2.1	2.0	0.4
140	3	95	2	2.4	2.0	1.0

Sedimentary Framework of the Southern Maine Inner Continental Shelf

TABLE 2: CONTINUED.

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SB 5	317	26	43° 41.8' N 67° 53.8' W	25958.2 13146.2

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
10		99	1	1.4	1.2	0.5
40	94	94	5	1.7	1.8	0.8
60		96	4	2.0	2.0	0.6
100	8	88	4	0.7	0.2	1.3
140		98	2	2.3	2.5	0.4
160		97	3	2.3	2.5	0.4
200		98	2	2.4	2.5	0.4
240		96	4	2.7	2.8	0.3
260		96	4	2.5	2.5	0.4
300		96	4	2.6	2.8	0.4

CORE:	LENGTH (cm)	WATER DEPTH (MHW, m)	LAT./LON.	LORAN POSITION
SB 6	410	42	43° 38.8' N 69° 51.1' W	25931.0 13148.6

CORE	GRAIN SIZE DISTRIBUTION			MEAN	MODE	SORTING
Sample Depth (cm)	% Gravel	% Sand	% Mud	(phi)	(phi)	(dimensionless)
20		95	5	2.1	2.0	0.9
60		97	3	2.5	2.5	0.4
80		96	4	2.5	2.5	0.4
100		83	17	3.6	2.2	2.5
120		94	6	2.8	2.8	0.9
160		76	24	4.0	3.0	1.9
180		72	28	5.2	3.0	3.1
200		74	26	4.7	3.0	2.7
220		70	30	5.0	3.0	2.8
260		57	43	5.0	3.0	2.7
280		59	41	5.0	3.2	2.8
300		57	43	5.0	3.2	2.6
320		62	38	6.1		3.7
360		65	35	4.8		2.6
380						

TABLE 3: MINERAL COMPOSITION OF UPPER AND LOWER SANDS FROM ARMY/USGS CORES FROM SACO BAY (from Luepke and Grosz, 1986)

MINERAL	UPPER FLUVIAL SAND (n = 10)	LOWER GLACIOMARINE SAND (n = 10)
Magnetite**	0.1 (0.0001)	2.7 (2.5)
Ilmenite	3.73 (1.18)	3.10 (0.98)
Mica	1.88 (1.82)	1.83 (1.01)
Garnet	31.1 (10.4)	30.5 (4.5)
Staurolite	4.88 (1.4)	4.70 (0.5)
Epidote	8.36 (2.1)	8.06 (1.60)
Pyroboles**	26.9 (5.6)	22.5 (3.9)
Sillimanite / Andalusite	8.35 (2.5)	8.85 (1.6)
Tourmaline**	7.57 (2.55)	5.65 (1.3)
Sphene	2.08 (0.89)	2.02 (0.69)
Apatite**	1.50 (0.54)	2.04 (0.77)
Zircon	1.86 (0.83)	1.50 (0.64)
% Heavy Minerals**	1.62 (0.68)	0.24 (0.26)
% Economic Heavy Minerals	14.65 (3.06)	13.7 (2.23)

Minerals with two asterisks differ significantly in abundance in the two core positions. Weight percent of heavy mineral fraction in parentheses.

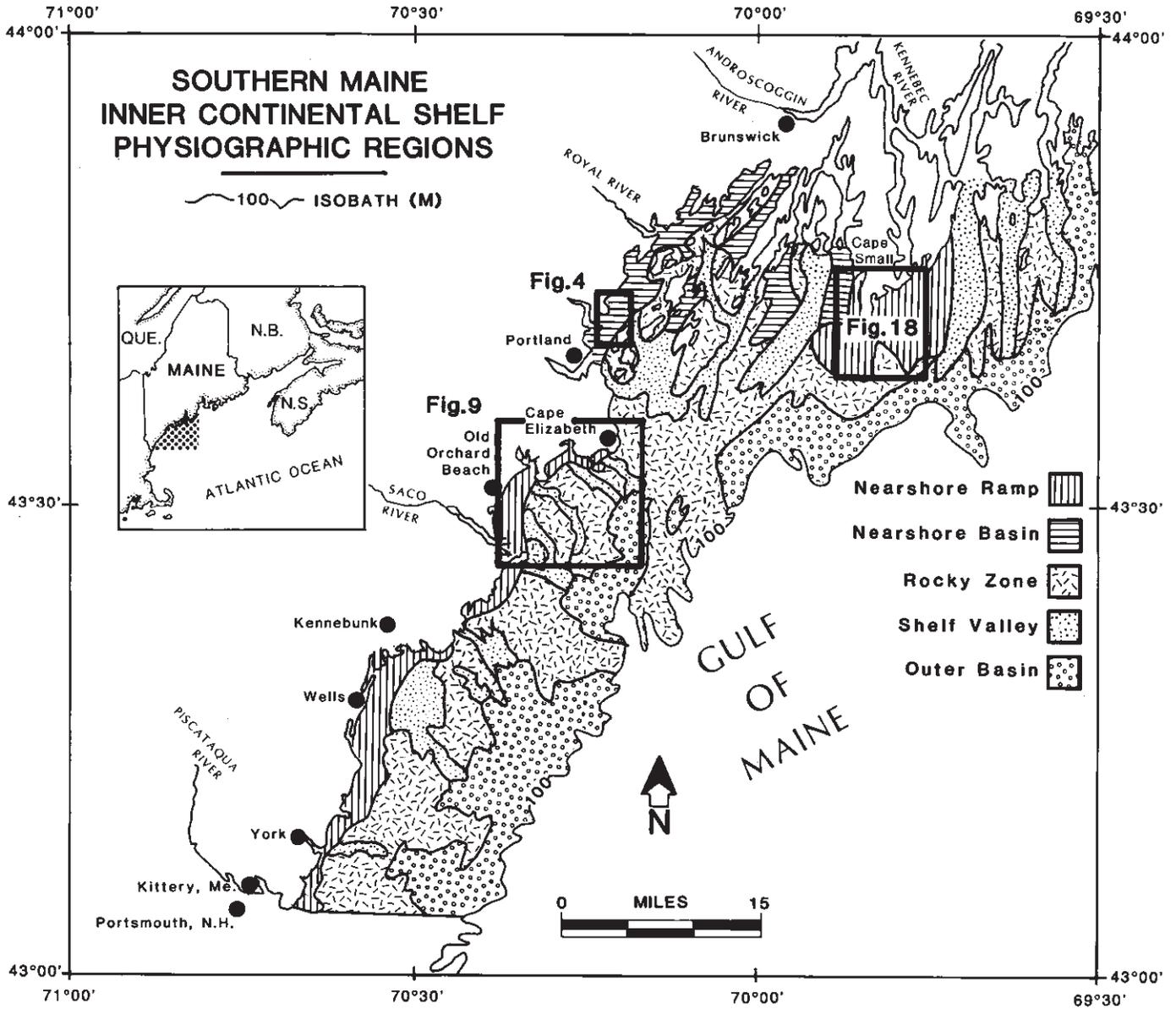


Figure 1: Physiographic map of the inner continental shelf of southern Maine (modified from Kelley et al., 1989c). Boxed areas are where cores were collected and are shown at a larger scale in the figures indicated.

STRATIGRAPHIC CROSS-SECTION :
SOUTHWESTERN COASTAL MAINE

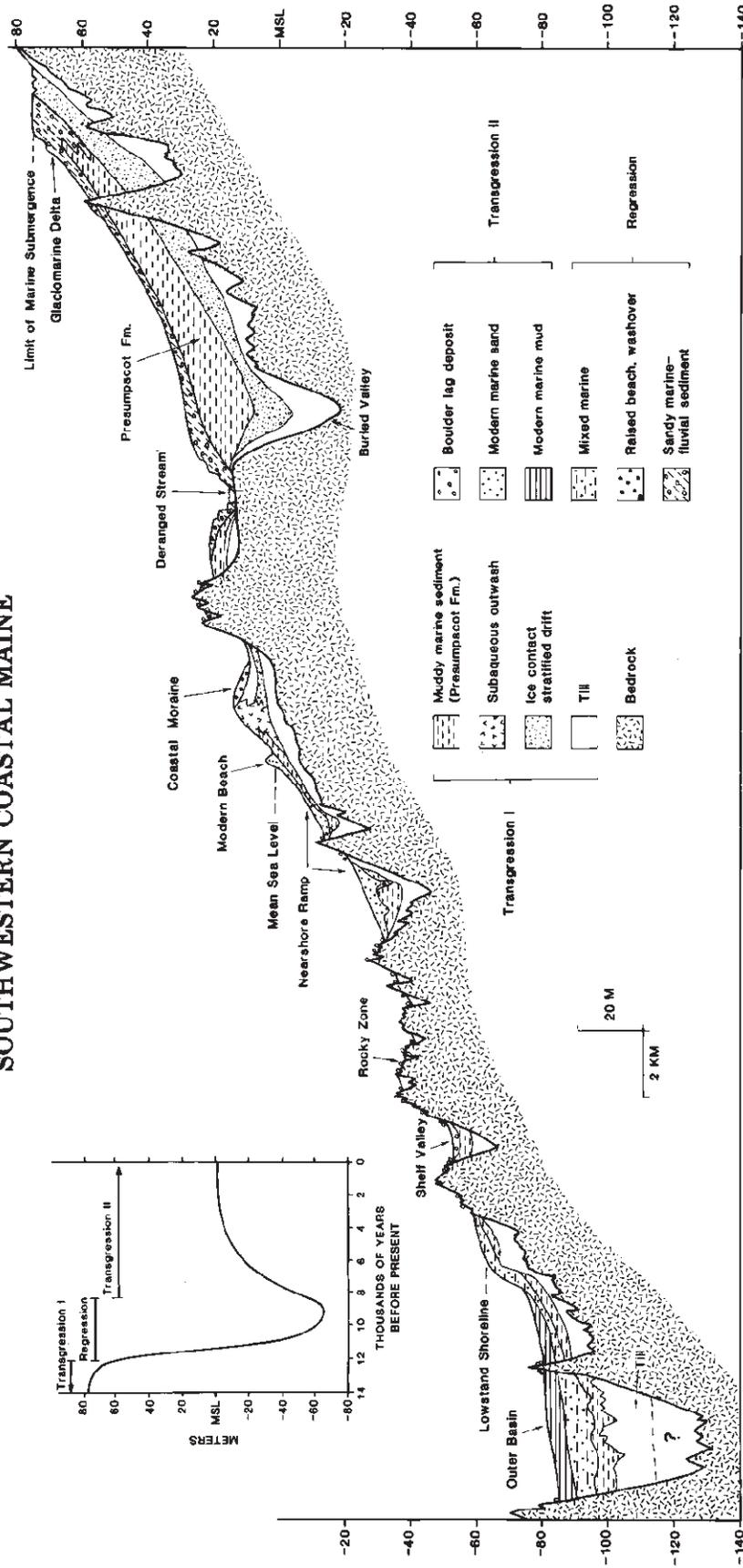


Figure 2: Stratigraphic model for the Quaternary coastal zone of Maine, from the Pleistocene marine limit on land to the early Holocene lowstand shoreline on the inner shelf. Terrestrial inferences after Smith (1985); figure from Kelley et al., 1987a, 1989c.

QUATERNARY DEPOSITIONAL SEQUENCE MODEL
WEST-CENTRAL MAINE INNER SHELF

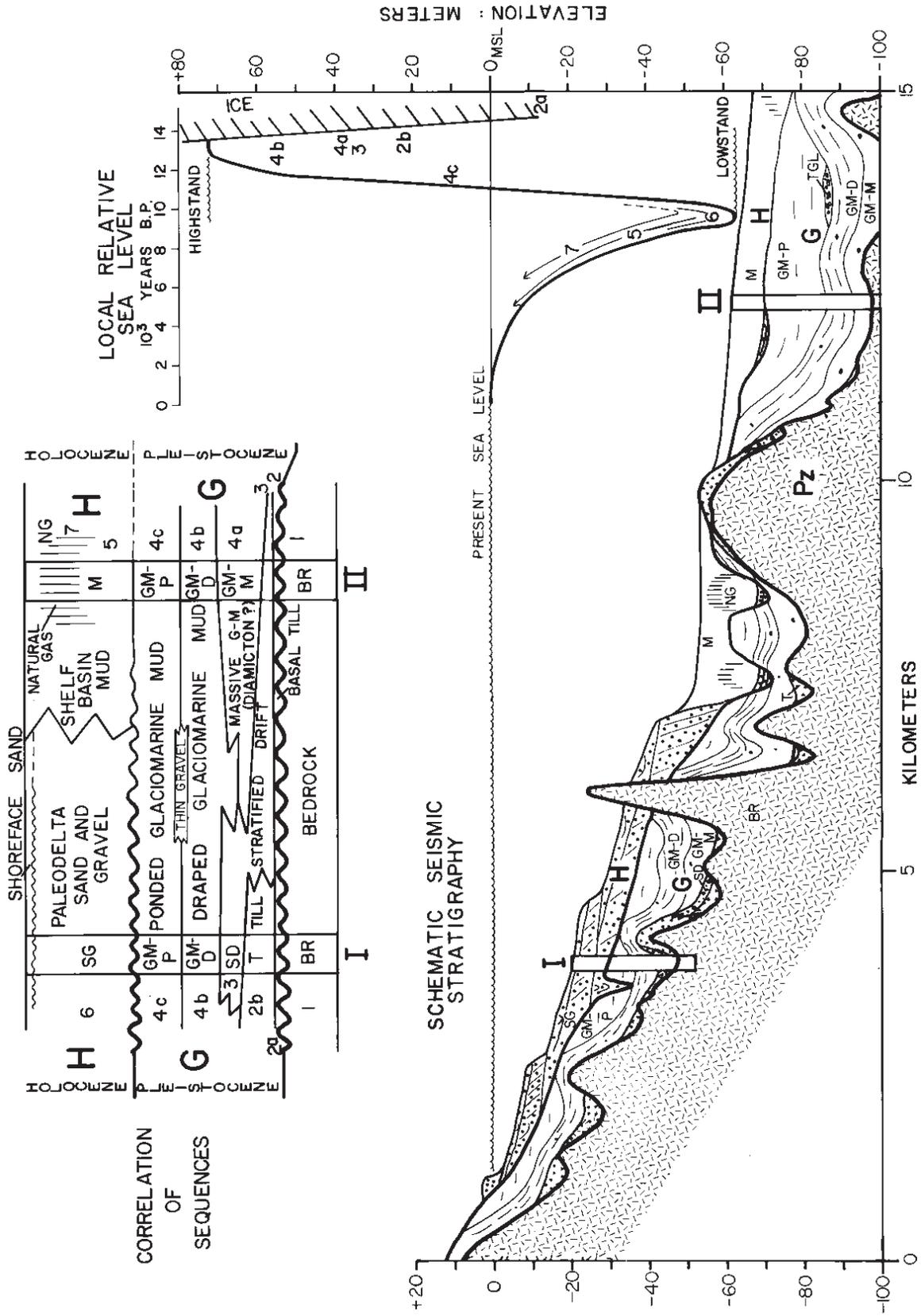


Figure 3: Seismic sequence model for the central Maine inner shelf (Belknap et al., 1989).

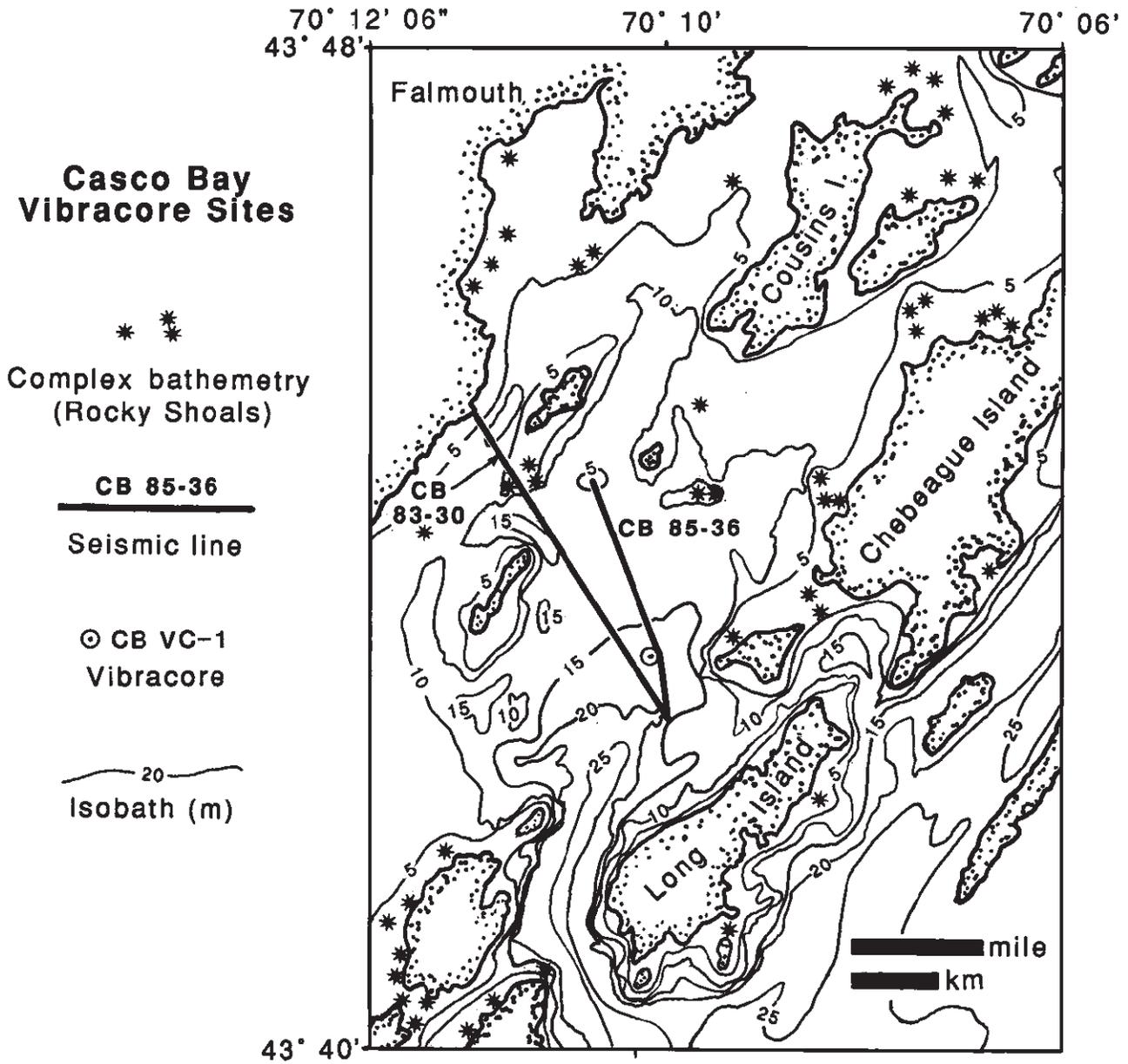


Figure 4: Detailed bathymetric map of the Casco Bay site for CBVC88-1 (modified from USGS/NOS, 1988).

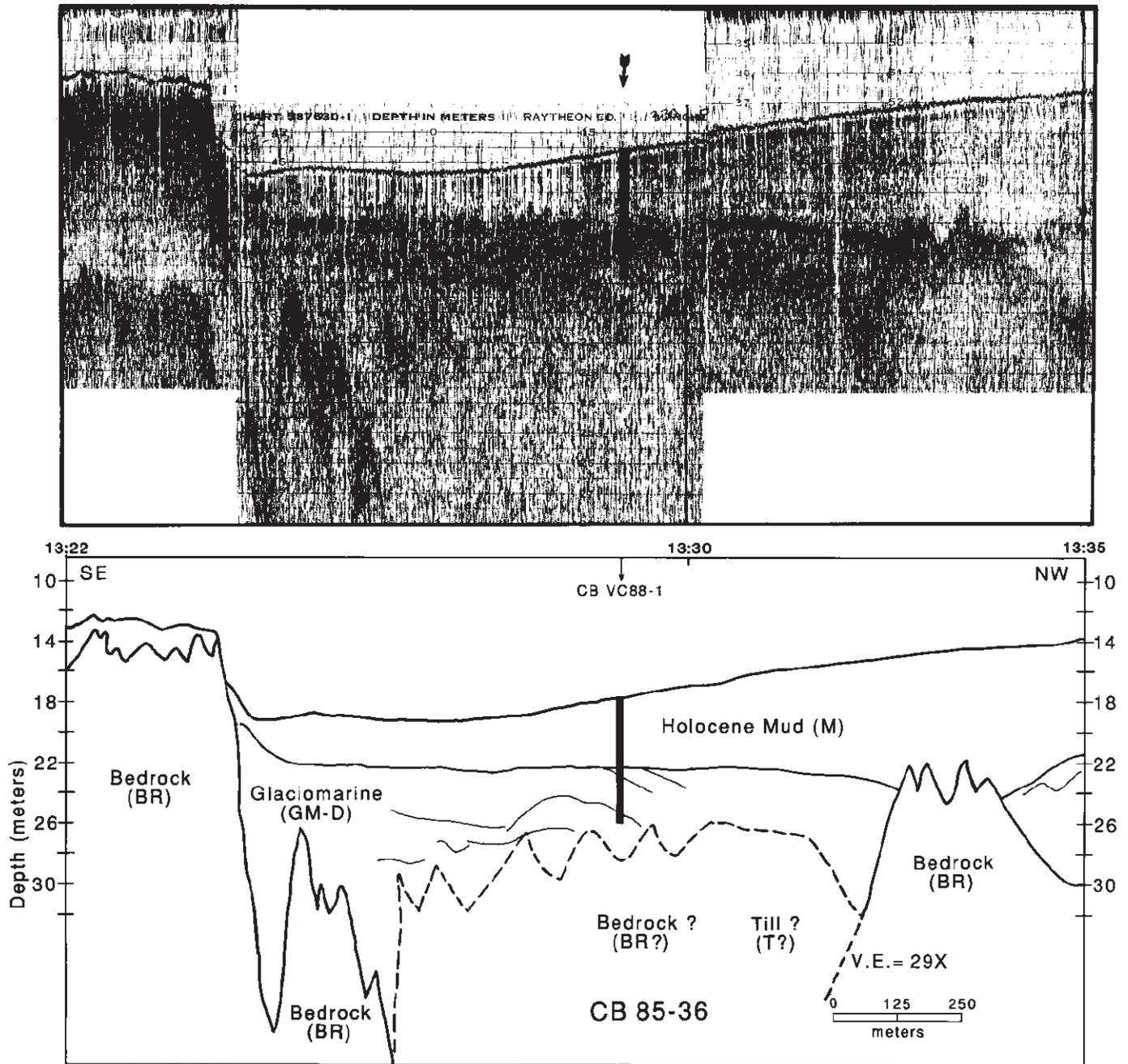


Figure 5: Seismic reflection profile CB85-36 near site of CBVC88-1.

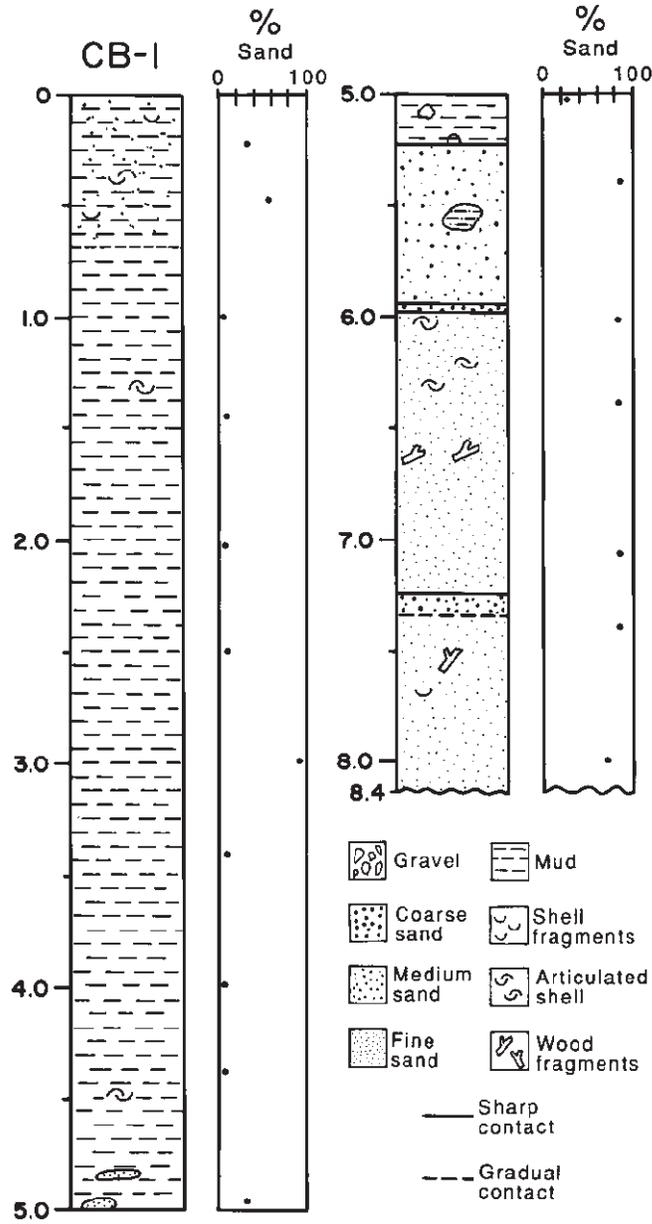


Figure 6: Log of CBVC88-1 with percent of sand recorded in select samples.

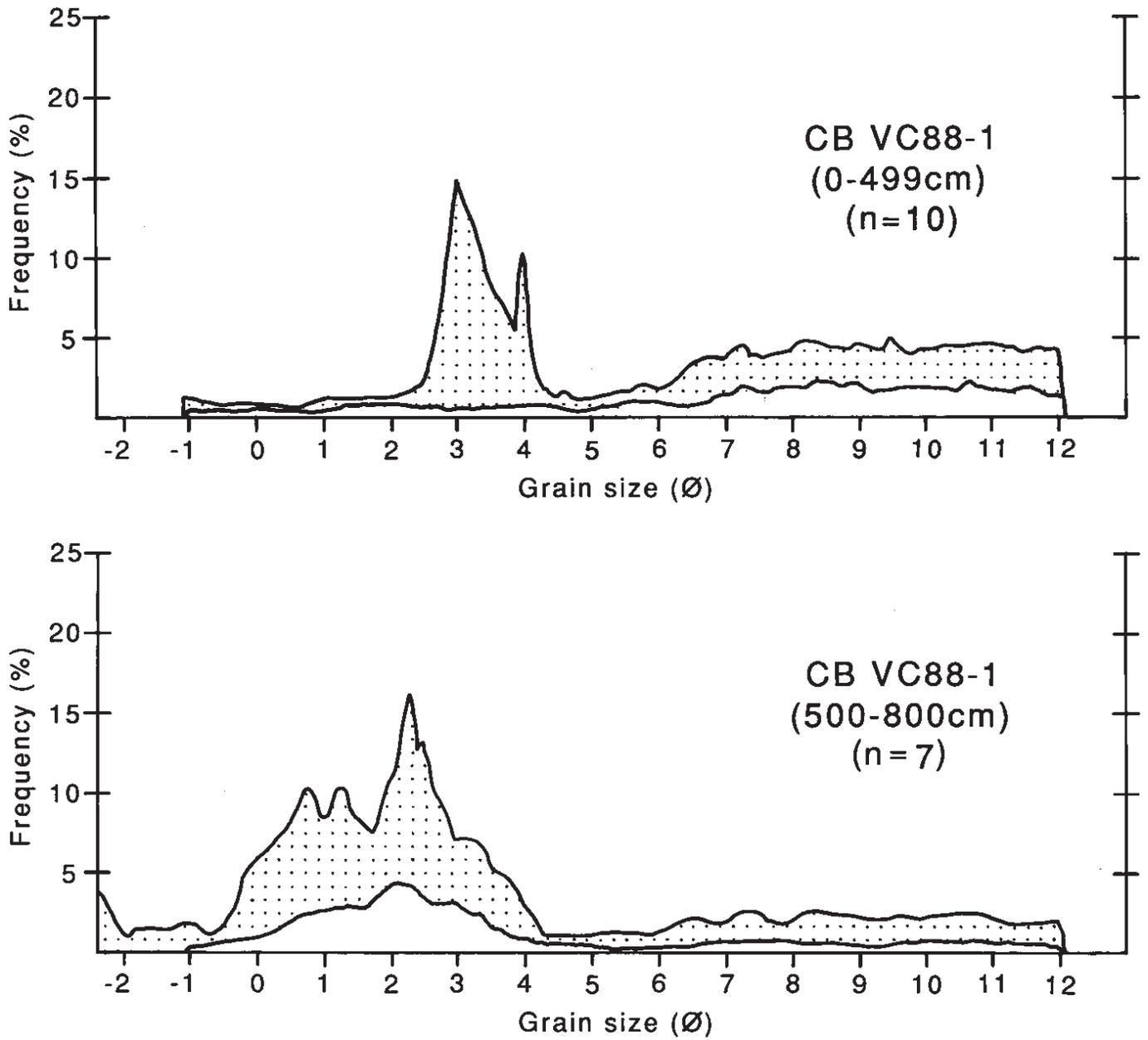


Figure 7: Histogram depicting the envelope of grain size analyses (in phi units) for 17 samples from CBVC88-1.

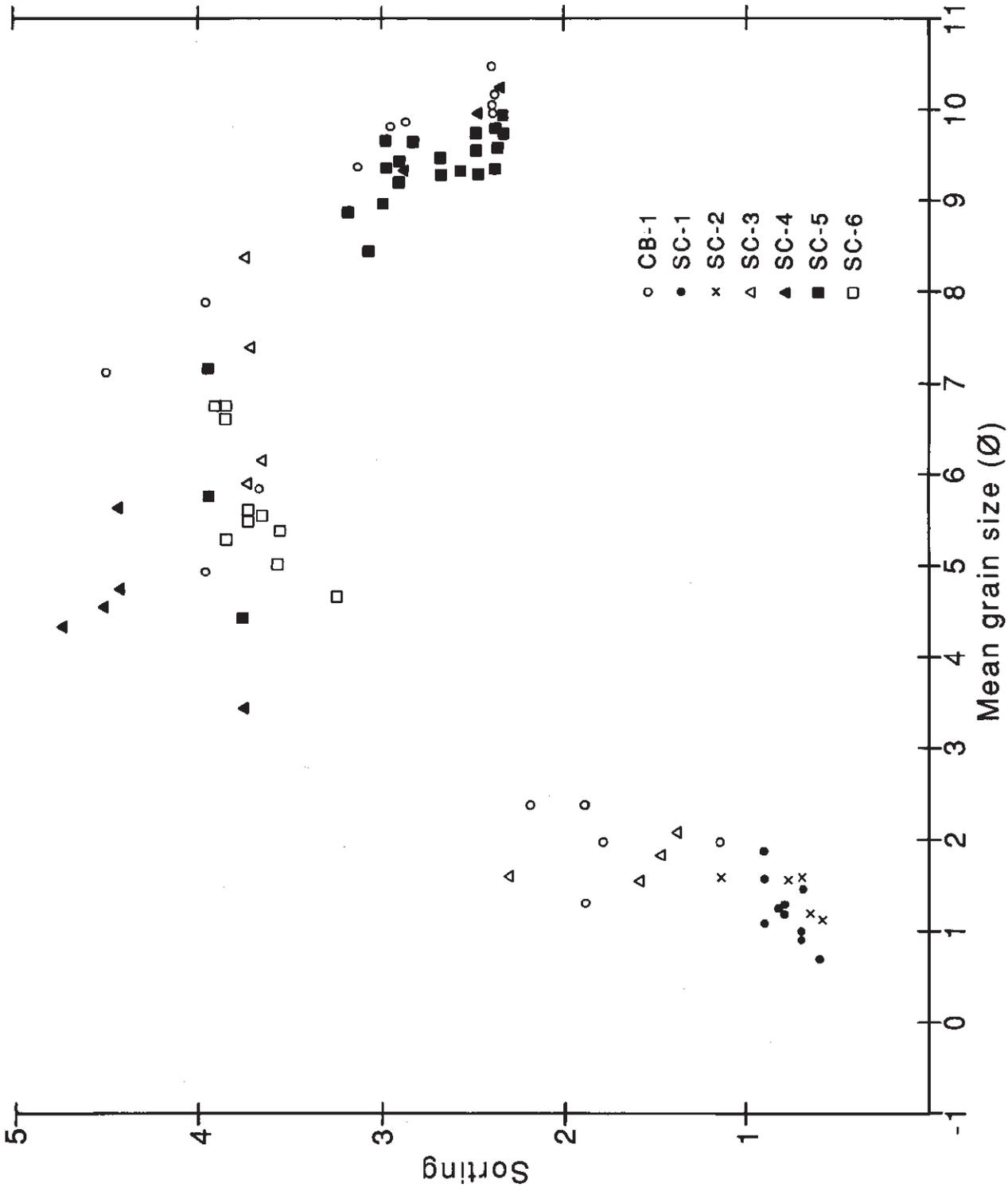


Figure 8: Mean grain size (in phi units) versus sorting of sediment from samples from the Casco Bay and Saco Bay vibracores.

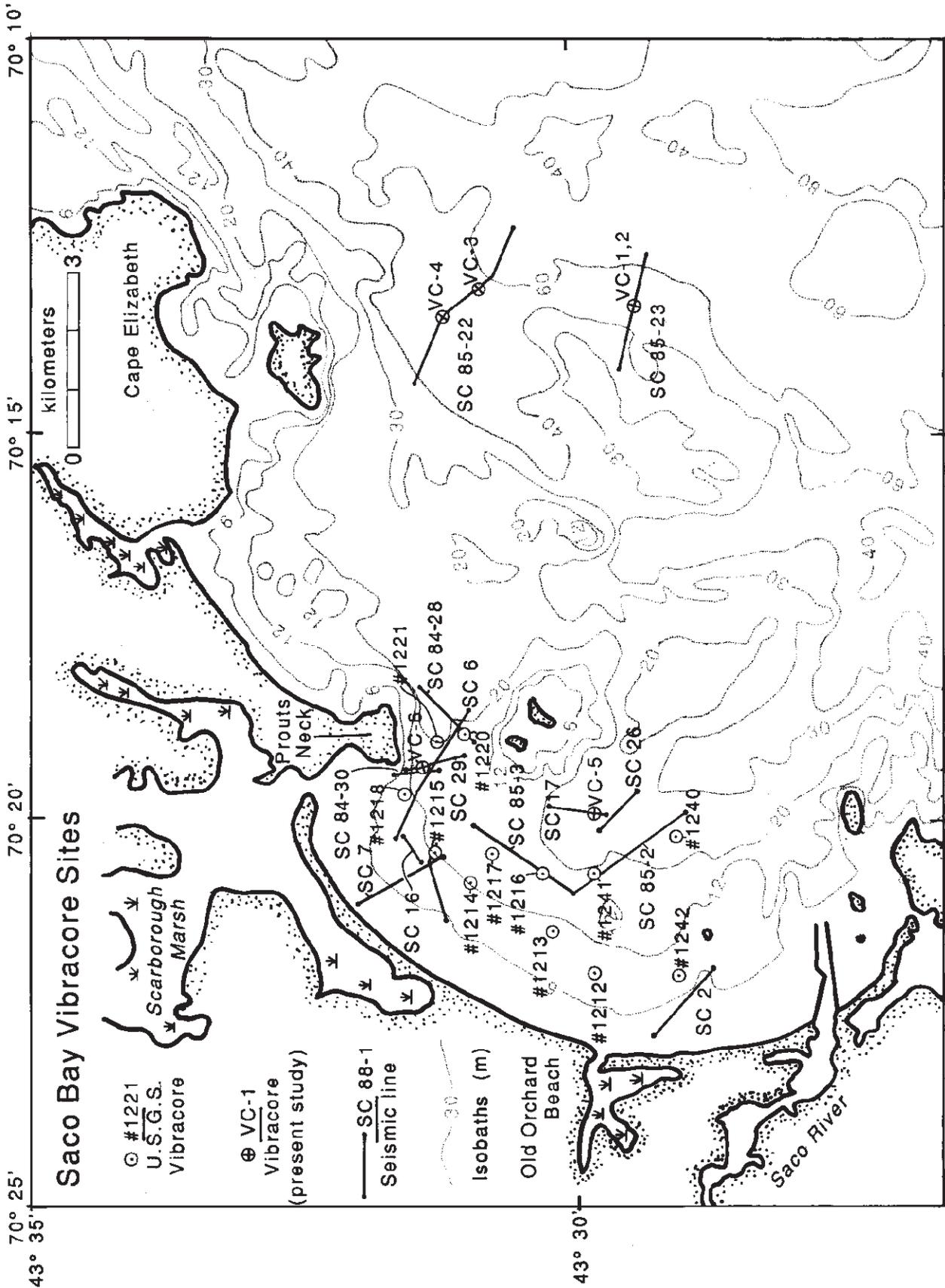


Figure 9: Bathymetry, seismic tracklines, and vibracore sites in Saco Bay. Bathymetric contours modified from USGS/NOS (1988).

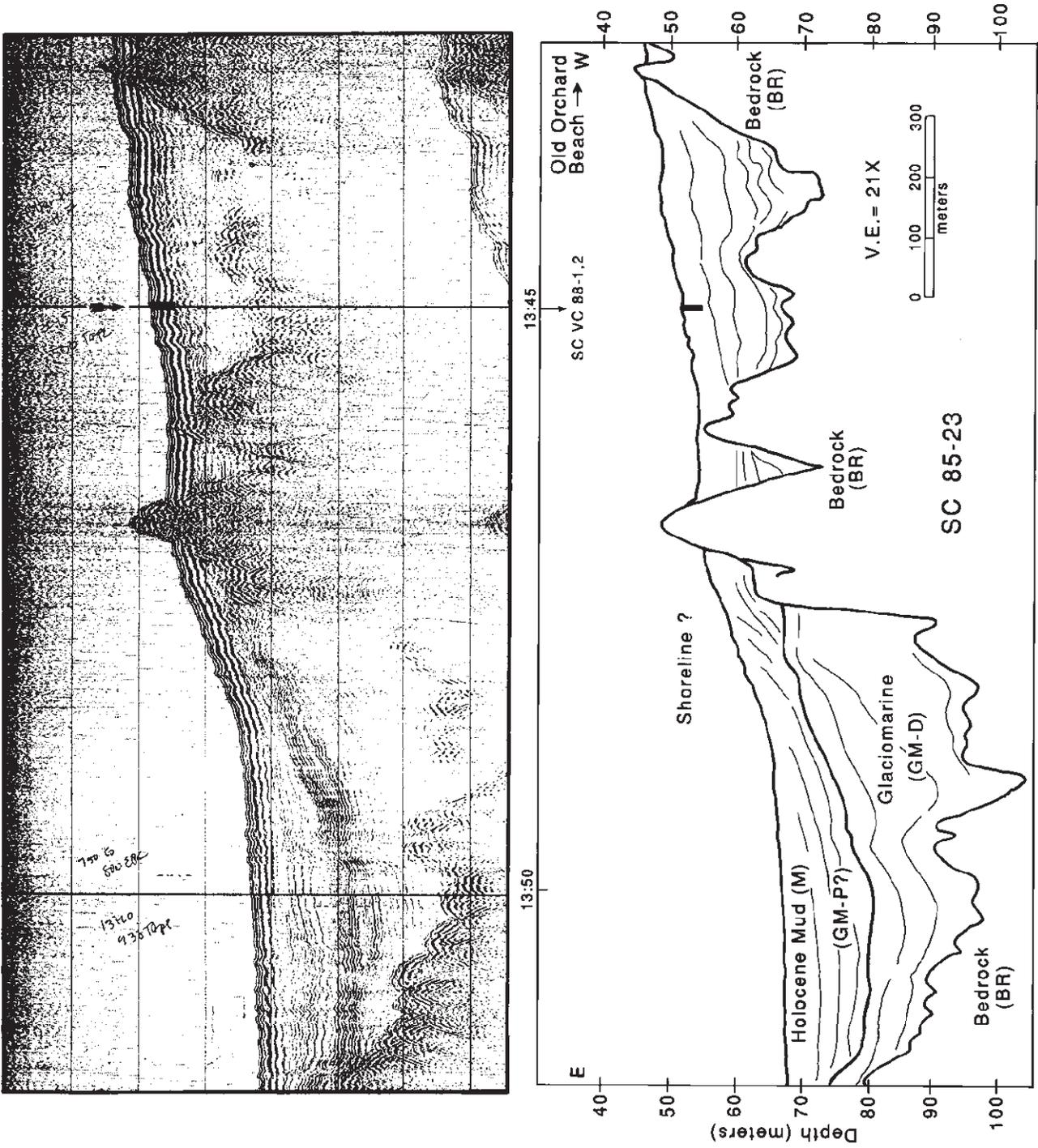


Figure 10: Geopulse seismic reflection profile SC85-23 over vibracore sites SCVC88-1 and 2, and inferred shoreline (Figure modified from Kelley et al., 1987a).

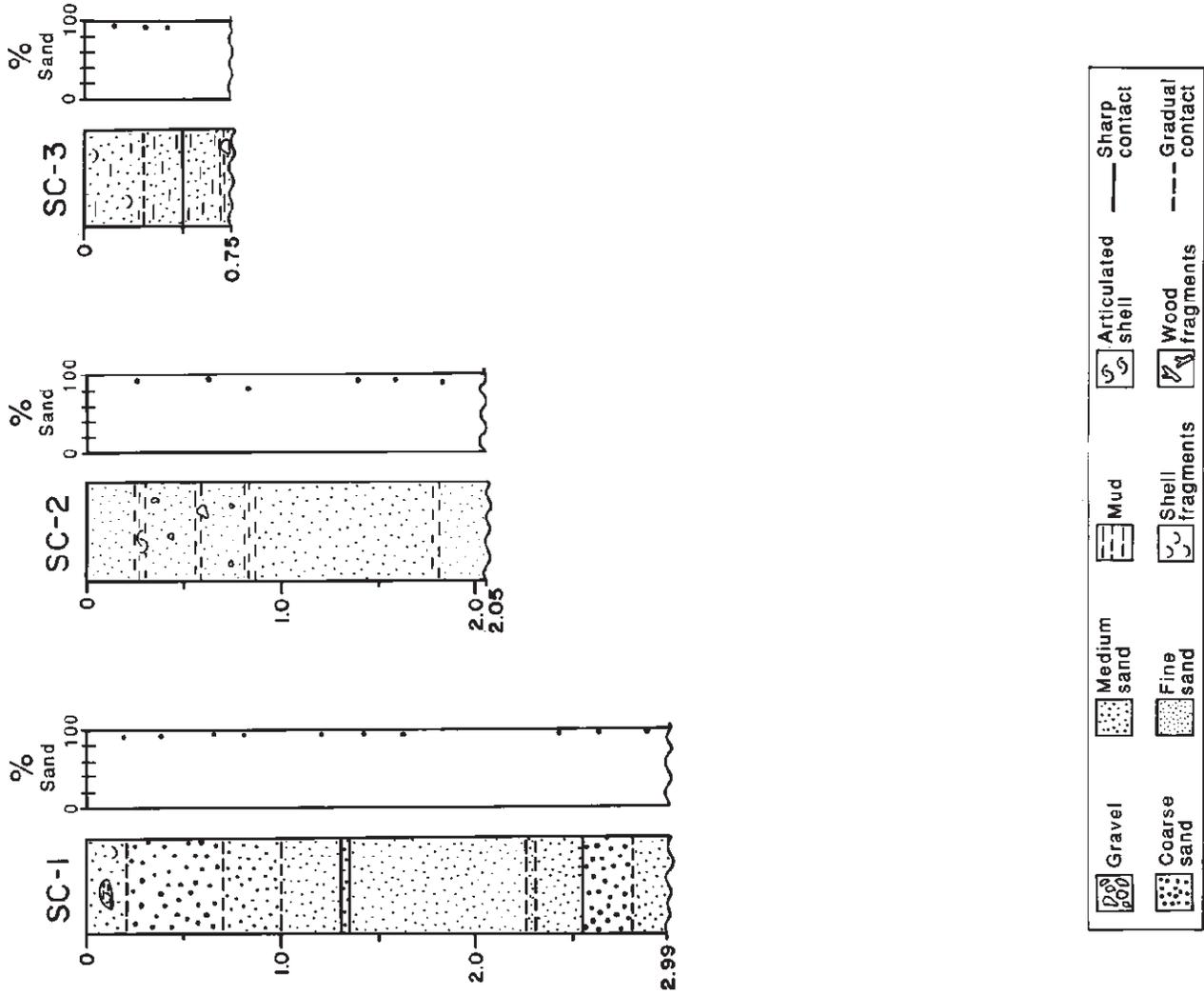


Figure 11: Logs of vibracores from Saco Bay.

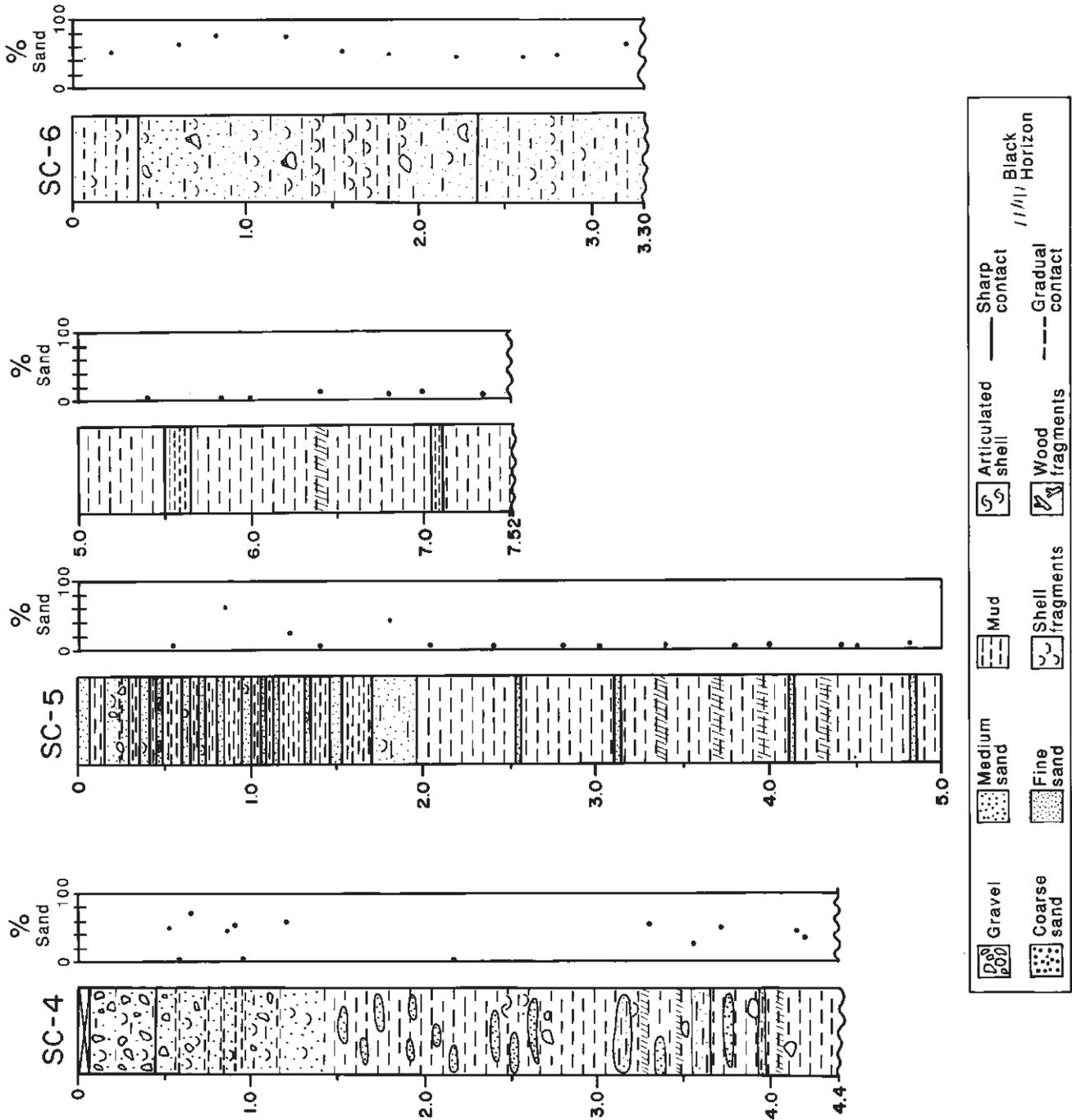


Figure 11: Logs of vibracores from Saco Bay.

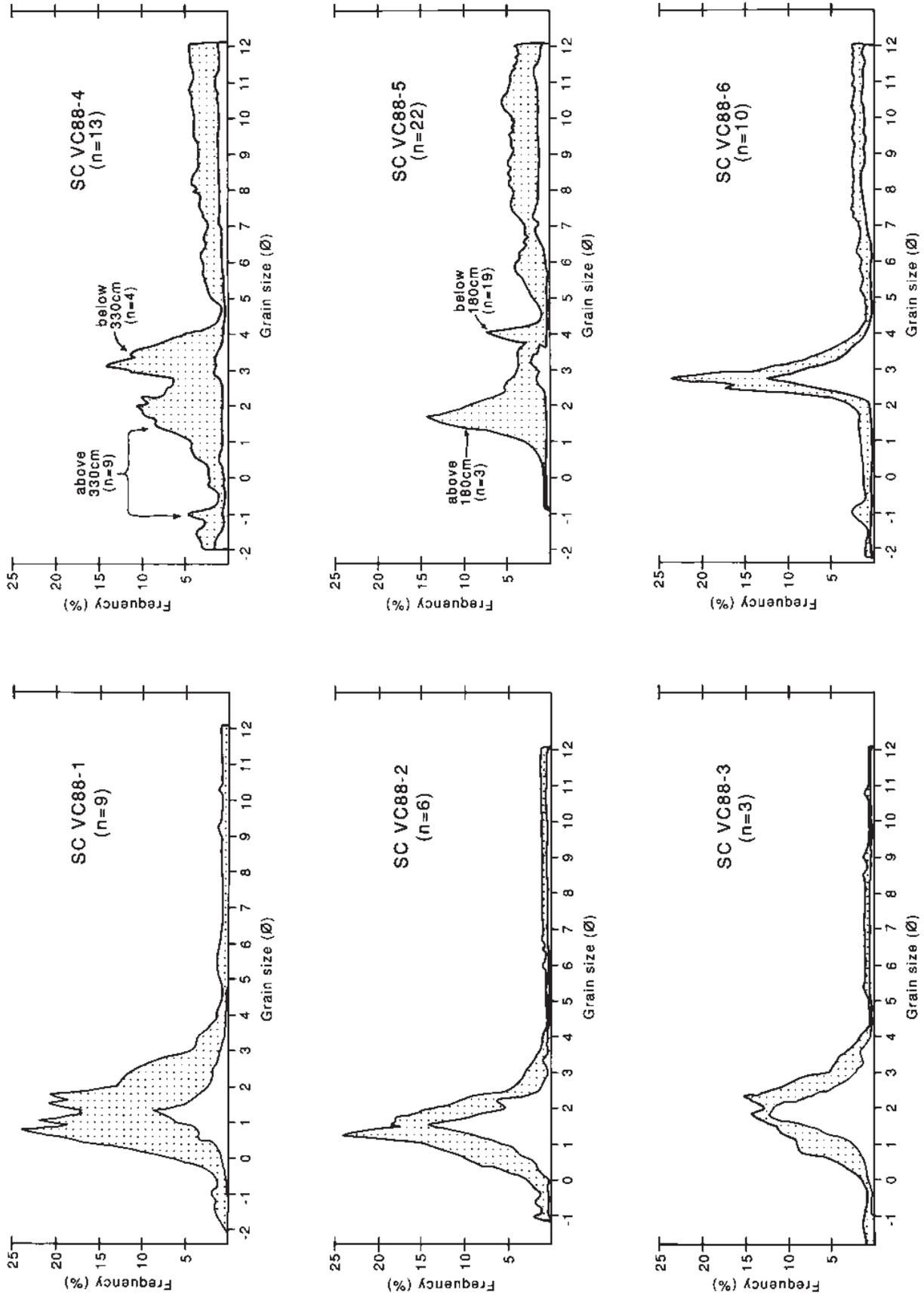


Figure 12: Histograms depicting the envelope of grain size analyses (in phi units) for Saco Bay vibracores. Modes from samples at different depths are indicated with arrows.

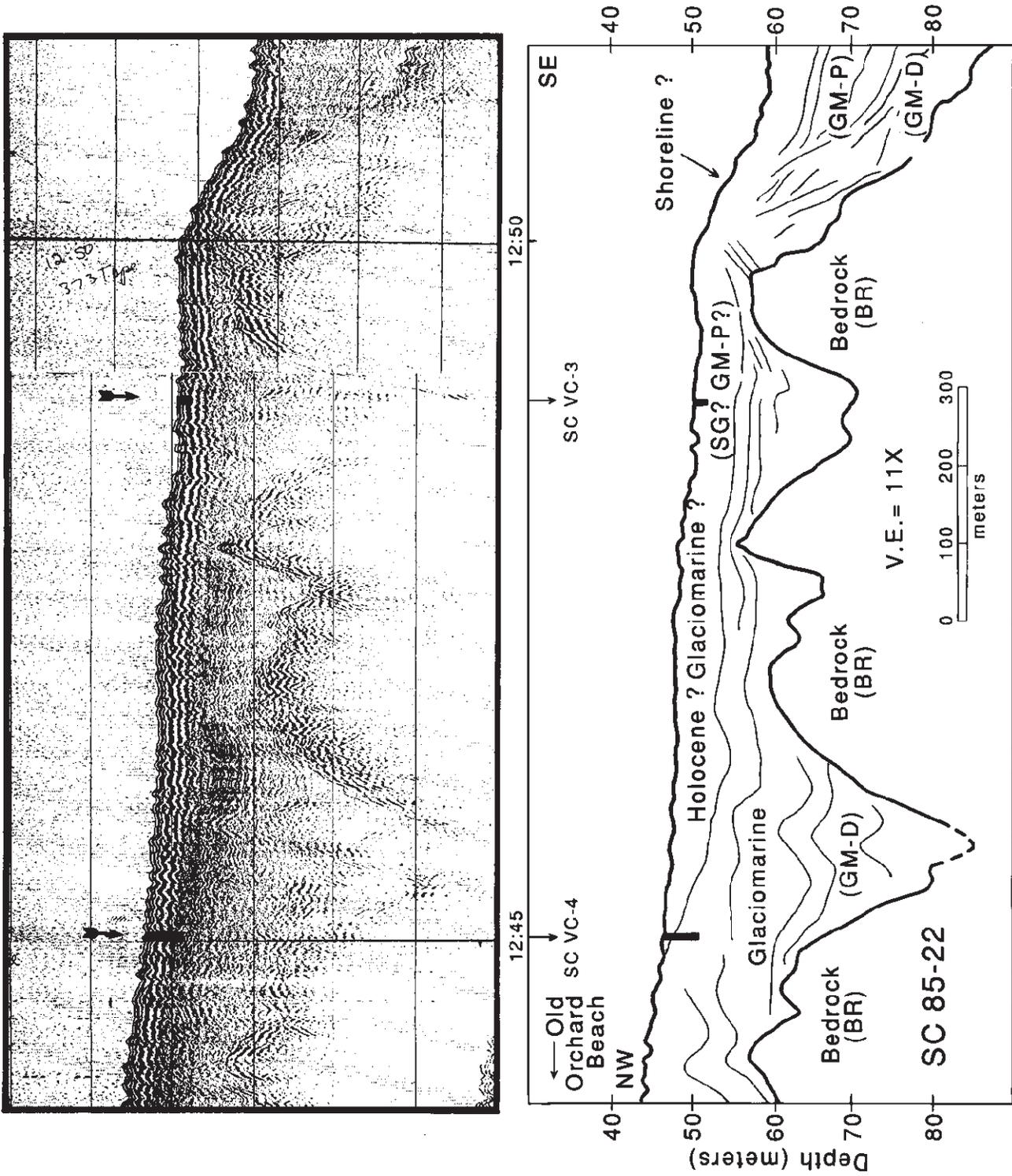


Figure 13. Geopulse seismic reflection profile SC85-22 over vibracores SCV88-3 and 4 (modified from Kelley et al., 1986, Figure 6a, 8a).

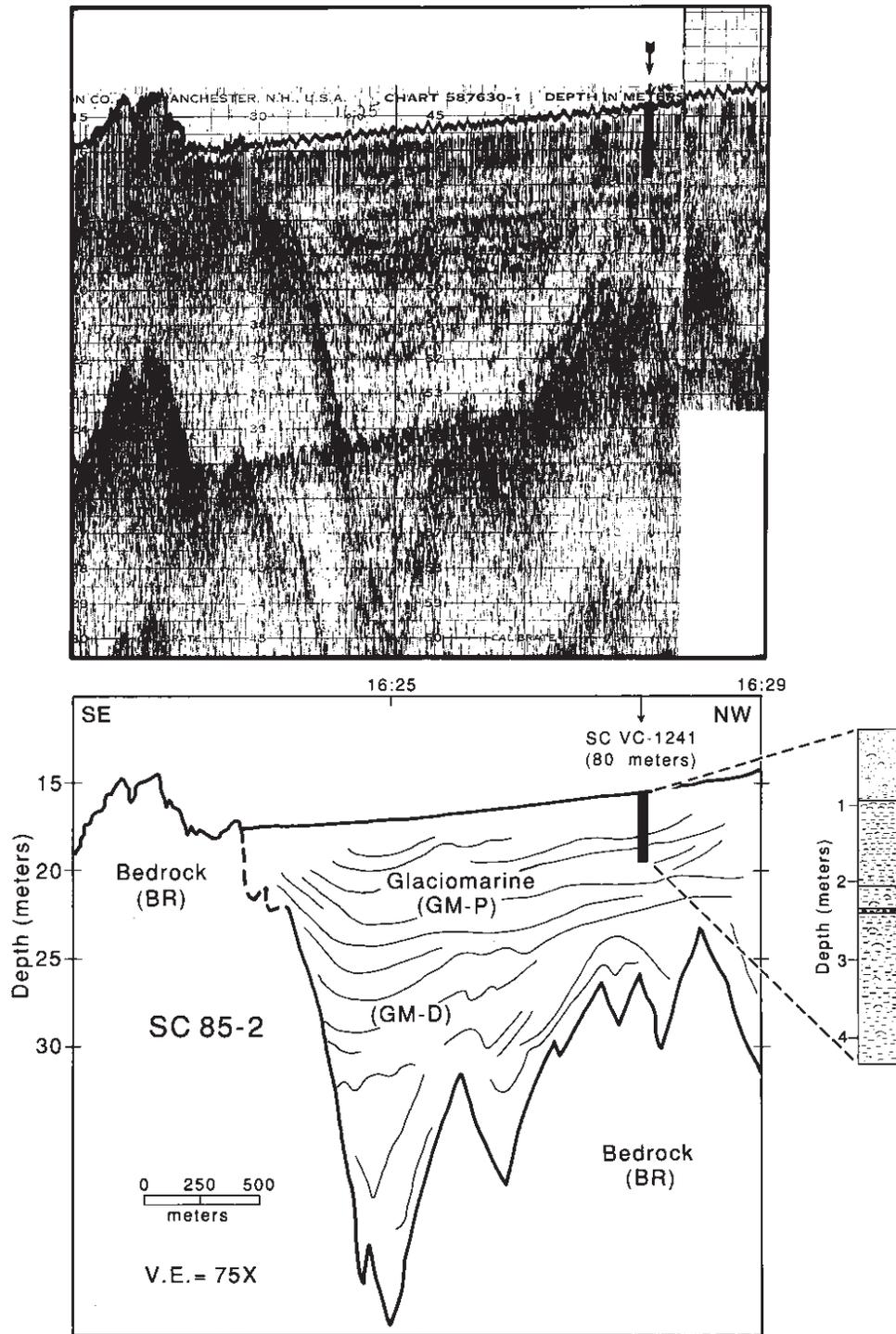


Figure 14. A 3.5 kHz seismic reflection profile 80 meters from U.S. Army Corps of Engineers/USGS core 1241. Core interpretation is from Luepke and Grosz (1986).

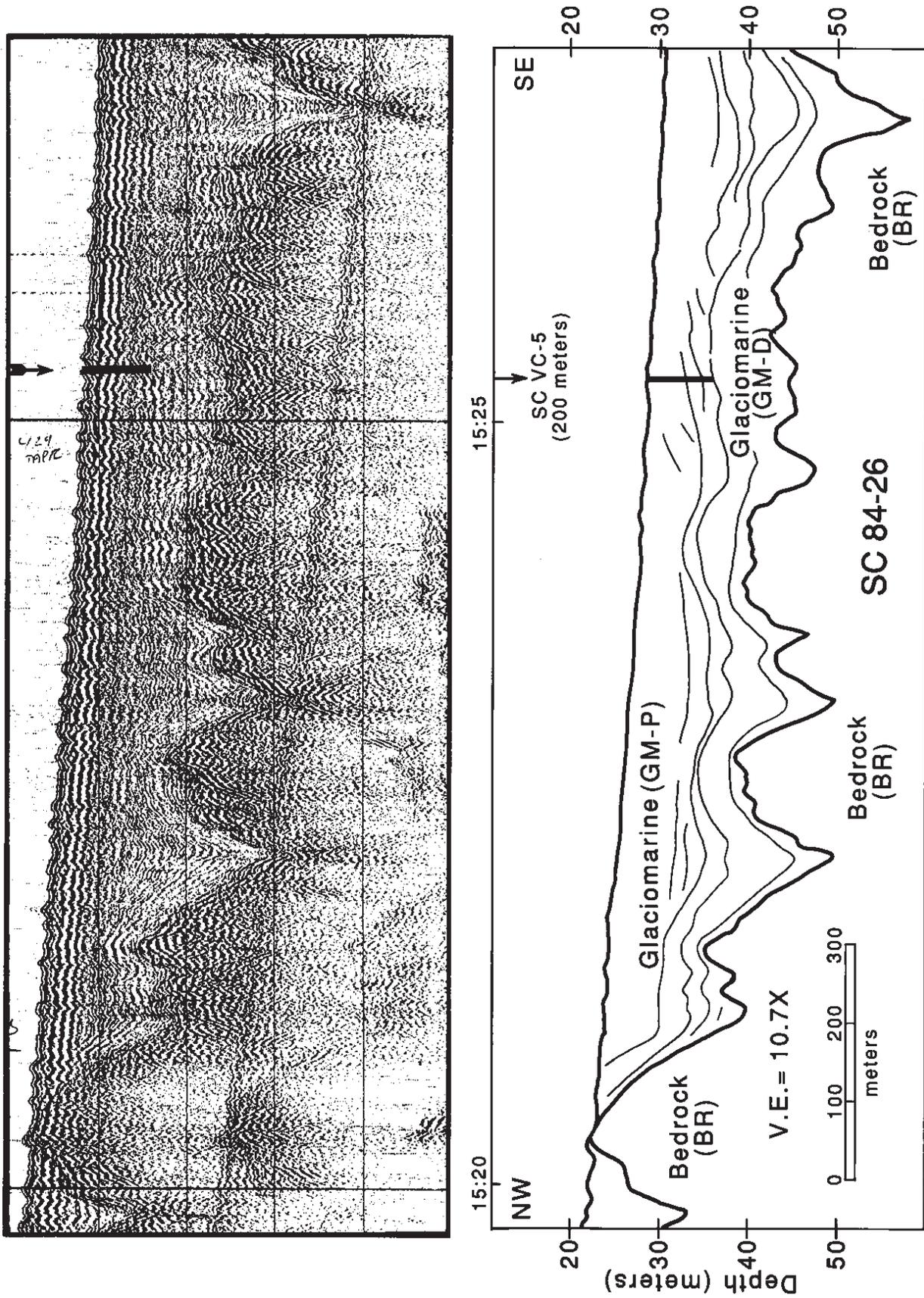


Figure 15. Geopulse seismic reflection profile SC84-26 passed 75 meters from vibracore SCVC88-5.

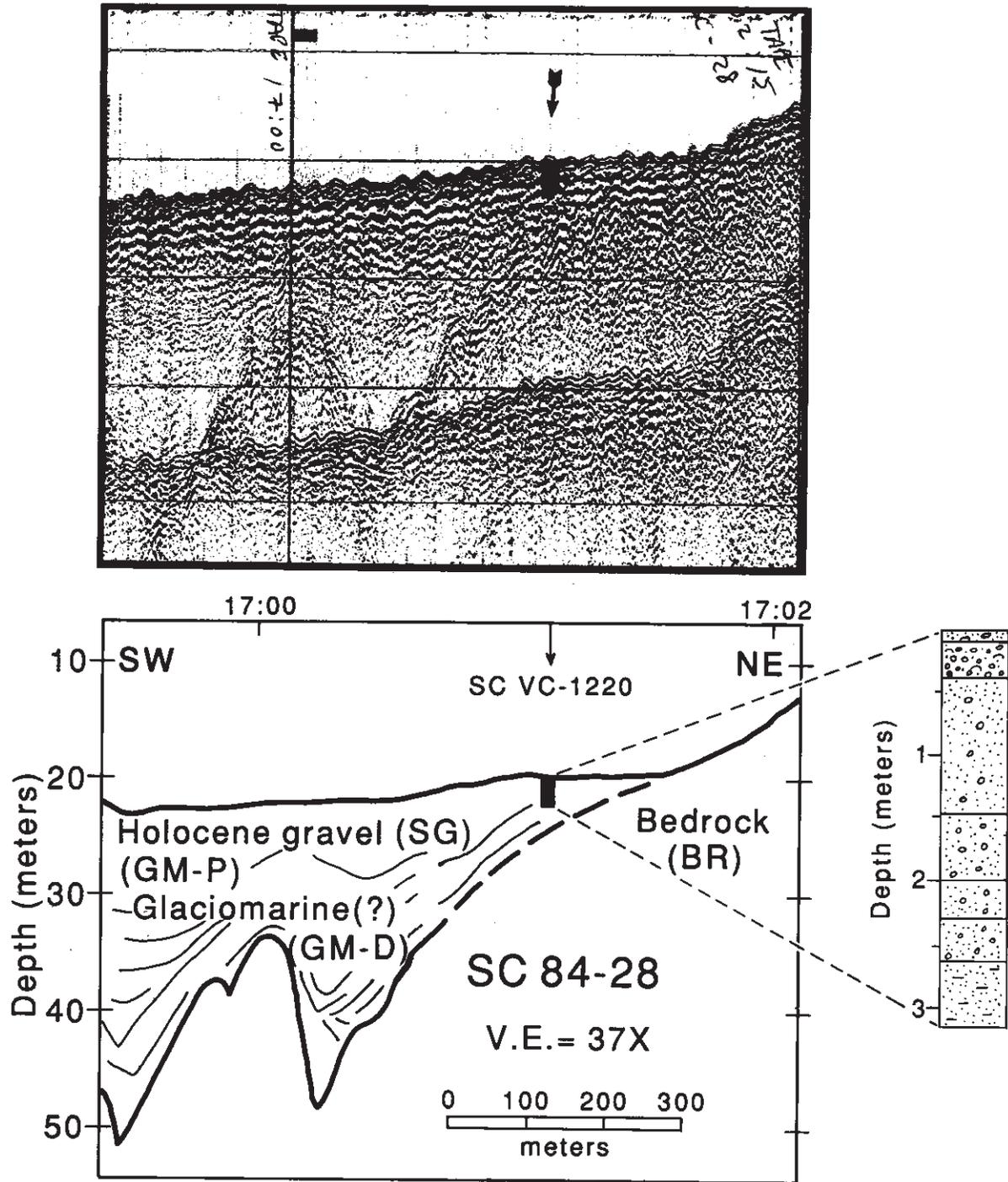


Figure 16. Geopulse seismic reflection profile SC84-28 over U.S. Army Corps of Engineers/USGS core 1220 near Prouts Neck. Core interpretation is from Luepke and Grosz (1986).

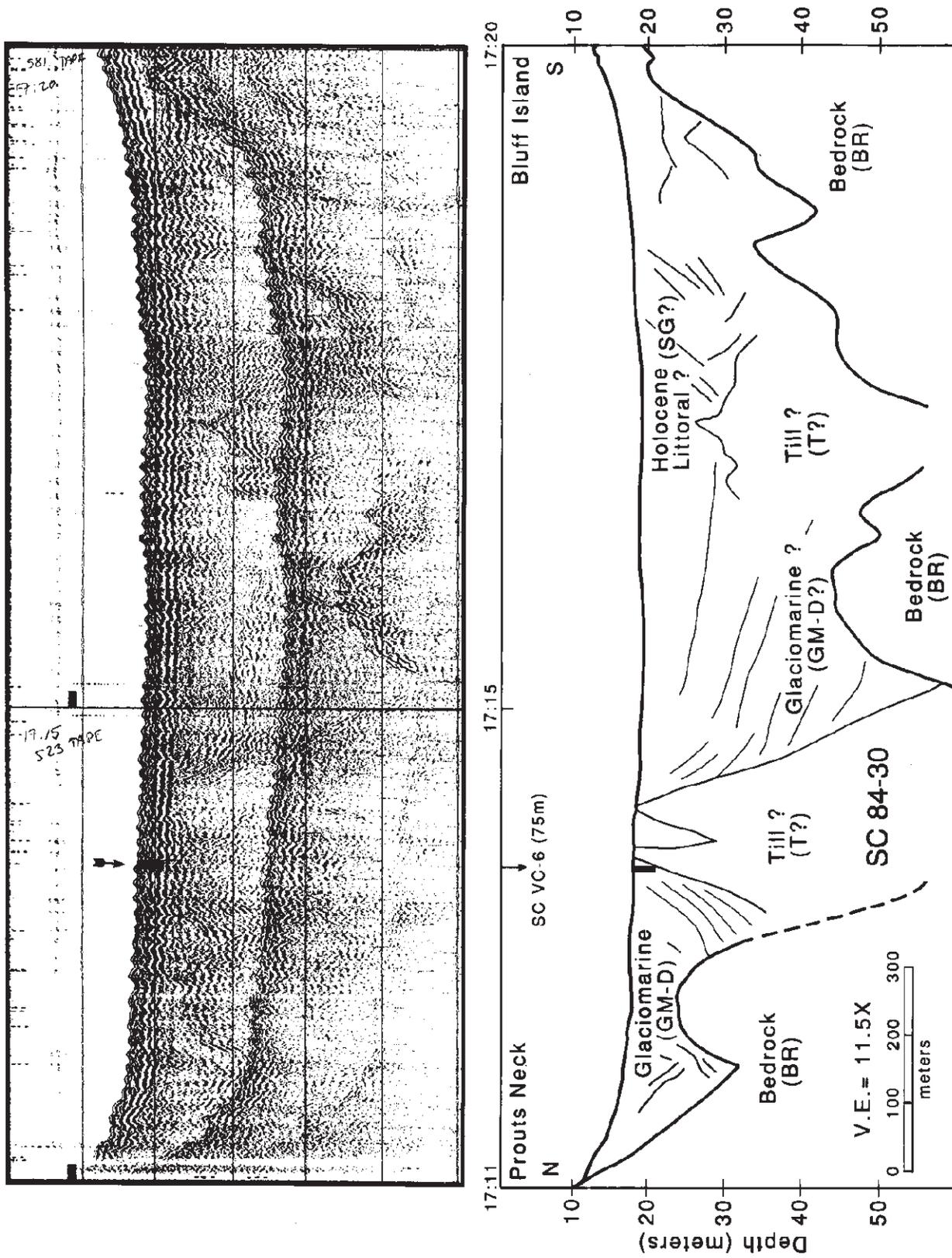


Figure 17. Geopulse seismic reflection profile SC84-30 positioned 75 meters from vibracore SCVC88-6.

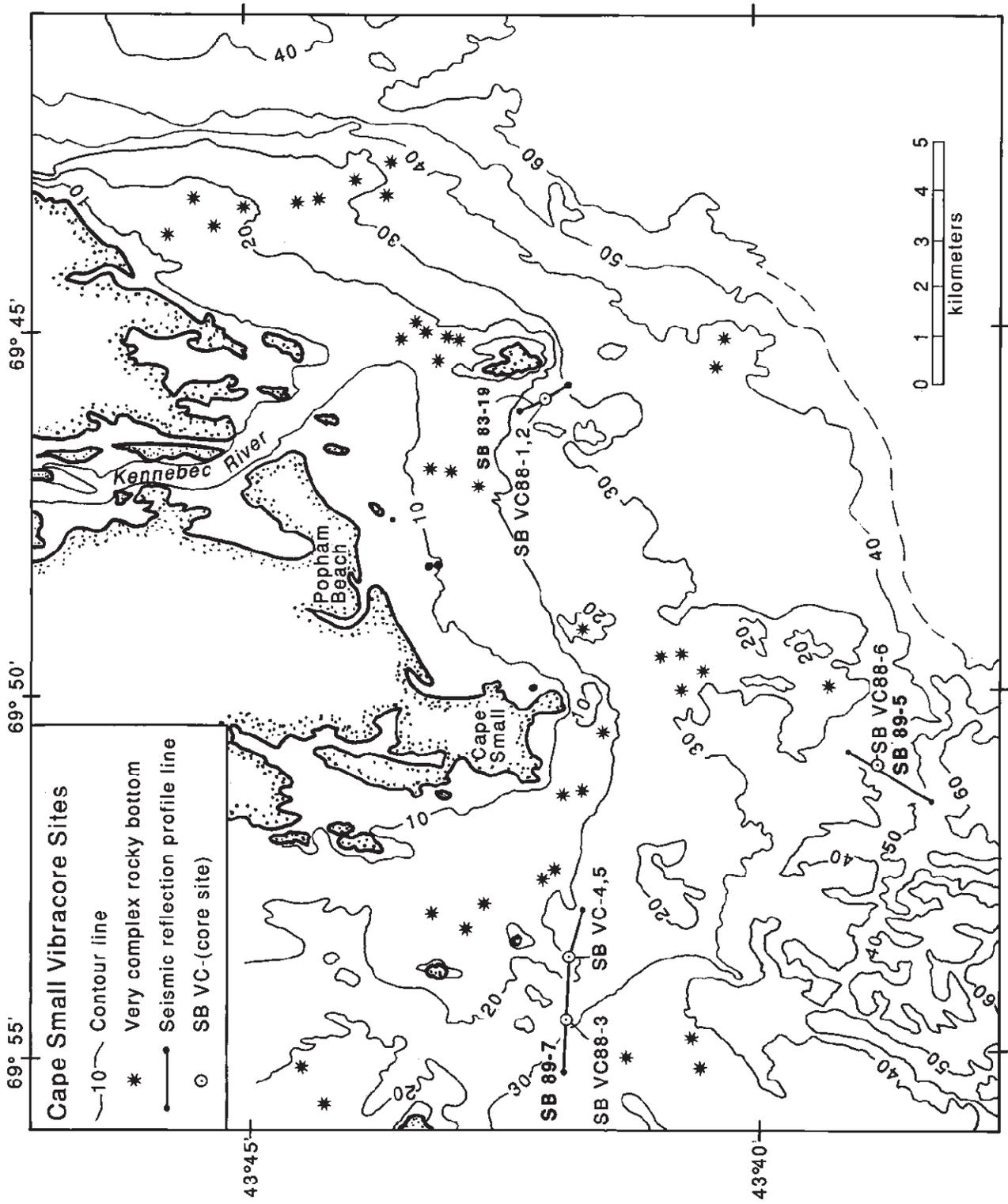


Figure 18. Location of seismic lines and vibracores in the Cape Small area. Bathymetry modified from National Ocean Service Provisional Chart No. 71, Bath, ME.

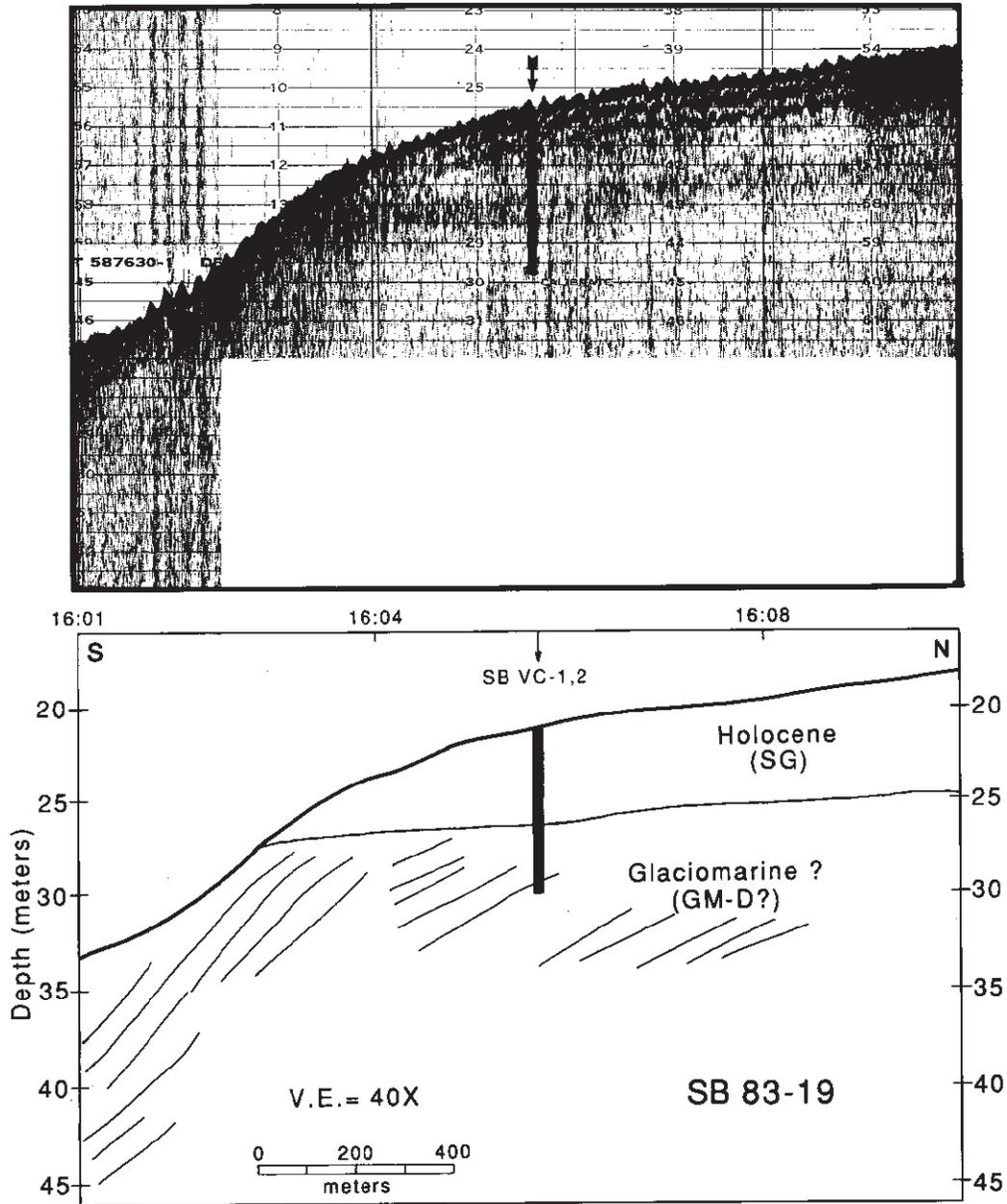


Figure 19. A 3.5 kHz seismic reflection profile SB83-19 over site of SBVC88-1 and 2.

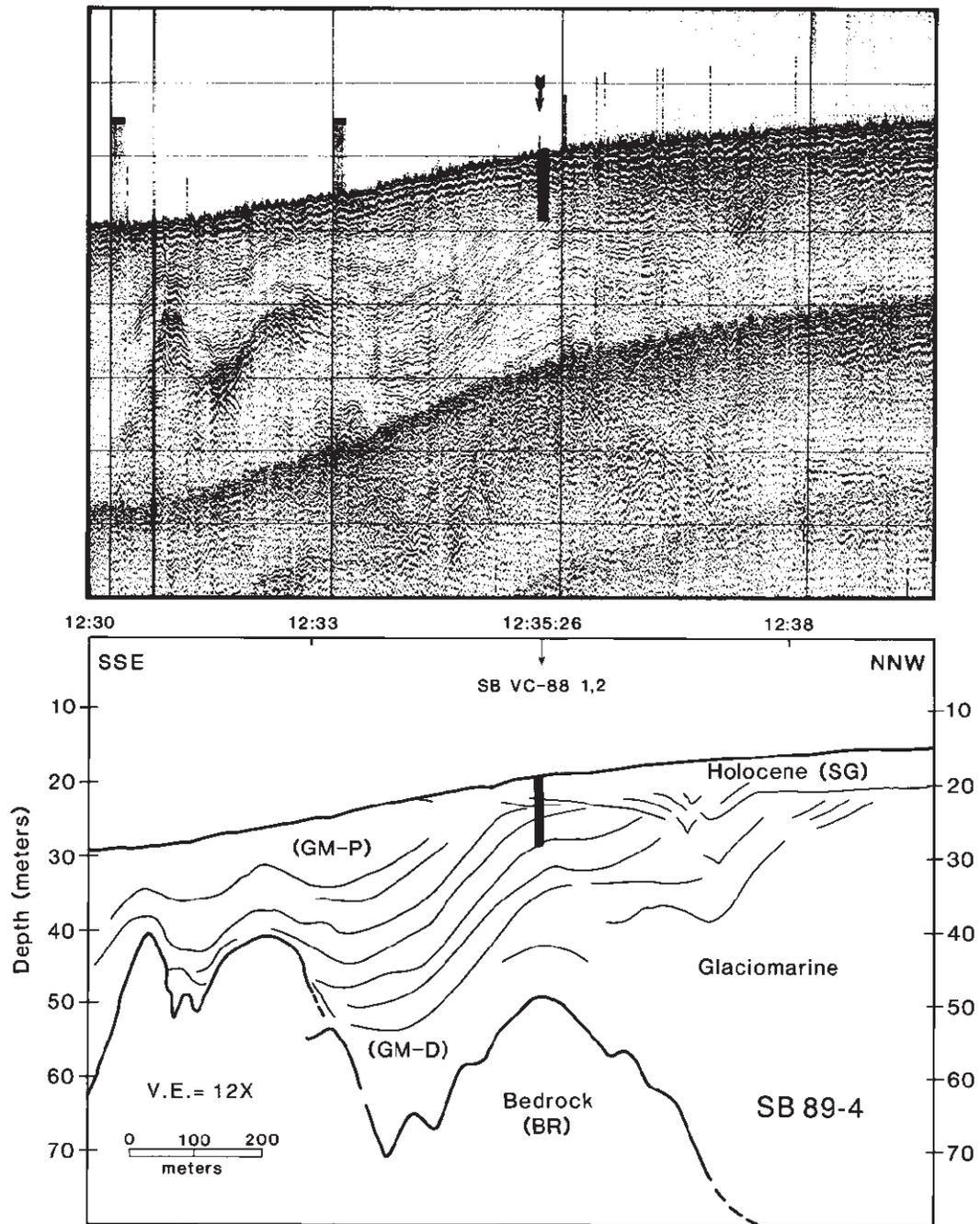


Figure 20. Geopulse seismic reflection profile SB89-4 over site of SBVC88-1 and 2.

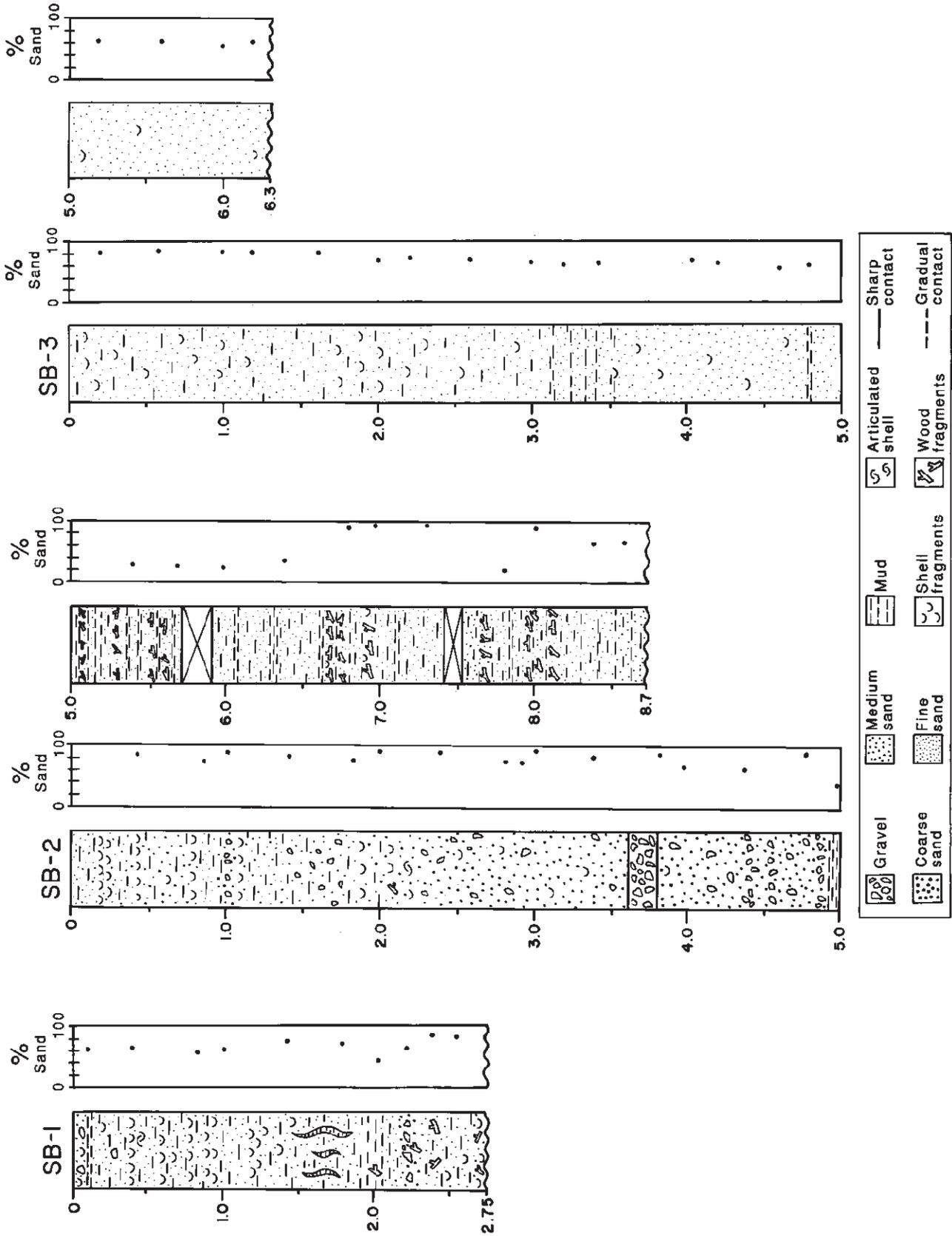


Figure 21. Log of vibracores from Cape Small.

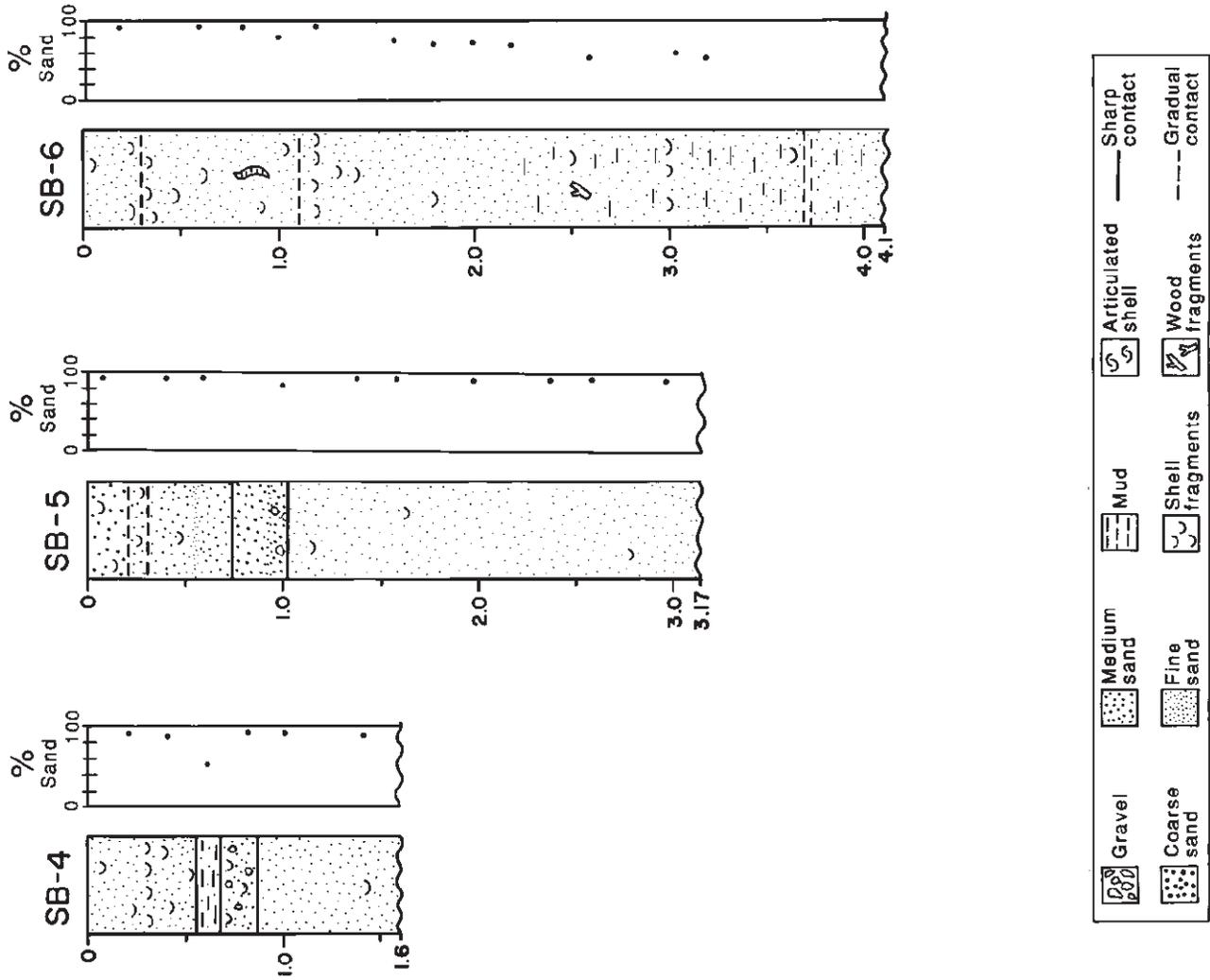


Figure 21. Log of vibracores from Cape Small.

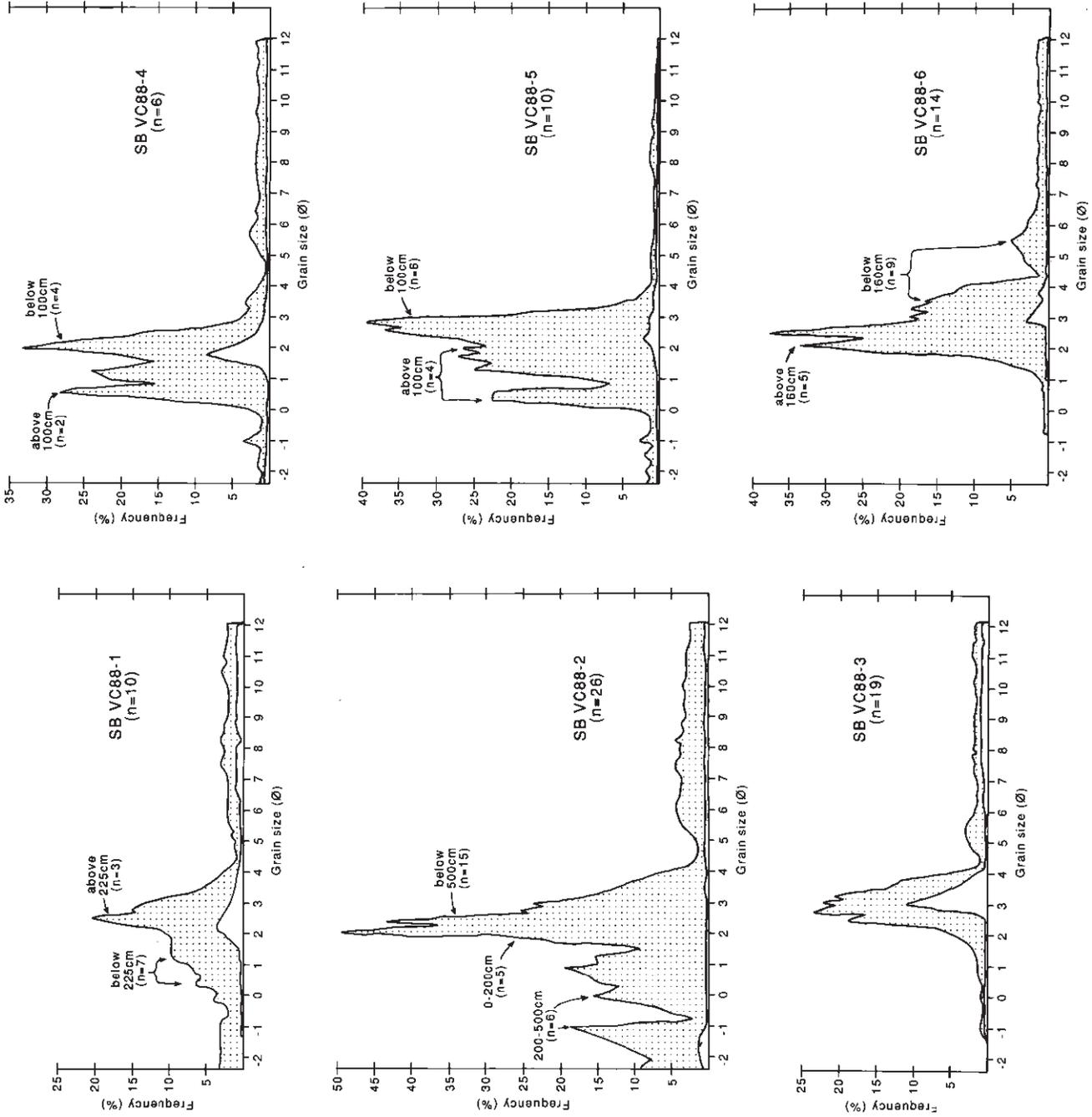


Figure 22. Histograms depicting the envelope of grain size distributions for the Cape Small cores. Modes from samples at different depths are indicated with arrows.

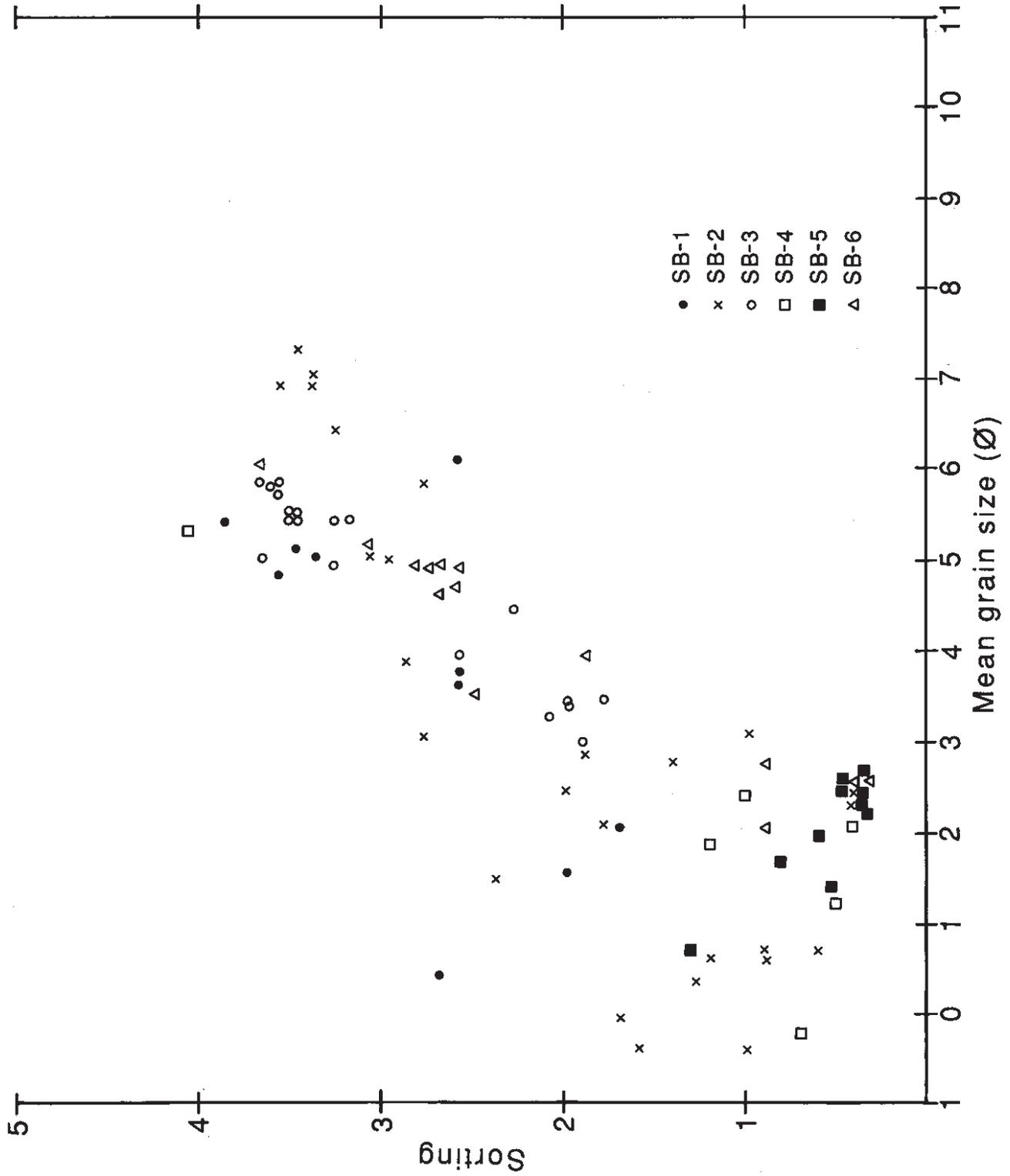


Figure 23. Mean grain size (in phi units) versus sorting for sediment samples from Cape Small vibracores.

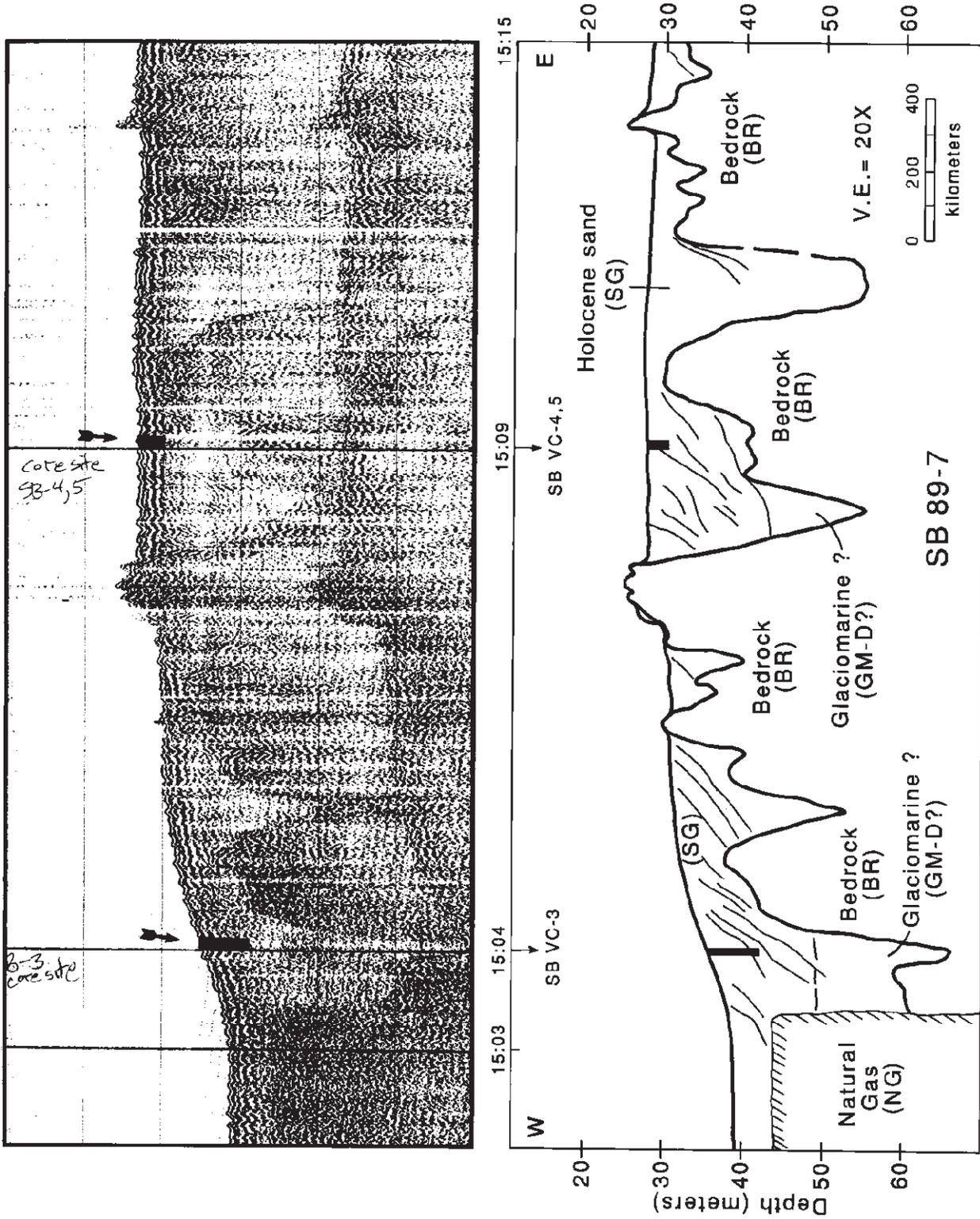


Figure 24. Geopulse seismic reflection profile SB89-7 over vibracores SBVC88-3, 4, and 5.

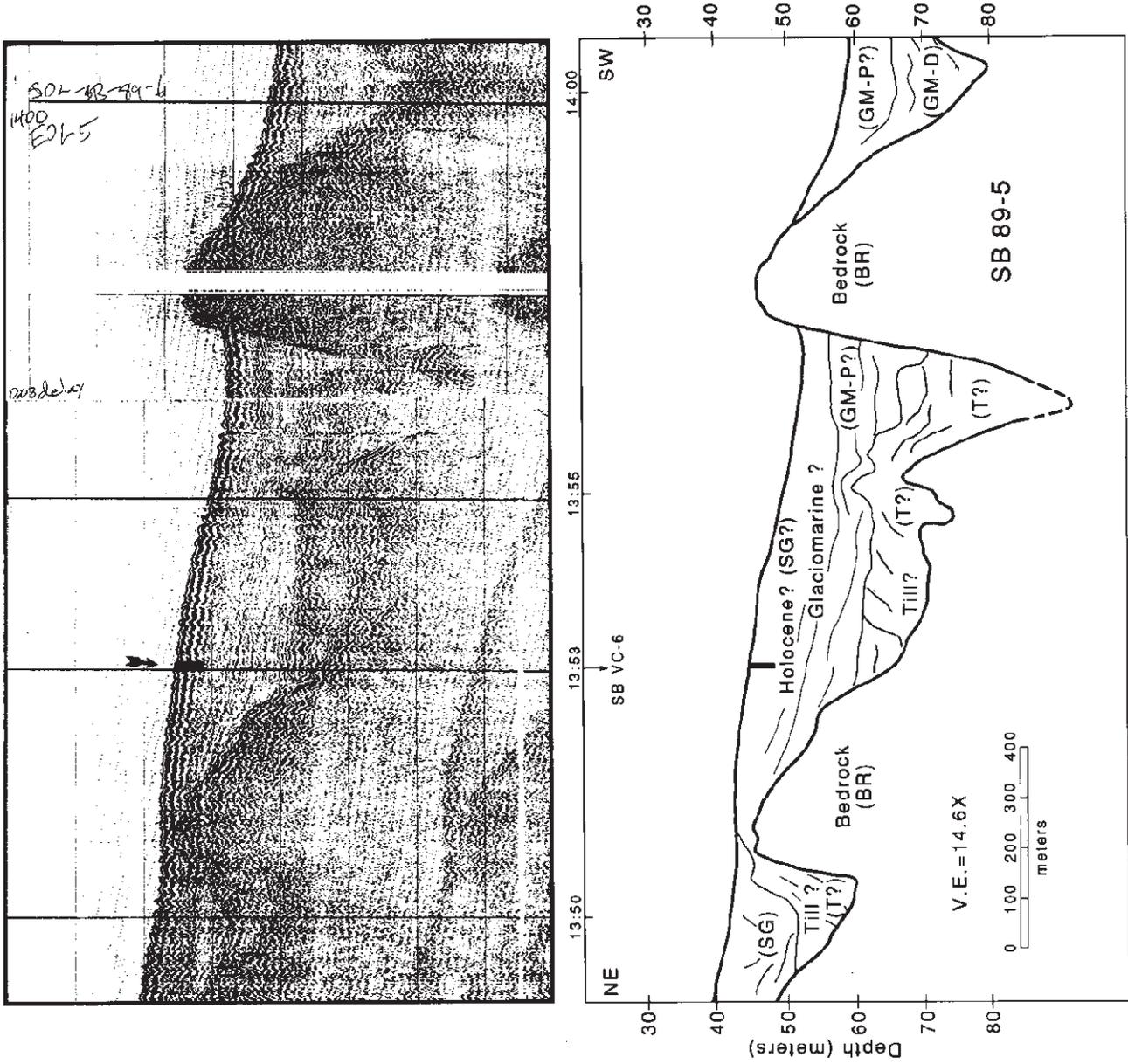


Figure 25. Geopulse seismic reflection profile SB89-5 over vibracores SBVC88-6.

MAINE COAST

LOCAL RELATIVE SEA LEVEL 14,000-0 B.P.

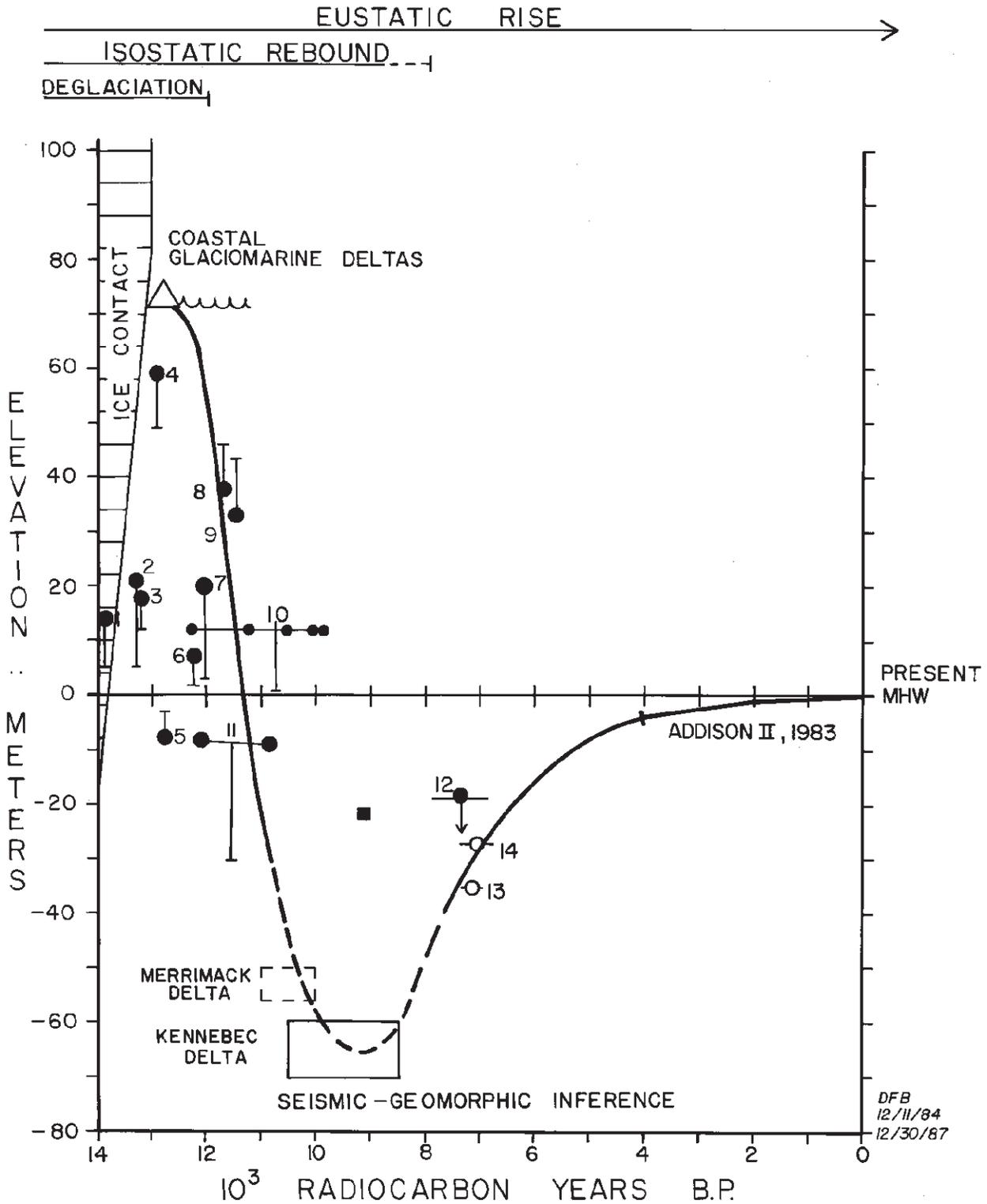


Figure 26. Sea-level change curve for coastal Maine. The illustration is from Belknap et al. (1989a, Figure 2), and modified by inclusion of one point at 9,100BP, 21 m depth (data for the additional point from R. Stuckenrath, University of Pittsburgh).