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Geomorphology and Sedimentary Framework of the Inner Continental Shelf of Downeast Maine

by

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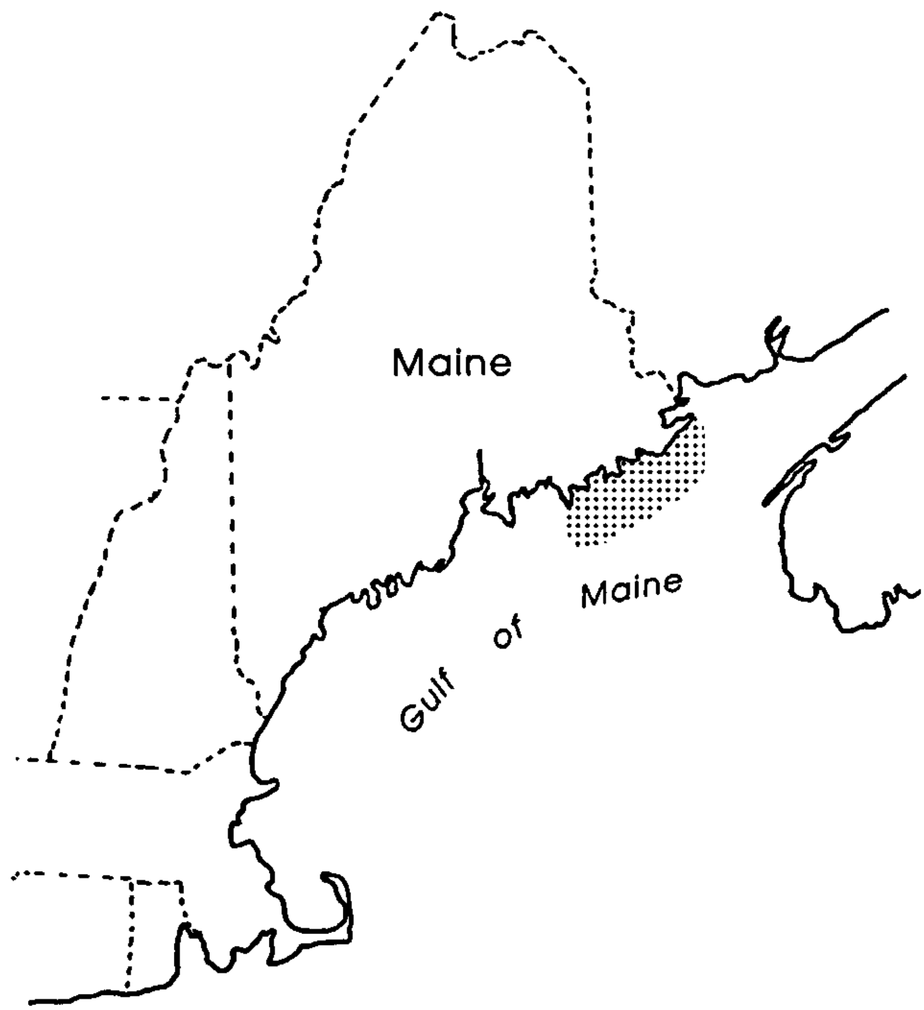

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INTRODUCTION

This report describes the submarine geomorphology, surficial sediments, and Quaternary stratigraphic framework of the western Gulf of Maine along the inner continental shelf from Gouldsboro Bay (68° W longitude) to the United States - Canadian border (Fig. 1). The research focuses on the offshore region of the Washington County coast to the 12-mile limit, the U.S. contiguous zone, an area we call the Downeast Maine inner continental shelf. In addition, five nearshore bays: Gouldsboro Bay, Narraguagus Bay, Machias Bay, Cobscook Bay and Oak Bay, are described in greater detail. Emphasis in this study is on sand and gravel sediments and physiographic characterization of the seafloor.

Along the coastline of the study area, bedrock ranges in age from Silurian to Devonian (440 to 360 million years ago; Osberg et al., 1985). Igneous intrusive rocks are dominant along the mainland from the western boundary of the study area to Chandler Bay in the middle of the study area. These rocks are predominantly granites, quartz diorites, syenites, monzodiorites and gabbros. From Chandler Bay east, mafic to felsic volcanic rocks of the Eastport and Quoddy Formations are of local importance inland of a cliffed coast of Silurian gabbros. From Gouldsboro Bay to Englishman Bay the coast is part of the Island-Bay Complex coastal compartment of Maine (Kelley et al., 1988). This area is characterized by embayments protected by islands. In many locations bedrock, exposed along the shoreline, exercises primary control on the shape of the coastline (Kelley, 1987). Similarly, the submarine bedrock strongly influences seafloor relief.

Surficial sediments on land are of both glacial and marine origin. Extensive sand and gravel deposits of glaciomarine deltas, fans, eskers, moraines, outwash, and till dominate the surficial geology of Washington County, landward of the study area (Thompson and Borns, 1985). Ashley and others (1991) estimated that sediment fans and deltas cover about 250 km^2 and have a volume of nearly 5 billion cubic meters.

The intertidal zone of numerous downeast bays is dominated by tidal flat deposits of mixed gravel, sand, and mud textures. Sediments of these muddy flats are derived from local erosion of glacial sediments (Kelley, 1987). Intertidal shoreline types also include extinsive salt marshes in the upper portions of embayments and estuaries (Kelley et al., 1988).

Sand and gravel pocket beaches are common along the coastline. These deposits typically consist of a single barrier ridge of sand and gravel several meters thick and several tens of meters wide and hundreds of meters long (Duffy et al., 1989). Barrier overstepping by sea level rise may have resulted in sand and gravel deposits of similar size submerged on the inner continental shelf. Boyd and others (1987) have developed a model of transgressive barrier sedimentation for the Nova Scotia shoreline that would also apply to this study area.

Like other continental shelf areas of New England and the Canadian Maritimes, the Downeast shelf has probably experienced numerous Quaternary glaciations, and relatively thin glaciogenic sediment only partly mantles submerged bedrock exposures (Needell et al., 1983; Piper et al., 1983; Syvitski, 1991). Unlike the outer regions of the Gulf of Maine, local relative sea level has most likely fluctuated profoundly in Downeast Maine due to isostatic crustal movements as well as eustatic sea-level changes related to growth and disintegration of the Laurentide ice sheet (Belknap et al., 1987; Kelley et al., 1992; Schnitker, 1974; Stuiver and Borns, 1975). Within the past 14,000 years, the study area has experienced a deglaciation, two marine transgressions and a regression. It is these changes in sea level, which have permitted a variety of terrestrial and marine processes to repeatedly erode, deposit, and rework sediments on the inner continental shelf. The regional stratigraphic framework, and most significantly the nature of the surficial sediments have been affected by these late- and post-glacial changes. The purpose of this paper is to describe the surficial sediments of the Downeast area in the context of a stratigraphic framework produced by Holocene sea-level fluctuations.

PREVIOUS WORK

Previous geological investigations in the downeast Maine coastal region have involved several disciplines. Quaternary glacial deposits on land and offshore have been studied and are most relevant to this study. Heavy mineralogy of the offshore and estuaries has been investigated for provenance and economic minerals. In addition, bedrock geology, geophysics, and tectonics research has identified a variety of underlying rock types and structures offshore and in the Gulf of Maine. The bedrock control of relief may have been important in determining sedimentary deoposition beneath the Laurentide ice sheet or subsequently in the deglaciation and post-glacial regression and transgression. Table 1 summarizes previous work in the downeast and nearby Gulf of Maine region.

Bloom's description (1960, 1963) of southwestern Maine's glaciomarine sediment, the Presumpscot Formation, matches the muddy, late Quaternary deposits of the downeast area very well. Thompson and Borns (1985) compiled regional surficial maps into a state surficial map that depicts the inland marine limit of glaciomarine clay. This clay extends offshore in many parts of the study area. The origin of this muddy deposit is from a marine-based ice shelf or sheet during early stages of deglaciation (Bacchus, 1993; Syvitski, 1991). Where ice grounded on topographically high bedrock or slightly readvanced, bouldery moraines and till tongues were deposited adjacent to and interfingering with glaciomarine mud. Consequently the spatial pattern of coarse-grained and fine-grained glaciomarine sediments is commonly variable over a scale of several meters both horizontally and vertically.

On the basis of data collected for previous reports in this series (Barnhardt and Kelley, 1991; Kelley and Belknap, 1988; Kelley et al., 1987a,b; Kelley et al., 1990) and other research (Table 1), a relative sea level lowstand occurred on the Maine inner continental shelf about 10,500 years before present (Kelley et al.,1992). In some locations at that time, coastal processes created shoreline deposits close to the 60 meter isobath (Shipp et al., 1991). Sand and gravel deposits are expected to be part of this paleoshoreline complex.

METHODS

Sediment Samples

During the summer of 1991, 42 bottom samples were collected from the downeast region by means of a Smith-MacIntyre grab sampler which gathered 0.25 cubic meters of sediment with minimal loss of surficial material. Triplicate samples were taken from each grab sample and had wet weights of two to five kilograms. Sample stations were located by LORAN-C navigation and based on previous survey data. Depths were recorded on a paper-recording Raytheon fathometer.

After collection and field description, samples were chilled and stored in a cooler and taken to the sedimentology laboratory at the University of Maine. In the laboratory, samples were split and an archive sample separated from further analysis (Fig. 2). Grain size analysis began by sieving and weighing the gravel portion (> 2 mm). The sediment passing the screen had organics removed with a NaOCl solution. The remaining inorganic sediment was wet sieved at 63 microns to separate silt and clay from sand. The sand subsample was weighed and then passed through a rapid sediment analyzer (large settling tube) to determine the sand size distribution. Clay and silt fractions were dispersed with $Na(PO_4)_6$ and analyzed in a Micrometrics Sedigraph to determine the weight percent of silt and clay. Samples were described based on dry weight percentages of gravel, sand, and mud (silt and clay) following Folk (1974). Figure 3 illustrates the classification scheme used to describe sediments in this report.

Mapping of surficial sediments used grain size data from samples collected, composition data shown on nautical charts, bathymetric trends from fathometer recordings, National Ocean Service 1:100,000 scale metric bathymetric maps, seismic reflection profiles, and side-scan sonar images. General inferences were made across large areas of seafloor and are likely to underepresent the detailed sediment variations on scales of less than a kilometer. A much more detailed sampling and survey would be needed to create a more detailed seafloor sediment map.

Seismic Reflection Profiles

Seismic reflection profiles were collected within the study area in 1990 and 1992 on the R/V ARGO Maine (Plate 1). Shipboard navigation used LORAN-C and position fixes were made every 4-5 minutes along profile tracklines. An ORE Geopulse "boomer" system emitted a frequency band from 550 to 2,000 Hz. Seismic reflection profiles were analyzed to deduce subsurface geology and surficial material. In addition, seismic lines were used for surficial geomorphology.

Interpretation of the surface echocharacter and subsurface geology was based on previous investigations of Maine's innercontinental shelf (Kelley et al., 1987a,b, 1988; Barnhardt and Kelley, 1991) and published work (Belknap and Shipp, 1991; Belknap et al., 1989). Crystalline Paleozoic bedrock was not penetrated by the acoustic signal of the boomer system and its surface usually produced a high amplitude reflector when present. Distinguishing bedrock from glacial till in seismic reflection profiles can be difficult and lead to some uncertainty in data interpretation. The presence of a seismic unit with chaotic internal reflectors and an irregular surface was interpreted as till. The glaciomarine Presumpscot Formation (Bloom, 1960, 1963) is acoustically stratified or transparent and may drape deeper relief or lie horizontally within depressions. Natural gas within the sediment column produces an "acoustic wipe-out" and results in an artificial absence of reflectors below the top surface of the gas.

Side-scan Sonograms

Acoustic mapping of the seabed was made with an EG&G Model 260 Seafloor Mapping System. A 105 kHz signal, emitted from two transducers on a deep-towed instrument, was used to map a 200 to 600 meter swath along tracklines. The system provided slant-range corrections and an analog output. Simultaneous side-scan sonograms and seismic reflection profiles were collected in 1990 on the R/V ARGO Maine.

Previous side-scan surveys of Maine's inner continental shelf have examined the acoustic return of the seabed and sediment grain size from bottom samples (Barnhardt and Kelley, 1991; Kelley et al., 1987a,b, 1988). In general, fine-grained sediments (silt and clay) return less acoustic energy and result in lighter gray images. Coarser sediments (sand and gravel) are more reflective and produce a darker acoustic recording than fine-grained sediments. Water depth below the instrument also affects the darkness of images. Sonograms collected for this study were interpreted based on grab samples, previous studies, and bathymetry.

RESULTS

Inner Continental Shelf Bathymetry

Bathymetric maps from the National Ocean Service provided detailed contours at 2 and 10 meter intervals. These contours from the Machias and Petit Manan 1:100,000 scale maps were digitized and compiled in a geographic information system for use in interpreting the geophysical and sedimentological data. Plate 2 shows a selection of 20 meter contour intervals between 68° and 67° W longitude. Some of the data furthest offshore was too under-sampled to provide meaningful contours and hence was not digitized.

Rocky nearshore and offshore areas are immediately evident from the contours on Plate 2. Even greater detail in inshore areas such as Narraguagus Bay was used in the interpretation of data collected for this study. Along the Downeast coast east of Machias Bay there is a steep slope near the coastline. This feature is called the Murr Escarpment and it is evident in the bathymetric map. This trend could parallel the Fundy Fault which bounds the Paleozoic rocks on land with the deeper offshore strata of the Mesozoic rift basin (Ballard and Uchupi, 1975; Hutchinson et al., 1988). The extent of Triassic sedimentary rocks (Ballard and Uchupi, 1975; Tagg and Uchupi, 1966) is nearly the same as the extent of relatively flat seabed in the Murr Basin. Areas with relatively few contours such as the outer Narraguagus Bay and Murr Basin may have much of the bedrock relief buried by sediments or overlie relatively flat bedrock strata.

Inner Continental Shelf Sediments

Bottom sediment texture on glaciated shelves is notoriously heterogeneous (Trumbull, 1972). All components of the particle size spectrum were encountered in bottom samples from the Downeast inner shelf and coastal bays. Although no "pure gravels" were recovered, numerous sandy gravels were found. Tables 2 and 3 detail the locations and textural composition of sediments in this study.

Most of the gravel and sand located is east of Western Bay in the Murr Basin (Fig.4). The average composition of samples 10 through 35 from the Murr Basin is 31% gravel, 49% sand and 17% silt and 3% clay. Muddier sediments were common in the outer portion of Narraguagus Bay. Two grab samples (3 and 42) were composed of a few cobbles but no grain size measurements were made of these clasts. Coarse deposits may make up small patches of the seafloor along the margins of Shelf Valleys and Nearshore Basins where sediments are reworked by waves from shallower areas of the Rocky Zone (discussed below).

Compilation of sediment data from other sources and this study allowed the construction of a generalized map of surficial sediments (Plate 3). The surficial geology of the inner continental shelf of Downeast Maine is hetereogeneous but regionally predictable. As in other parts of the Maine inner shelf, there are extensive muddy areas in water depths in excess of 40 to 50 meters. Muddy sediments are also found inshore in protected embayments. Coarse-grained sediments are found in coastal embayments exposed to wave action and near locally eroding sandy and gravelly glacial deposits.

The coarse-grained gravelly sand and sandy gravel of the Murr Basin is unique to the Maine inner shelf. No other offshore region studied to the south and west of the Downeast area has such an extensive deposit of sand and gravel. The next largest surficial deposit of sand and gravel on the Maine inner continental shelf is the Kennebec paleodelta (Belknap et al., 1989; Kelley et al., 1987b). This Murr basin plain is at least 5 and 10 times area of the coarse-grained surface area of the Kennebec paleodelta in the South Central Maine inner continental shelf.

Geophysical Observations Within Inshore Embayments

The study area extends from the eastern portion of the Island-Bay Coastal Compartment (Gouldsboro Bay to Machias Bay) to the end of the Cliffed Shoreline Coastal Compartment (Figs. 1, 5; Kelley, 1987; Kelley et al., 1988). Although a long stretch of the Cliffed Shoreline lacks bays, more than a dozen embayments punctuate the coast of the study area. Cobscook Bay and Oak Bay lie along the United States border with Canada and numerous smaller bays exist southwest of Machias Bay. It was beyond the scope of this project to examine all the bays in detail, but several representative bays have been investigated at a reconaissance level and provide a glimpse of the diversity present in this relatively remote stretch of the Maine shoreline.

Gouldsboro Bay. Gouldsboro Bay is a composite indentation in the coastline, comprised of a large, north-south elongated bay, Gouldsboro Bay/Joy Bay, and a smaller parallel bay, Grand Marsh Bay/West Bay, to the west (Fig. 6). Several small streams enter the Gouldsboro embayment, although none with a discharge large enough to be gauges ($<1 m^3/s$). Depth in Central Gouldsboro Bay increases regularly from Joy Bay towards the sea, with a maximum depth of 31 meters (Fig. 7). Both Joy Bay and Grand Marsh/West Bays are generally shallower than 6 m, with extensive intertidal regions. The outer bay mouth is sheltered from the sea by islands (the Sally Islands), a characteristic feature of the Island-Bay Coastal Compartment (Kelley, 1987; Kelley et al., 1988).

Seismic records reveal an irregular bedrock (br) basement with a central axis parallel to the orientation of the bay (Figs. 8, 9). Bedrock crops out commonly along the shoreline and in nearshore waters, as well as in shallows near the Sally Islands (Fig. 9). Rock is generally absent from the smaller peripheral bays which, because of their protection from waves, have a thicker cover of modern sediment (Shipp et al., 1985, 1987).

Till (t) is uncommon in the outer bay, but becomes increasingly abundant in upper Gouldsboro Bay, near Joy Bay. The peninsula bordering Gouldsboro and Joy Bays is a prominent moraine, with a significant offshore trend (Fig. 10). More than 10 meters of relief exists in the morainal topography in the submerged sections which have had their upper portions removed by erosion (Figures 8, 10).

Glaciomarine sediment (gm) unconformably overlies bedrock or till throughout the embayment (Figs. 8, 10). This material is up to 20 meters thick where it infills bedrock depressions near the Sally Islands and in Joy Bay (Figs. 8, 10). In all locations in the embayment the surface of the glaciomarine sediment is marked by a strong seismic reflector interpreted as an erosional unconformity. In several locations in Gouldsboro Bay cores penetrated through modern mud to the glaciomarine material (Figs. 11, 12; Shipp, 1989).

Modern mud unconformably overlies Pleistocene sediment throughout the bay. Visual interpretation of 364 bottom samples indicated that sandy or gravelly sediment was restricted to 1) local areas near bedrock outcrops; 2) intertidal beaches and coarse-grained flats derived from eroding bluffs of till; and 3) in the bay mouth region near the Sally Islands (Fig. 13; Shipp et al., 1985, 1987). In the latter area, carbonate shell hash makes up most of the coarse-grained sediment.

A sediment isopach map indicates several basins with 25 meters or more sediment (Fig. 9). Basins in West Bay and at the confluence of West and Gouldsboro Bays contain largely glaciomarine mud of no value as aggregate. Only at the bay mouth, in the lee of the Sally Islands is there a thick deposit of modern sediment which is sandy, at least at the surface. This is probably carbonate sediment, however, derived from encrusting organisms (barnacles, mussels, sea urchins) on the rocky outer islands.

Narraguagus Bay. Narraguagus Bay is a broad embayment, cluttered with islands near the shoreline (Fig. 5; Plate 2). The many islands are only the surface manifestation of an equally complex seafloor with extensive rocky shoals projecting seaward from each peninsula. Depths are generally less than 30 meters over the rocky shoals, which are more complex than can be depicted. Bedrock valleys extend seaward from each of the estuaries, and within the major valley the bathymetry slopes gently seaward from less than 10 meters to greater than 70 meters depth (Fig. 14). An abrupt change in depth between 30 meters and 40 meters near Great Wass Island marks the trend of the Fundy Fault, separating Mesozoic and Paleozoic rocks (Osberg et al., 1985).

Rocky shoals were avioded in this reconaissance study of the coast; bedrock under the major shelf valleys was channel-shaped with more than 40 meters of local relief (Figs. 15, 16, 17). Till was not observed in the area, although prominent moraines mark the surface of the upper Petit Manan peninsula (Thompson and Borns, 1985). Glaciomarine sediment was recognized over bedrock and cropping out at the seafloor in many locations (Figs. 15, 16, 18, 19). In some locations the glaciomarine material chokes the bedrock valley (Fig. 16), while in other places (Fig. 17) it is a minor component of the stratigraphic section.

Apparently unconformably overlying the glaciomarine sediment is a strongly reflecting seismic unit interpreted as a sandy delta (d) (Figs. 15, 17, 18). The clinoform reflectors are suggestive of delta foresets, with sandy material derived from the extensive deltas on the nearby mainland (Thompson and Borns, 1985). A related seismic facies, interpreted as "estuarine" (e), fills small channels adjacent to the delta and occupies a similar stratigraphic setting as the deltaic material (Figs. 15, 16). This appears to have been a deposit which accumulated on the margin of the more extensive deltaic sediments.

The smooth, seaward dipping seafloor is apparently covered with sand and gravel reworked from the deltaic and estuarine deposits during the Holocene transgression (Figs. 15, 16, 17, 18). Side-scan sonar images reveal the surface sediment as rippled, coarse-grained sediment, although the seismic bubble pulse obscures the contact between the truncated deltaic and estuarine reflectors and the surficial sediment.

In the outer Narraguagus Shelf Valley (described below), the seafloor is mantled with muddy material, apparently the fine-grained equivalent of the estuarine and deltaic sands (Fig. 19). Natural gas is common here, and wipes out the acoustic signal from most of the area.

Machias Bay. Machias Bay is the last major coastal embayment along the Maine coast until the Canadian border (Fig. 5). The upper bay is defined by the channels of the Machias and East Machias Rivers which converge before entering the upper part of the bay (Fig. 20). Their combined channels average deeper than 6 meters and remain a distinct trough in the upper bay (Fig. 21). Much of the upper bay is a shallow intertidal or subtidal flat broken up by several islands. Extending due south from Holmes Bay is a broad depression sloping gently seaward until about Sprague Neck. South of Sprague Neck the depression becomes a very broad plain in a region lacking islands. Just north of the islands at the bay mouth (Cross Island, Stone Island; Fig. 21) the plain ends and the seafloor abruptly plunges from 18 to 48 meters into the offshore region.

Bedrock (br) topography is somewhat irregular and forms a prominent channel which parallels the bathymetric depression down the axis of the center of the bay (Figs. 21, 22). The relief of this bedrock valley is around 30 meters where it can be measured in the upper bay (Fig. 22e), but exceeds 60 meters in the outer bay (Fig. 22h). The bedrock surface is mostly covered by Quaternary sediment, but rims the numerous islands of the central and outer bay, and generally becomes more exposed in the outer bay (Fig. 23).

Probably nowhere in Maine is till more prominent than in Machias Bay. Sprague Neck is one of the largest moraines in the region (Thompson and Borns, 1985), with till too thick (at least 50 meters) to be penetrated by seismic methods in its vicinity (Figs. 22c; 24). Smaller deposits occur around the bay, and till outcrops are common in coastal bluffs (Thompson and Borns, 1985).

All three facies of the glaciomarine sediment, gm-m, gm-d, and gm-p, are widespread in Machias Bay. The lower seismic facies, gm-m, often contains hyperbolic returns interpreted as dropstones (Figs. 25a, b). This seismic facies does not crop out at the surface and is most abundant south of Sprague Neck. Seismic facies gm-d is probably more abundant than gm-m, and reaches thicknesses of 20 to 30 meters both north and south of Sprague Neck (Figs. 24, 26). The ponded seismic facies, gm-p, is most prevalent in the in the deeper water south of Sprague Neck, with a thickness greater than 20 meters.

Although no bottom samples exist from the bay, on the basis of seismic reflection observations, modern sediment is inferred to cover all portions of the seabed except near bedrock outcrops (Fig. 23). On the basis of the weak surface return on the seismic profiles, most of the surface sediment in the upper bay is inferred to be mud. South of Sprague Neck, however, the surface material appears to be coarser grained. The relatively thin modern sediment here appears to be reworked glaciomarine sediment, and one study in the area reported sand at the surface (Lehmann, 1991). In the bay mouth area, between the Libby Islands, a large accumulation of sand and gravel is inferred from the seismic observations (Fig. 27). In a bathymetric depression it appears that a coarse-grained spit built out during a lower stand of sea level (Shipp, 1989).

There are several major sediment basins in Machias Bay, mostly following the north-south trend of the bedrock channel (Fig. 23). The deepest is greater than 60 m, and extends for several kilometers south of Sprague Neck. Much of the surficial material here is coarse-grained sediment, but without cores it is impossible to speculate on material at depth. There are basins with more than 25 meters of sediment in the upper bay, but surficial material here is muddy. Most of all the sediment in the bay is till or glaciomarine sediment with the exception of the possible spit near Libby Island. This deposit of sediment is greater than 30 meters thick, and could be all coarse-grained sediment.

Cobscook Bay. Cobscook Bay is an extremely complex embayment along the Canadian border (Figs. 5, 28). Folded bedrock controls the orientation of the many peninsulas which shape the bay (Osberg et al., 1985), and a tidal range of about 6 meters strongly influences the distribution of modern sediment. Channels deeper than 6 meters are common in the inner bays, and passages between peninsulas and islands are up to 18 meters deep (Fig. 29). The larger bays (South Bay, Johnson bay, East Bay) are flat bottomed with depths generally less than 10 meters. In the outer reaches of the bay depths exceed 25 meters near channels, and locally reach to greater than 70 meters between Deer Island and Eastport.

Bedrock crops out almost continuously along the shoreline, and is covered by a thin deposit of sediment along channel margins (Figs. 30, 31). Bedrock could not be traced in the central axes of most bays with the 3.5 kHz seismic system.

Till is not an important component of the sedimentary sequence in Cobscook Bay, and was usually recognized as a thin sediment pond in bedrock depressions (Fig. 32). Glaciomarine sediment varies in its acoustic properties from transparent and featureless (Figs. 31, 32), to a seismic unit with coherent and strong reflectors (Fig. 31). A strong acoustic reflector on the surface of the glaciomarine sediment is often present, and inferred to be the transgressive unconformity (Figs. 31, 32).

Modern sediment varies greatly in thickness in a manner apparently determined by tidal currents. Relatively thick deposits of mud occur in the protected reaches of inner embayments (Fig. 32). Slump scars near channel thalwegs suggest that this material is only marginally stable and is susceptible to reworking by tides (Figs. 30, 32. Where tidal currents are strong, as in the outer bay, little or no modern sediment is accumulating and Pleistocene sediment is at or near the seafloor.

Oak Bay. Oak Bay occupies a linear fault zone along the United States and Canadian border (Fig. 5). The bay has two riverless embayments at its head as well as the estuary of the St. Croix River (Fig. 33). Extensive areas of tidal flat occupy the upper bays, and a 6 meters deep channel marks the thalweg of the St. Croix River (Fig. 34). Water depths increase greatly a short distance from the land and reach maximum depths of 28 meters in seveal places in the bay.

Bedrock relief is great within Oak Bay, and several islands and many rocky outcrops occur. Relief exceeded the penetration of the 3.5 kHz seismic profiler (50 m) in many locations (Figs. 35, 36, 37). Till was rarely observed within the bay, although it crops out on some islands and along the shoreline. We infer that glaciomarine sediment fills most of the bay, although sesimic penetration and resolution preclude confidence in the absence of cores. The strong seismic surface return suggests a coarse-graoned bottom, and possibly a thin modern surficial sediment deposit, or a lag deposit developed on the glaciomarine sediment. No natural gas pockmarks were observed in Oak Bay, as they have been in nearby Passamaquoddy Bay (Fader, 1991), although slump deposits occur (Fig. 35).

Physiography of the Downeast Inner Continental Shelf

Maine's inner continental shelf may be characterized based on the relief of the seafloor and its sediment types (Kelley et al., 1989). This physiographic description results in a classification scheme of five provinces: Nearshore Basins, Nearshore Ramps, Shelf Valleys, Rocky Zones and Outer Basins. Each of these areas has been mapped for this report and are shown in Plate 4. This section describes the characteristics of each zone and hightlights their notable aspects on the Downeast inner continental shelf.

Nearshore Basins. Nearshore Basins are generally shallow, low relief regions adjacent to the mainland and separated from other phsiographic areas by islands and/or shoals. The contact between nearshore basins and the mainland is gradational. Mudflats are the most common intertidal environments bordering these basins. In most nearshore basins in Maine, the seafloor is smooth except near bedrock outcrops (Barnhardt and Kelley, 1991; Kelley and Belknap, 1991; Kelley et al., 1987a,b, 1988). Large nearshore basins were not common in the study area. The largest one identified is in the upper reaches of Western Bay (Plate 4).

Nearshore Ramps. Nearshore Ramps are smooth sedimentary slopes in water depths of 10 to 40 meters. These areas are commonly reworked by waves and are coarse-grained. Sand and gravel sediments of nearshore ramps are often have 1 to 3 meter wavelength wave-oscillation ripples that are clearly visible in side-scan sonar images. The active sediment reworking results in a relatively mud-free seafloor. Fine-grained sediments are either exported to outer or nearshore basins by tidal currents.

In the study area, Nearshore Ramps are not common and only found in the head of Narraguagus Bay. Gravel commonly flanks the Rocky Zone in the transition to the gravelly sand of the Nearshore Ramp. A gravelly sand sheet in Narraguagus Bay has wave-oscillation ripples (Figs. 15, 16, 17, 38). The bedrock outcrops of the Rocky Zone delimit sharp boundaries with the sediments of the Nearshore Ramp.

Shelf Valleys. Shelf Valleys are long, narrow depressions which usually extend from the Nearshore Basins to gradual terminations in deep water. Shelf Valleys typically range in depth from 25 to 55 meters, although they may be deeper. These valleys are usually bordered by bedrock walls and may have rock outcrops along their axes when not fully infilled with sediments.

Because of the Murr escarpment and, presumably the underlying presence of the Fundy Fault and flat-lying Mesozoic sedimentary rocks, Shelf Valleys are rare east of Western Bay (67° 40' W longitude; Plate 3). The major Shelf Valley of the study area is south of the Narraguagus and Pleasant Bays. This valley has a pronounced submarine channel even south of 44° 20' N latitude (Fig. 19). The valley has more than 20 meters of relief, and is frequently underlain by natural gas-charged sediments. Thick sediments appear in the valley where they are not obscured by the presence of gas (Fig. 19).

Rocky Zones. Rocky Zones typically exhibit the greatest relief of any physiographic province. These areas may have steep or vertical cliffs tens of meters high. Conversely, Rocky Zones may be more gently sloped but have an extensive flat-lying bouldery seafloor. Rocky zones can be found in all water depths where sediments have not buried the local relief. Depending on the local wave and current energy there may be mud, sand, or gravel sediments infilling local depressions in the bedrock.

Rocky zones are common in the inner continental shelf of the study area. Typically the rocky areas are barren or covered by patches of sand and gravel. The relief in this physiographic province can be 50 meters or more. Portions of the Rocky Zone in water depths of 50 meters or more generally include small mud basins rather than sand and gravel patches.

Outer Basins. Outer Basins generally form the seaward border of the inner continental shelf. These basins are usually deeper than 40 meters and may be as deep as 300 meters in the outer Gulf of Maine. The thickness of sediment infilling these basins, and hence their relief, is variable. Commonly, however, outer basins have low slopes and few rock outcrops. Sediment-starved areas may have the physiographic expression of a deep basin yet have a relatively irregular basin floor.

Geophysical work on the outer basins offshore of Gouldsboro Bay has been summarized by Shipp (1989) and in the deeper Gulf of Maine by Bacchus (1993). Typically a thin Holocene mud (m) conformably oververlies glaciomarine mud (gm-p and gm-d) in most deep basins (Fig. 10b). Glacial till (t) and bedrock (br) commonly underlie the glaciomarine sediments in outer basins. Offshore outer basins have thin sediment cover and appear to be sediment-starved.

The most unusual feature found in this region of Maine's inner continental shelf is the flat-lying Murr Basin (Plate 2; Figs. 39, 40) which has been classified as an outer basin (Plate 4). This extensive area covers more than 500 square kilometers and has a relatively limited depth range from 70 to 90 meters. As metioned in the section above on sediments of the inner shelf, the average composition of this seafloor is 31% gravel, 49% sand and 20% mud. Some samples have as much as 70% gravel. This is quite uncharacteristic of Outer Basins in general on Maine's inner shelf. Most commonly, the Outer Basin is muddy with sediments containing little sand or gravel. This is represented in the outer portion of

Narraguagus Bay where samples were 55% to 85% mud (Fig. 4; Tables 2 and 3).

DISCUSSION AND CONCLUSIONS

The Quaternary sediments of the Downeast inner continental shelf of Maine are generally similar to the adjacent inner shelf regions to the southwest with one striking difference. The physiograhy and sediments of the Murr Basin are unique to the Maine inner continental shelf. The basin is relatively flat and expansive (Plate 2). Relief in the basin is locally 10 to 20 meters in the 70 to 90 meter water depth range. Most of the large-scale relief may be due to broad relief in till or buired Mesozoic rift basin sediments. Local relief appears to be due to ridges that are most likely moraines (Figs. 39, 40; Shipp, 1989). In a coast-parallel direction the basin is approximately 60 kilometers long. The basin extends offshore of the Cliffed Coast 10 to 20 kilometers, in places beyond the international boundary. Sediments of this basin plain are muddy, sand gravels and gravelly, muddy sands (Plate 3). Gravel can compose 50% to 70% of the surficial sediments and the combined sand and gravel content can be 80% or more (Fig. 4; Tables 2, 3; Plate 1). The thickness of the sandy gravel plain is unknown since no cores were taken in this study and seismic reflection profiles show little subsurface structure (Fig. 40). Consequently, the total volume of sand and gravel for this are is unknown but potentially very large.

In other areas of the Downeast inner continental shelf there are sand and gravel deposits in physiographic and stratigraphic settings similar to the rest of the Maine shelf. In the northwestern part of Narraguaus Bay there is a Nearshore Ramp physiographic setting that is very similar to the Nearshore Ramps at the Kennebec River mouth (Kelley et al., 1987b) and in Saco Bay (Kelley et al., 1987a) to the southwest. In the 10 to 30 meter depth range sediments are sandy gravels and gravelly sands (Fig. 38). As the nearshore slopes up into shallower water adjacent to the Rocky Zone or down into the Outer Basin the sediments become gradually muddier. One exception to this pattern is that, adjacent to the Rocky Zone in areas with a high wave exposure, there are patches of gravel in shallow water. Unlike the Nearshore Ramps in southwestern and south-central Maine, there is no barrier beach system associated with this Nearshore Ramp. It is possible that the surficial sand and gravel sheet is relatively thin, as in the 10 to 30 meter depth range seaward of the southern beaches. A near-surface acoustic reflector could be masked in the seismic reflection profiles by the bubble pulse and thus hide a lithologic contact in the stratigraphic section (Figs. 16, 17). However, inclined reflectors resembling deltaic foresets, suggest that a buried paleodelta of the Narraguagus River may be 20 to 30 meters thick (Figs. 17, 18). It is possible that the sand and gravel of the Nearshore Ramp extend down to considerable depths in some locations as part of a deltaic lithosome.

Another setting for sand and gravel is in submerged shoreline deposits formed during the relative sea-level lowstand approximately 10,500 years ago. The presence of sediment wedges in seismic records in the 45 to 65 meter depth range is similar to other areas of the Maine inner continental shelf (Shipp et al., 1991). The full geographic extent of these potentially sandy areas are not well known from the reconaissance-level survey performed for this report. As in the present coastal setting, there are only some geographic settings in which sand and gravel beaches form (Duffy et al., 1989). While localized, these paleoshoreline deposits could be 10 to 20 meters thick (Fig. 27) and have compositions similar to pocket beaches along the Maine coast.

The final type of deposit of sand and gravel is one that is primarily biogenic. As found in the Island-Bay Complex just west of this study area (Barnhardt and Kelley, 1991), localized deposits of carbonate sand, consisting of a shell hash, can form adjacent to shallow, subtidal settings in the Rocky Zone. A shelly, silty sand and shell hash deposit is located landward of the Sally Islands in Gouldsboro Bay. This sandy surficial deposit covers more than a square kilometer of the bay (Fig. 13). Shipp (1989) estimates that this carbonate-rich sediment may be less than a meter thick. Despite the limited known occurrence of this type of deposit, it is possible to anticipate similar wave-sheltered accumulations elsewhere in the extensive Rocky Zone (Plate 4) of Downeast Maine.

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TABLE I. PREVIOUS WORK IN THE DOWNEAST MAINE REGION

Authors	Location	Data Sources
Ashley et al., 1991	Terrestrial glacial deposits	Sedimentology, geomorphology
Bacchus, 1993	Eastern Gulf of Maine	Seismic tratigraphy, cores
Barnhardt and Kelley, 1991	Frenchman and Blue Hill Bays	Sediments, seismic, side-scan sonar
Ballard and Uchupi, 1975	Gulf of Maine	Seismics, rock samples, magnetics
Belknap and Shipp, 1991	Maine inner shelf	Seismic stratigraphy
Belknap et al., 1987a	Maine coast	Cores, radiocarbon dates
Belknap et al., 1987b	Machias Bay	Seismic stratigraphy
Belknap et al., 1989a	Western Gulf of Maine	Seismic, cores, side-scan sonar, sub
Belknap et al., 1989b	Coastal Maine marshes	Cores, radiocarbon dates
Denny, 1982	Maine and New England	Geomorphology and bedrock geology
Duffy et al, 1989	Coastal Maine barrier beaches	Cores, geomorphology
Gehrels and Belknap, 1993	Gouldsboro, Addison, Machias	Cores, foraminifera, radiocarbon dates
Hutchinson et al., 1988	Gulf of Maine	Seismic reflection , gravity, magnetics
Kelley, 1987	Maine coast	Intertidal sediments
Kelley, 1989	Coastal Maine, bays, bluffs	Clay mineralogy
Kelley and Belknap, 1988	Maine inner shelf	Seismics, sediments
Kelley et al., 1988	Coastal Maine marshes	Geomorphology, cores
Kelley, et al., 1992	Maine inner shelf	Vibracores, radiocarbon dates, seismic
Lehmann, 1991	Maine estuaries, rivers	Heavy mineralogy
McClennen, 1989	Gulf of Maine	Seismic stratigraphy
Osberg et al., 1985	Maine	Bedrock geologic map of Maine
Poppe, et al., 1986	Gulf of Maine	Surficial sediments
Ross, 1967	Gulf of Maine, nearshore	Heavy mineralogy
Ross, 1970	Gulf of Maine	Heavy mineralogy
Shipp, 1989	Maine inner shelf	Seismic, cores, radiocarbon dates
Shipp et al., 1985	Gouldsboro Bay	Intertidal morphology and sediments
Shipp et al, 1987	Gouldsboro Bay	Coastal geomorphology, sediments
Shipp et al., 1991	Northern Gulf of Maine	Submerged shorelines
Tagg and Uchupi, 1966	Gulf of Maine	Seismic stratigraphy
Thompson and Borns, 1985	Maine	Surficial geologic map of Maine
Tucholke and Hollister, 1973	Western Gulf of Maine	Cores, radiocarbon dates, seismic
Valentine and Commeau, 1990	Gulf of Maine	Heavy mineralogy

TABLE 2. SEDIMENT SAMPLE LOCATIONS AND TEXTURES

Sample Number	Latitude (Deg. North)	Longitude (Deg. West)	Texture
1	44° 31' 24.20"	67° 23' 58.81"	silty sand
2	44° 30' 39.10"	67° 18' 46.15"	silty sand
3	44° 31' 7.41"	67° 17' 49.13"	cobbles
4	44° 31' 28.88"	67° 16' 55.65"	silty sand
5	44° 31' 58.21"	67° 16' 0.68"	silty sand
6	44° 33' 0.01"	67° 13' 59.55"	silty sand
7	44° 33' 48.69"	67° 12' 25.33"	silty sand
8	44° 34' 41.93"	67° 10' 37.83"	not analyzed
9	44° 34' 11.71"	67° 7' 46.92"	not analyzed
10	44° 33' 34.38"	67° 9' 6.65"	muddy, sandy gravel
11	44° 33' 4.70"	67° 10' 17.36"	sandy gravel
12	44° 32' 37.03"	67° 11' 25.72"	muddy, sandy gravel
13	44° 32' 25.81"	67° 15' 40.35"	gravelly, muddy sand
14	44° 31' 33.47"	67° 13' 20.97"	muddy gravel
15	44° 31' 10.01"	67° 14' 25.76"	muddy, sandy gravel
16	44° 27' 1.22"	67° 26' 22.34"	muddy, sandy gravel
17	44° 27' 40.30"	67° 24' 49.17"	sandy gravel
18	44° 27' 40.92"	67° 24' 46.17"	gravelly, muddy sand
19	44° 28' 21.41"	67° 23' 21.07"	gravelly, muddy sand
20	44° 29' 14.45"	67° 21' 45.91"	muddy, sandy gravel
21	44° 29' 48.08"	67° 20' 36.30"	muddy, sandy gravel
22	44° 28' 34.59"	67° 23' 2.47"	gravelly, muddy sand
23	44° 30' 23.43"	67° 15' 59.34"	muddy, sandy gravel
24	44° 29' 50.21"	67° 16' 56.37"	gravelly, muddy sand
25	44° 28' 58.57"	67° 18' 28.15"	muddy, sandy gravel
26	44° 28' 11.97"	67° 20' 7.27"	gravelly, muddy sand
27	44° 27' 26.08"	67° 21' 41.73"	gravelly, muddy sand
28	44° 26' 36.30"	67° 23' 12.89"	gravelly, muddy sand
29	44° 25' 44.69"	67° 24' 47.55"	slightly gravelly, muddy sand
30	44° 24' 58.17"	67° 26' 29.72"	slightly gravelly, muddy sand
31	44° 25' 43.31"	67° 29' 21.80"	gravelly, muddy sand
32	44° 32' 41.31"	67° 24' 20.44"	muddy, sandy gravel
33	44° 24' 5.76"	67° 32' 54.26"	gravelly, muddy sand
34	44° 23' 20.13"	67° 35' 4.22"	gravelly, muddy sand
35	44° 22' 41.19"	67° 36' 31.57"	gravelly, muddy sand
36	44° 21' 54.15"	67° 38' 5.66"	slightly gravelly, sandy mud
37	44° 19' 13.85"	67° 41' 36.37"	slightly gravelly, sandy mud
38	44° 23' 25.31"	67° 38' 55.62"	slightly gravelly, sandy mud
39	44° 24' 51.31"	67° 38' 57.51"	gravelly, muddy sand
40	44° 22' 27.98"	67° 41' 42.95"	slightly gravelly, sandy mud
41	44° 21' 54.51"	67° 42' 45.17"	slightly gravelly, sandy mud
42	44° 24' 15.99"	67° 42' 58.97"	cobbles
43	44° 27' 34.94"	67° 48' 24.07"	not analyzed
44	44° 27' 14.40"	67° 48' 59.33"	not analyzed
45	44° 27' 33.29"	67° 48' 39.42"	not analyzed
46	44° 27' 32.41"	67° 48' 59.54"	not analyzed

TABLE 3. GRAIN SIZE DISTRIBUTIONS OF SAMPLES.

Sample	% Gravel	%Sand	% Sand & Gravel	% Silt	% Clay
1	n.a.	n.a.	71.47	21.23	7.30
2a	n.a.	n.a.	77.76	16.34	5.90
2b	n.a.	n.a.	80.47	14.49	5.04
2c	n.a.	n.a.	80.19	14.97	4.83
3	cobbles				
4a	n.a.	n.a.	69.82	22.21	7.97
4b	n.a.	n.a.	70.74	21.76	7.50
5a	n.a.	n.a.	69.30	22.73	7.97
5b	n.a.	n.a.	67.09	24.37	8.54
6	n.a.	n.a.	77.48	16.64	5.88
7	n.a.	n.a.	76.17	17.76	6.06
8	n.a.	n.a.	n.a.	n.a.	n.a.
9	n.a.	n.a.	n.a.	n.a.	n.a.
10	50.06	35.39	85.45	7.21	7.34
11	45.86	49.04	94.04	2.48	2.62
12	40.29	40.60	80.89	17.38	1.73
13	29.81	52.56	82.37	16.01	1.62
14	36.74	27.22	63.96	34.46	1.58
15	36.48	48.75	85.23	11.95	2.83
16	49.65	36.18	85.83	12.52	1.65
17	60.70	36.18	96.88	2.17	0.96
18	18.58	56.10	74.68	22.12	3.20
19	24.15	55.54	79.69	16.21	4.10
20	38.66	48.00	86.66	12.13	1.20
21	69.09	23.80	92.89	6.77	0.35
22	20.52	62.58	83.1	14.03	2.86
23	40.22	44.31	84.53	11.50	3.96
24	26.30	50.31	76.61	20.65	2.73
25	39.38	51.38	90.76	6.41	2.82
26	23.73	54.30	78.03	19.04	2.92
27	31.09	52.79	83.88	12.62	3.50
28	26.36	59.76	86.12	11.20	2.68
29	4.44	55.09	59.53	33.98	6.49
30	0.10	54.90	55.00	40.61	4.39
31	25.54	45.98	71.52	26.02	2.46
32	39.74	44.51	84.25	11.31	4.44
33	7.54	61.41	68.95	28.12	2.94
34	6.00	70.23	76.23	20.59	3.17
35	13.51	52.88	66.39	30.73	2.88
36	2.37	40.74	43.11	51.36	5.53
37	0.36	37.11	37.47	49.78	12.75
38	0.08	36.68	36.76	46.31	16.93
39	10.85	48.77	59.62	11.13	29.25
40	0.04	20.44	20.48	71.33	8.19
41	1.02	13.83	14.85	30.90	54.25
42	cobbles				

(n.a. = not analyzed)

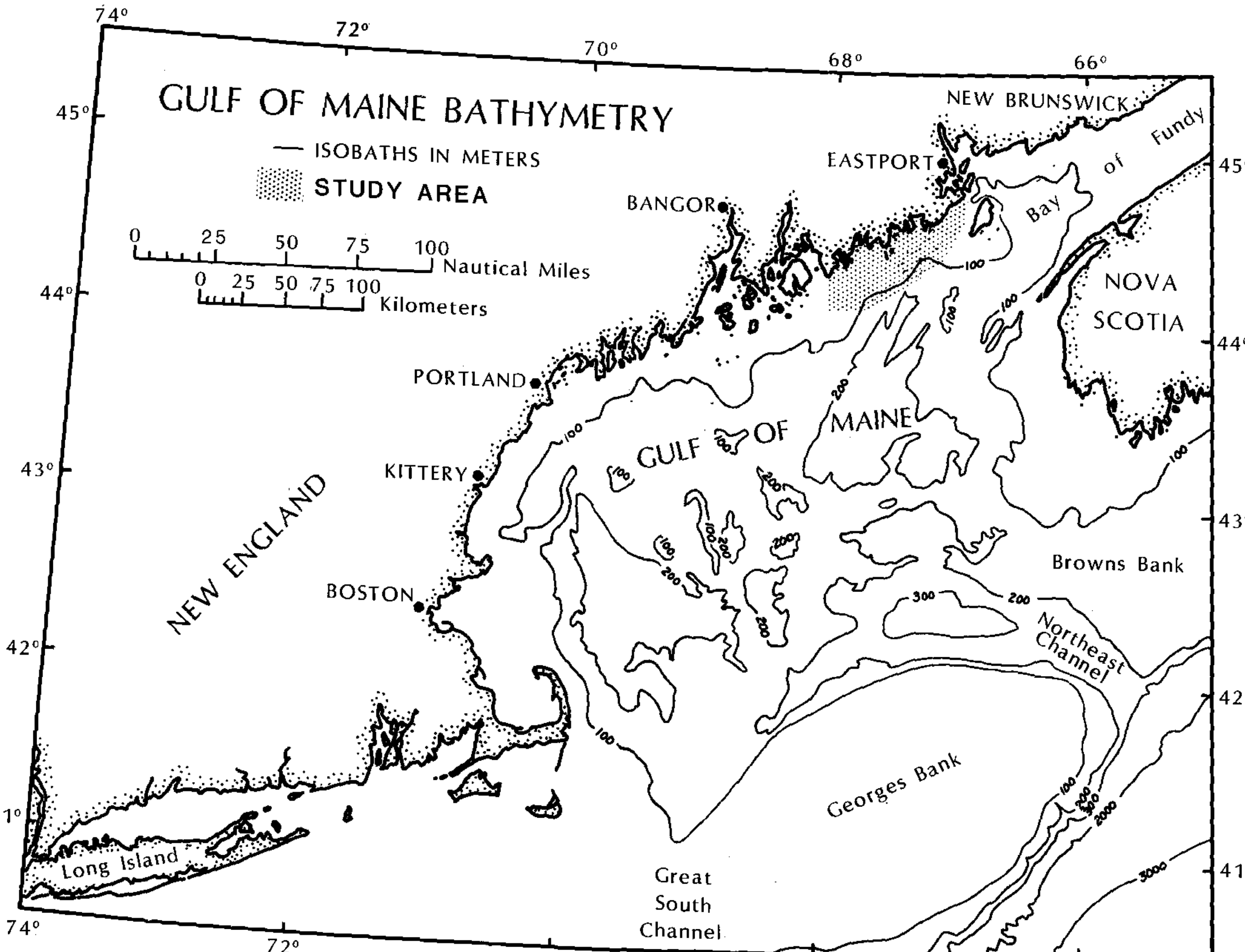


Figure 1. Location of the study area within the Gulf of Maine. This report examines the seafloor sediments and physiography of the downeast Maine inner continental shelf east of 68° W longitude and offshore to about the 100 meter isobath.

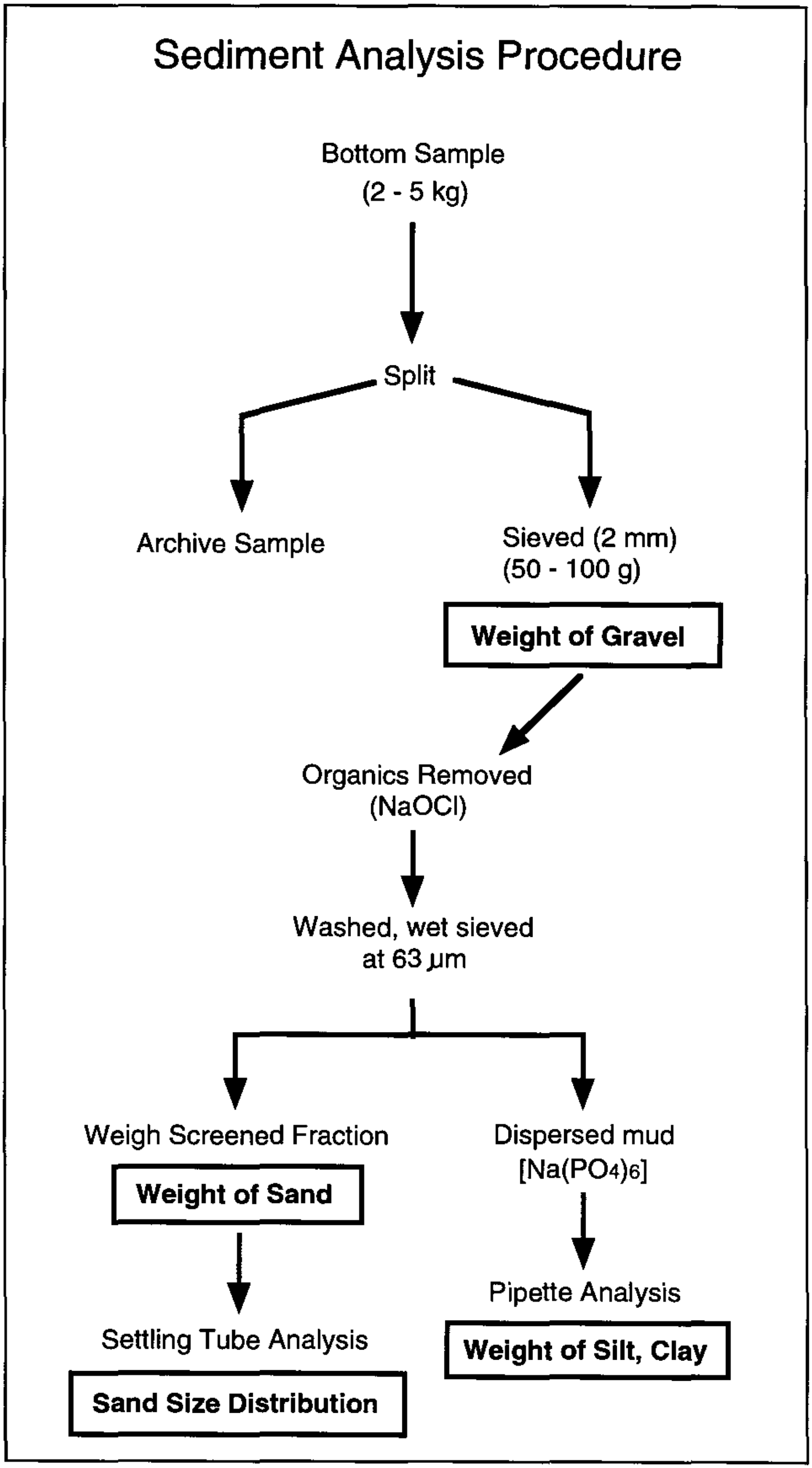
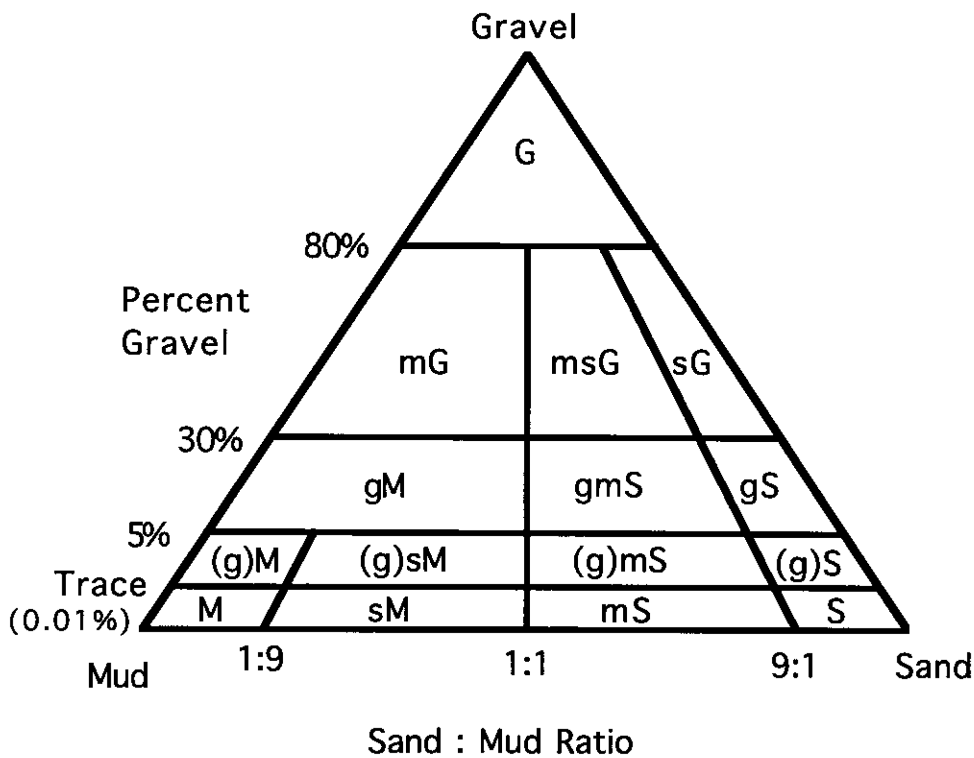


Figure 2. Laboratory methods of grain size analysis.

Classification of Sedimentary Textures



Grain Size Ranges:

Gravel	>2 mm
Sand	0.0625 - 2 mm
Mud (silt & clay)	<0.625 mm

Terminology:

G = gravel; g = gravelly; (g) = slightly gravelly
S = sand; s = sandy; (s) = slightly sandy
M = mud; m = muddy; (m) = slightly muddy

(After Folk, 1974)

Figure 3. Grain size classification scheme used to describe sediment samples.

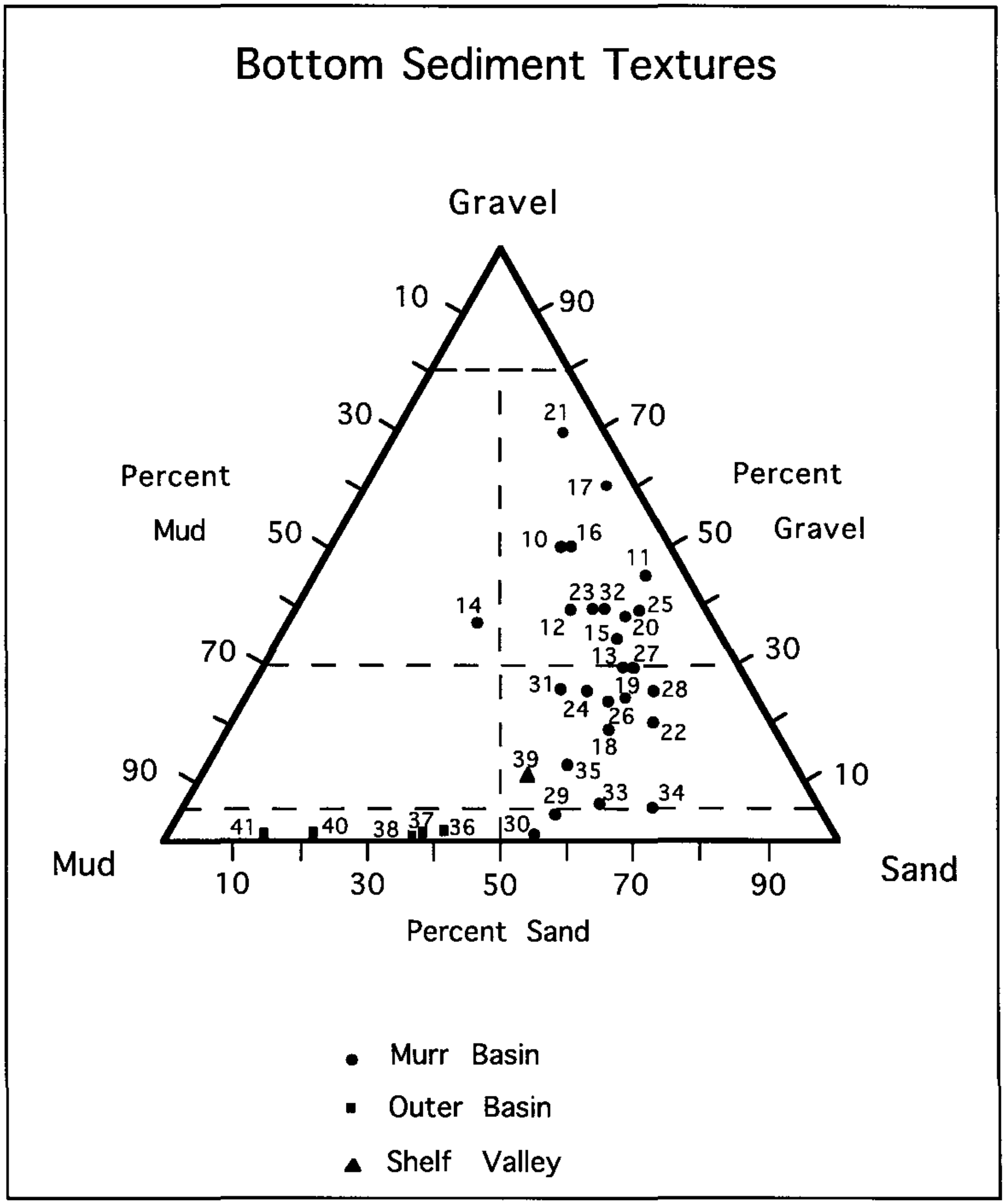


Figure 4. Ternary diagram of sediments from the Downeast inner continental shelf.

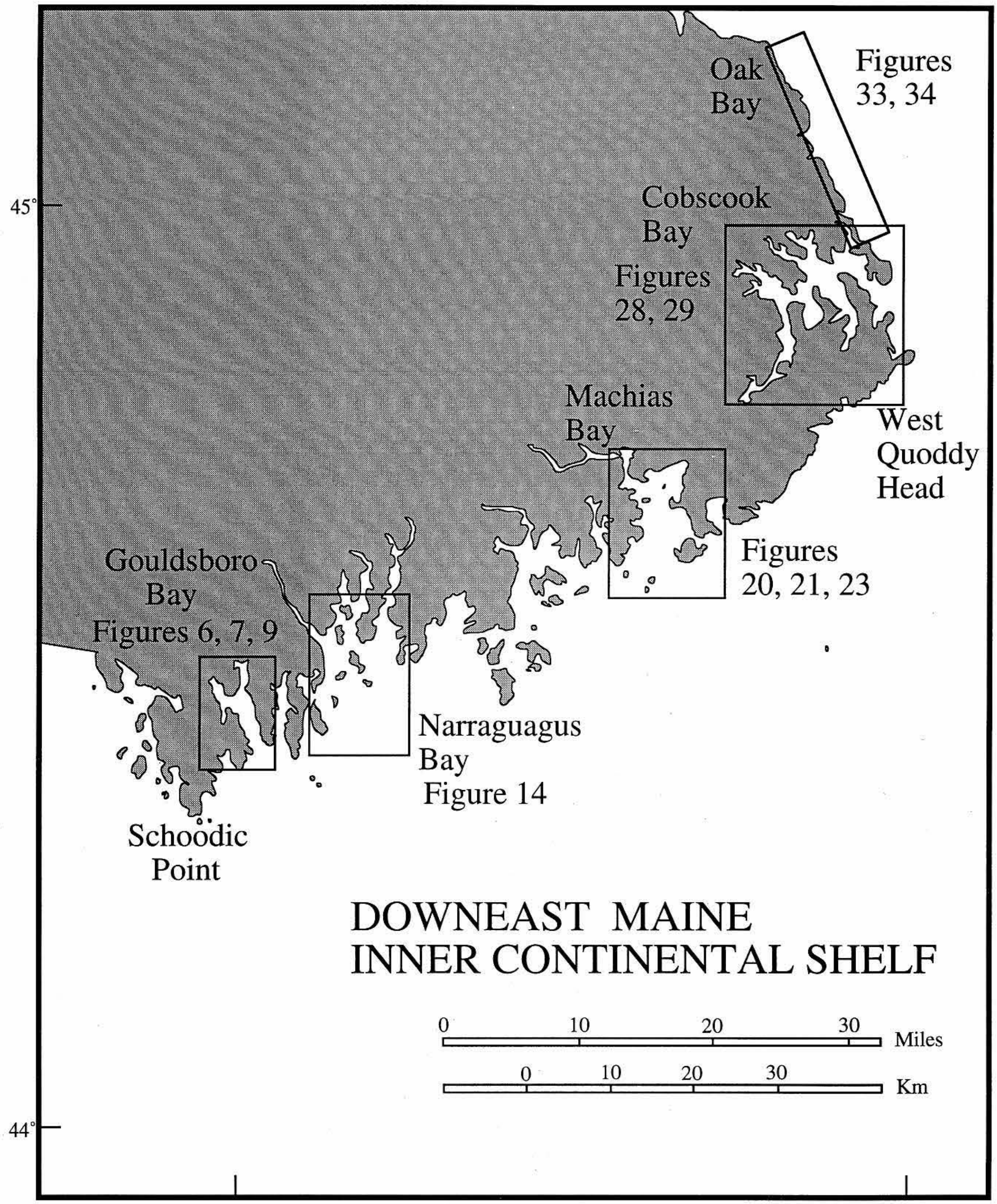


Figure 5. The study area extends from near Schoodic Point to the Canadian border at Oak Bay; from the shoreline to the 100 m isobath. Boxed areas depict the location of figures used in text.

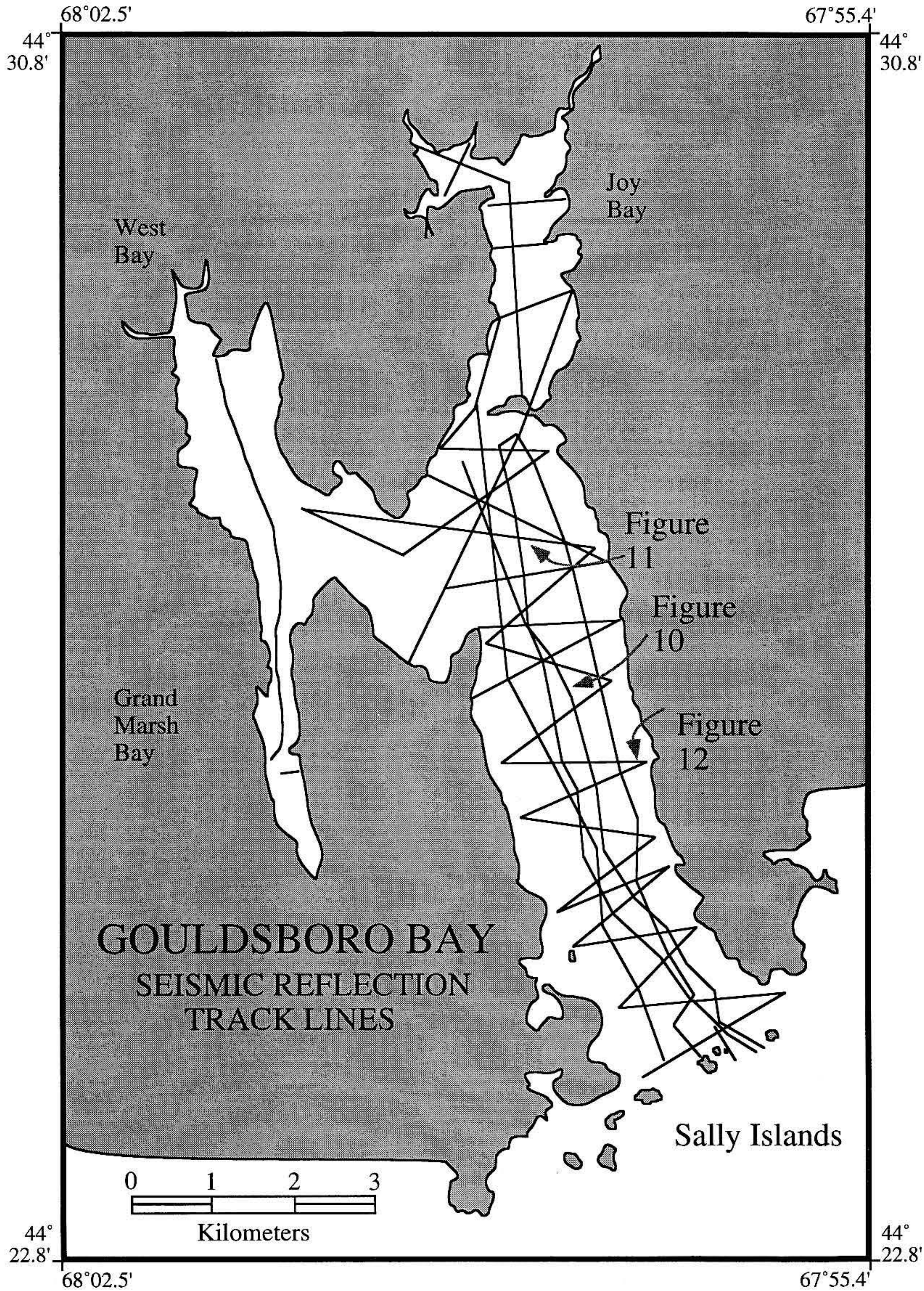


Figure 6. Location map of Gouldsboro Bay showing seismic trackline positions (from Shipp, 1989).

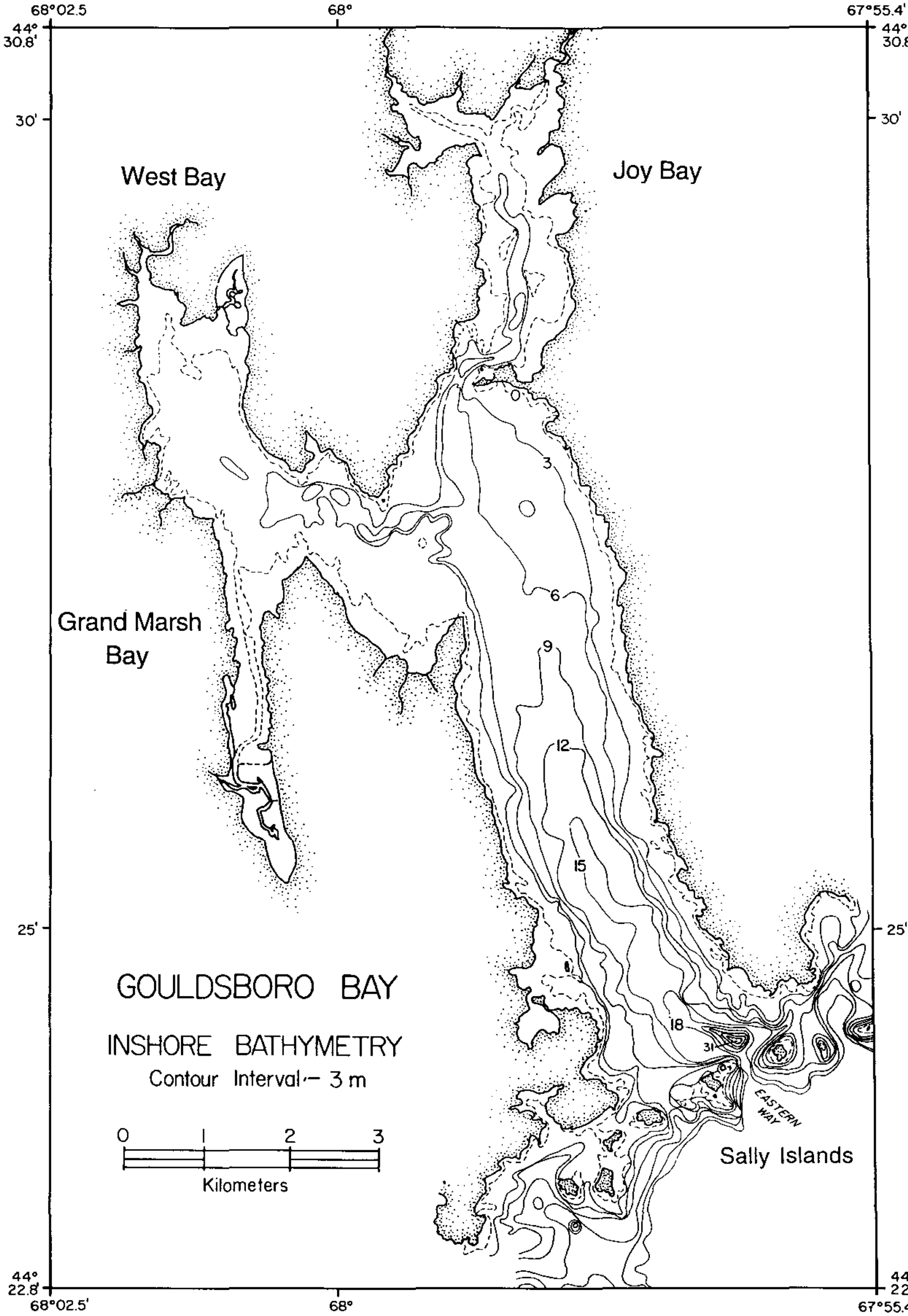


Figure 7. Bathymetric map of Gouldsboro Bay (modified by Shipp, 1989 from National Ocean Service Chart 13324).

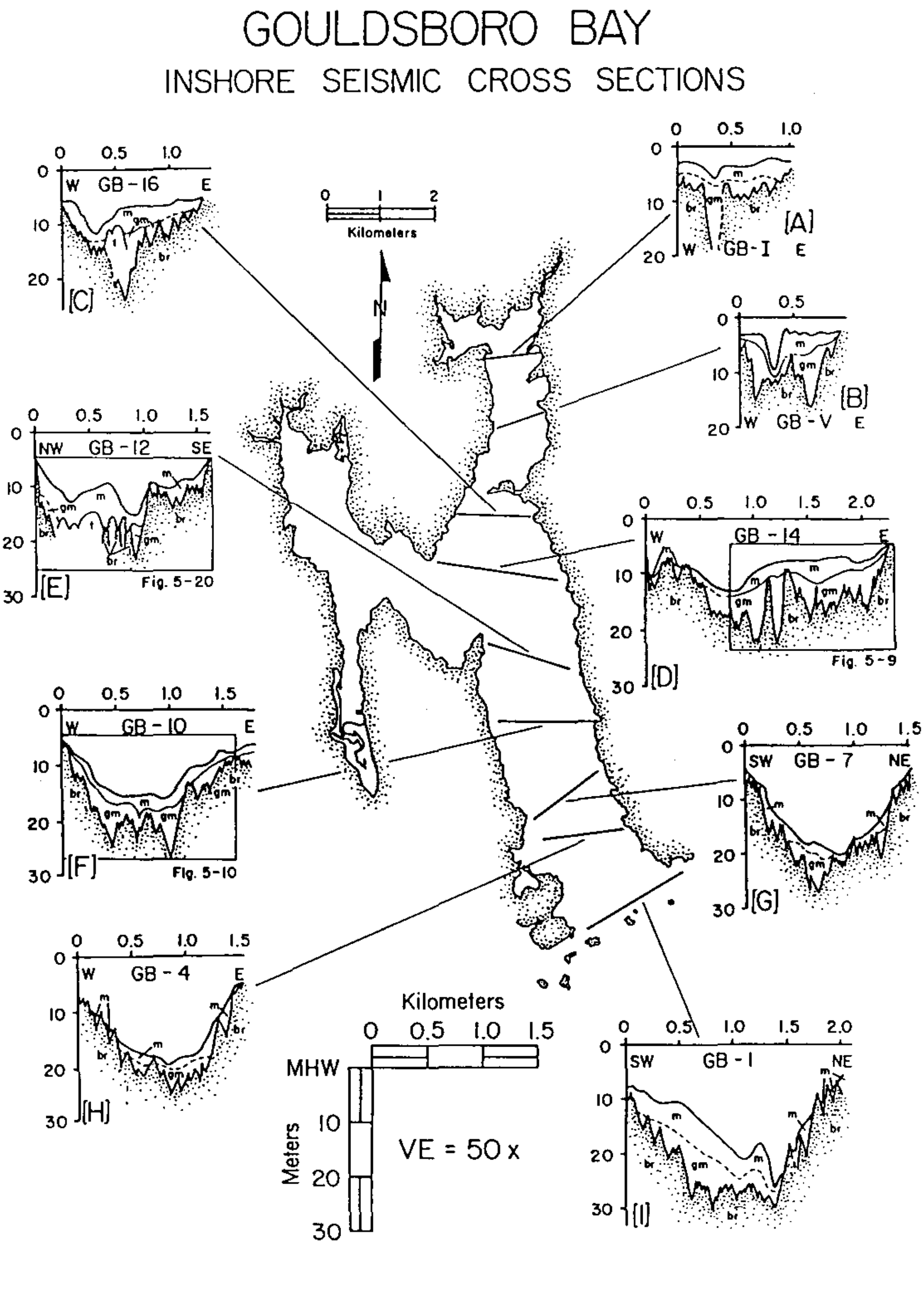


Figure 8. Interpreted seismic reflection profiles across Gouldsboro Bay (from Shipp, 1989).

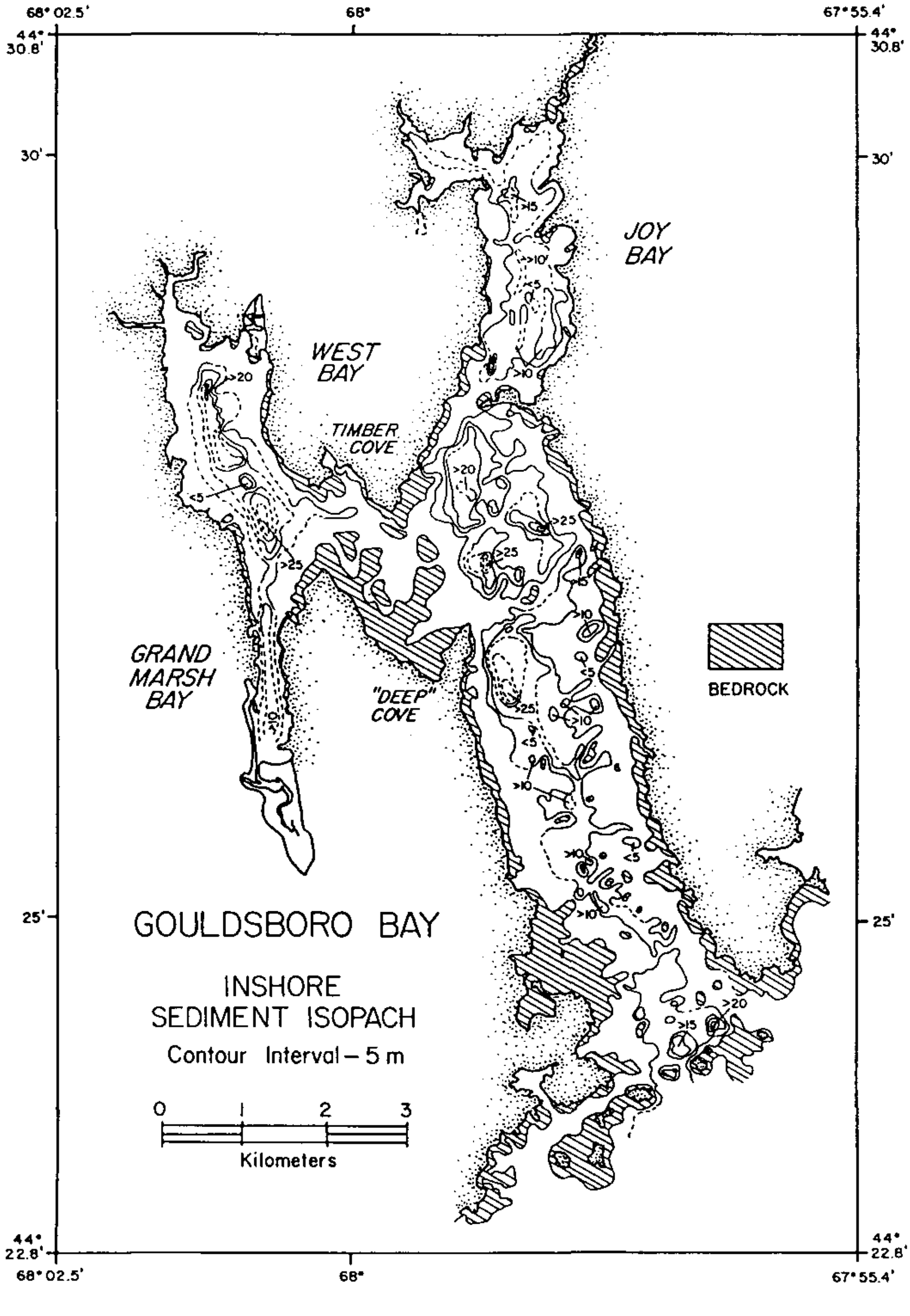


Figure 9. Sediment isopach map of Gouldsboro Bay based on seismic reflection profiles (from Shipp, 1989).

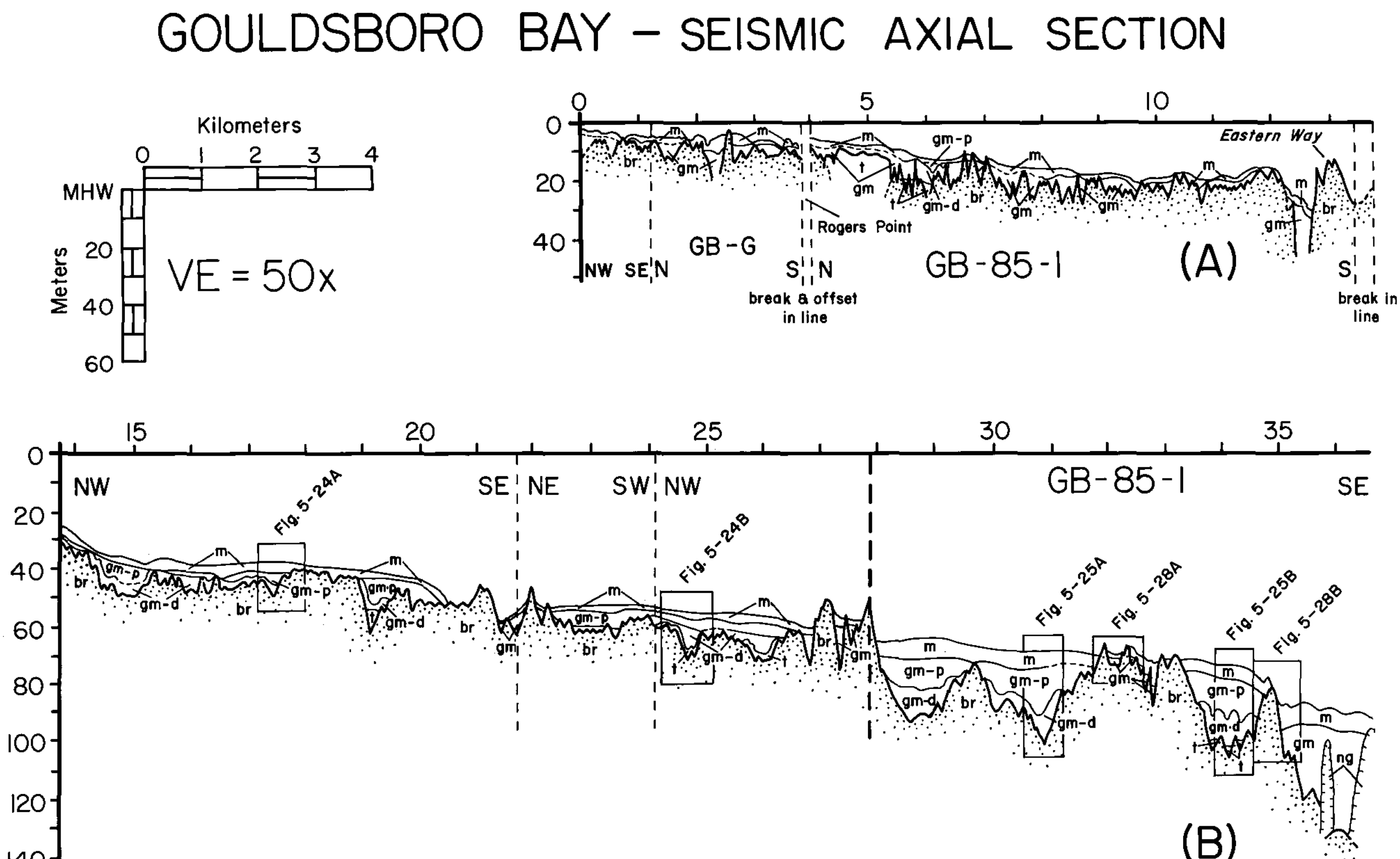


Figure 10. Seismic profile down the axis of Gouldsboro Bay (from Shipp, 1989).

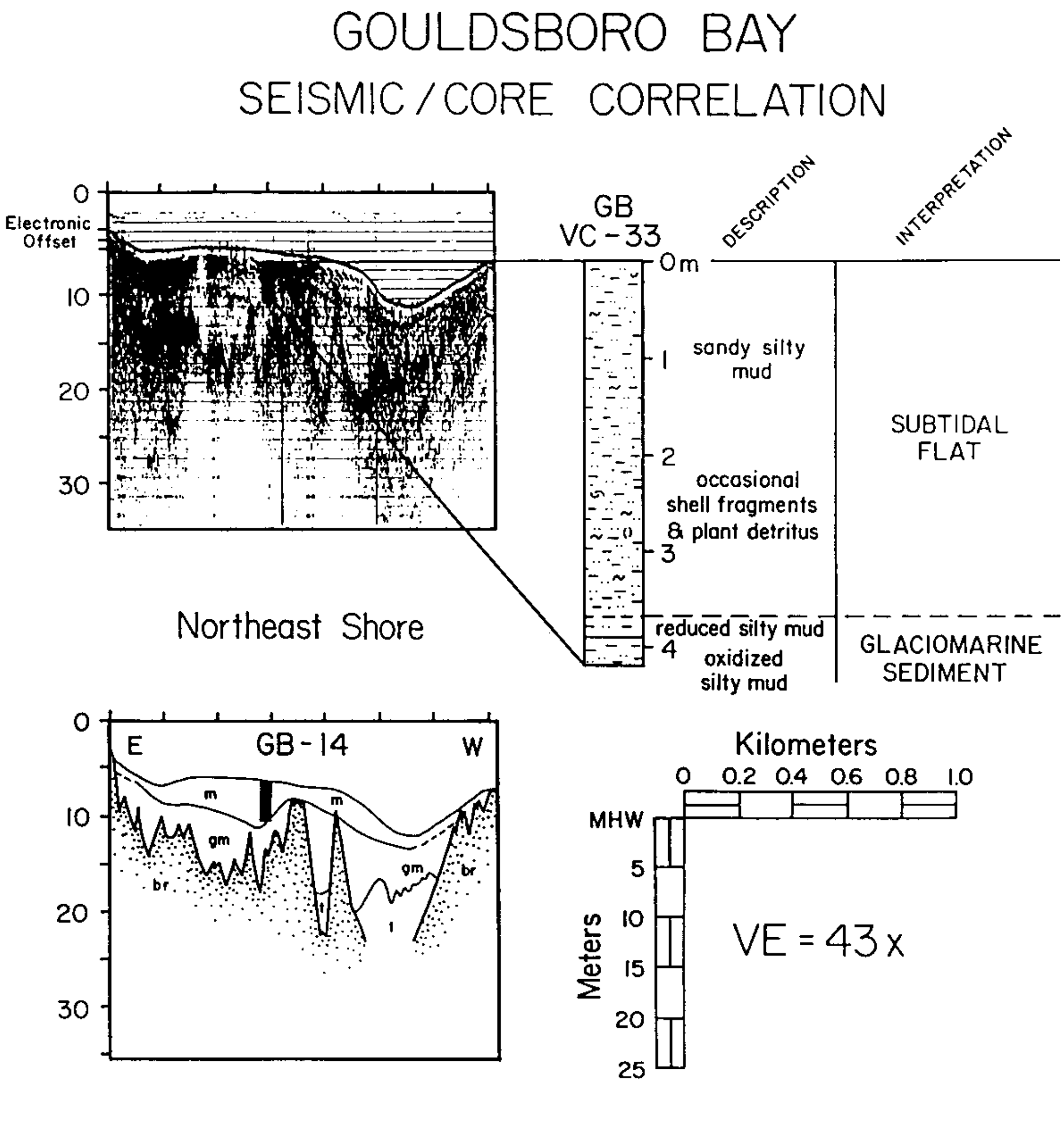


Figure 11. Seismic reflection profile with core interpretations from Gouldsboro Bay (from Shipp, 1989).

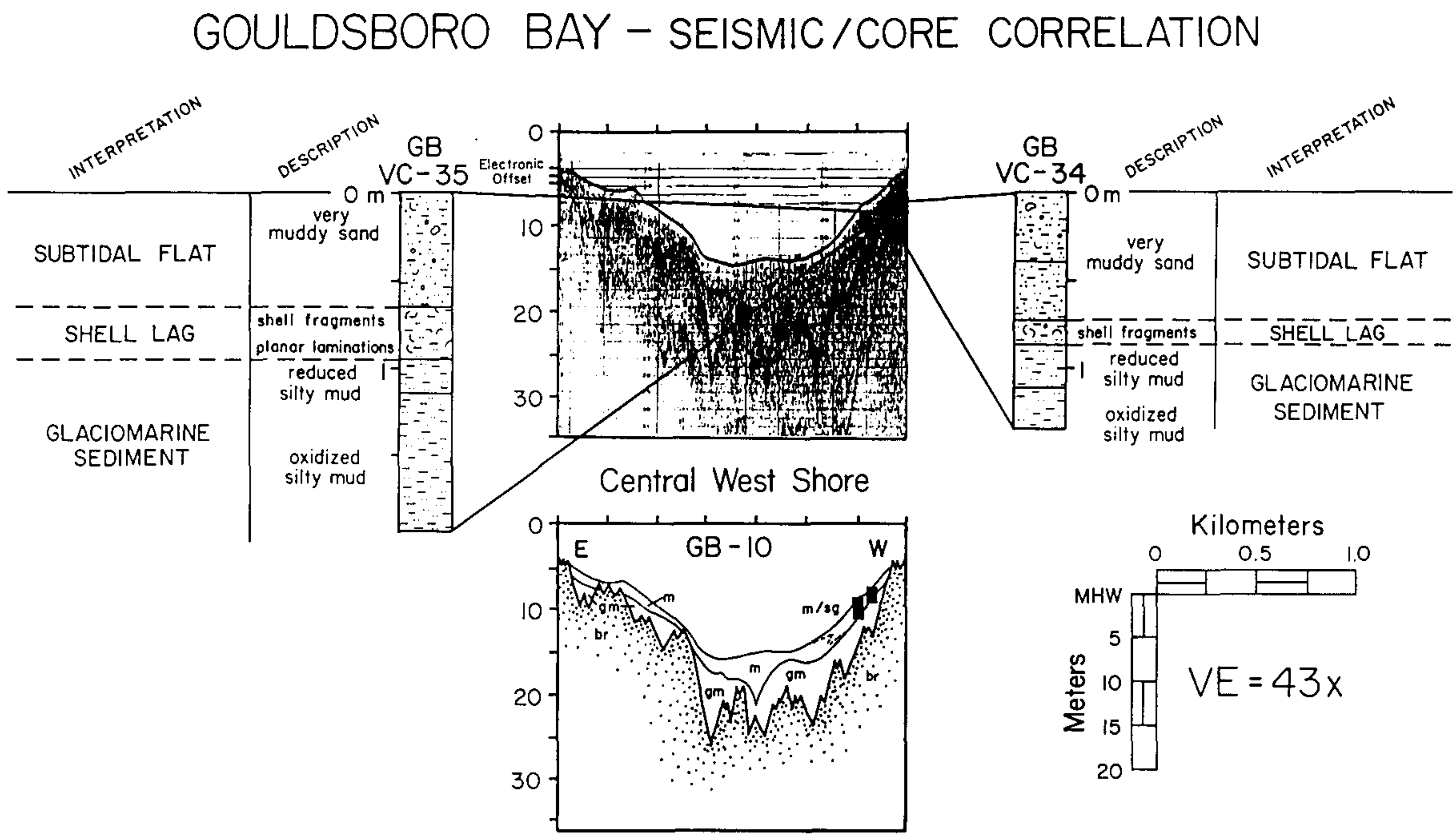


Figure 12. Seismic reflection profile with core interpretations from Gouldsboro Bay (from Shipp, 1989).

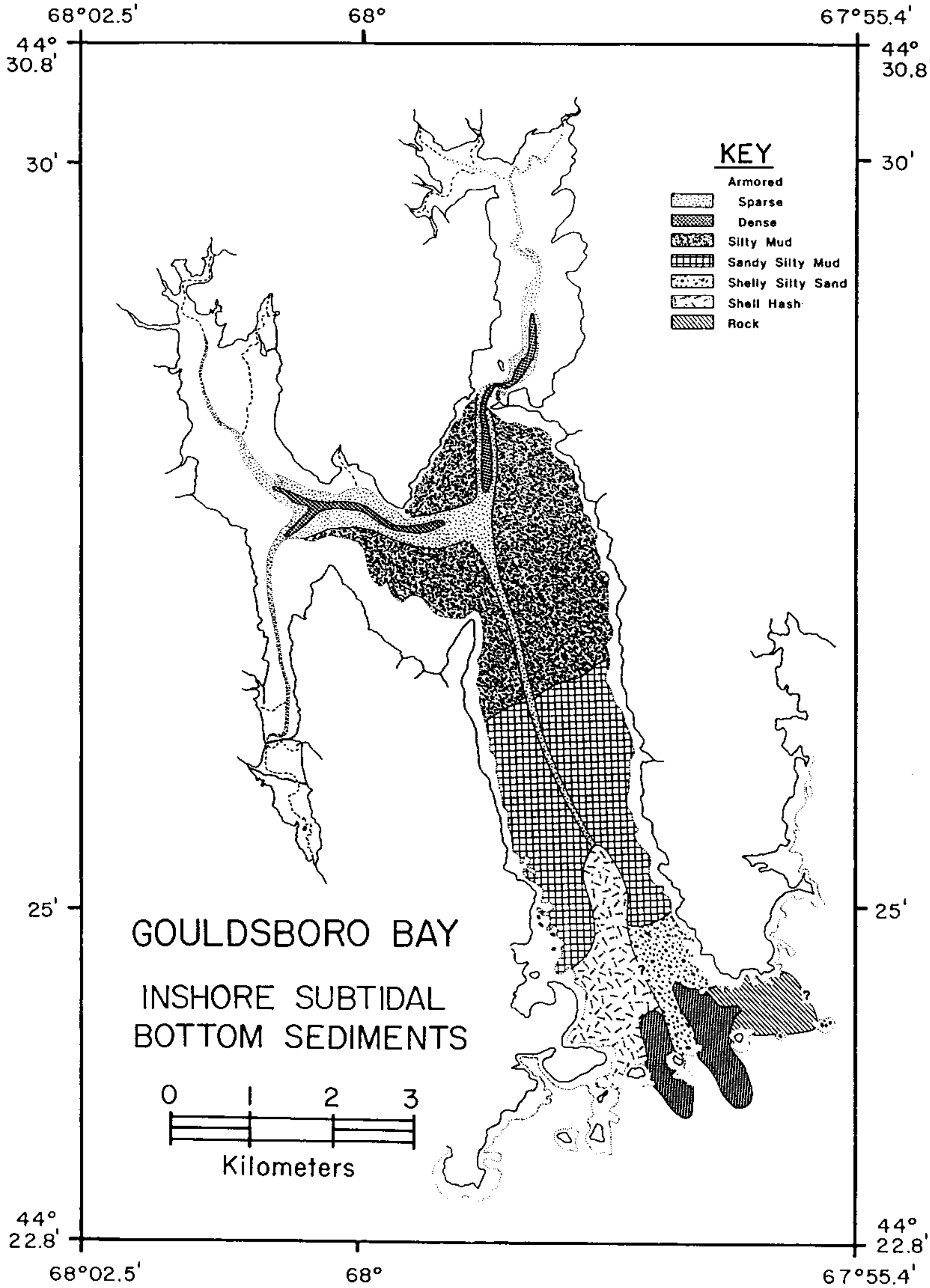


Figure 13. Surficial sediment map of Gouldsboro Bay (from Shipp et al., 1985).

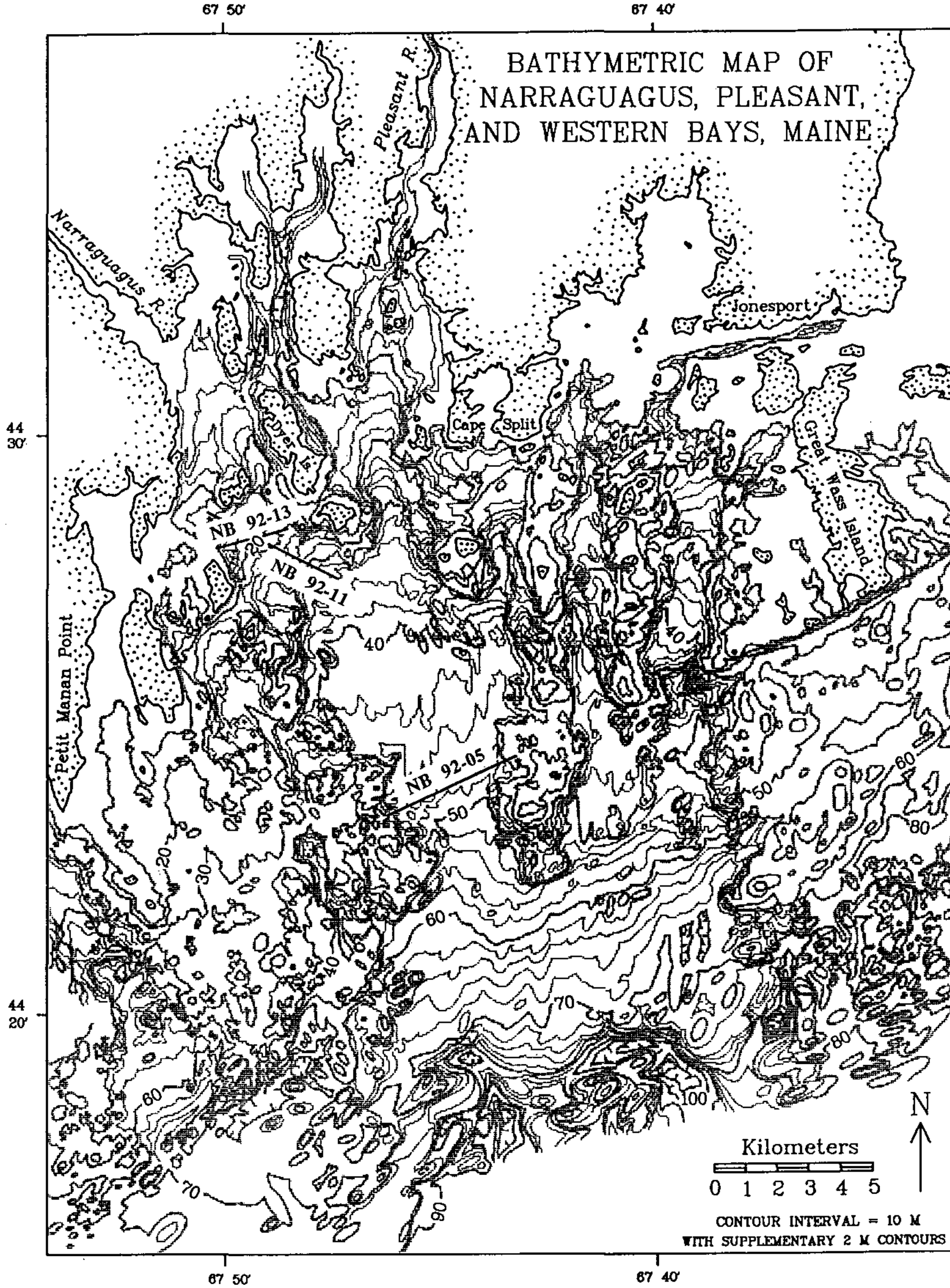


Figure 14. Bathymetry of Narraguagus Bay (from Barnhardt, 1994, in preparation).

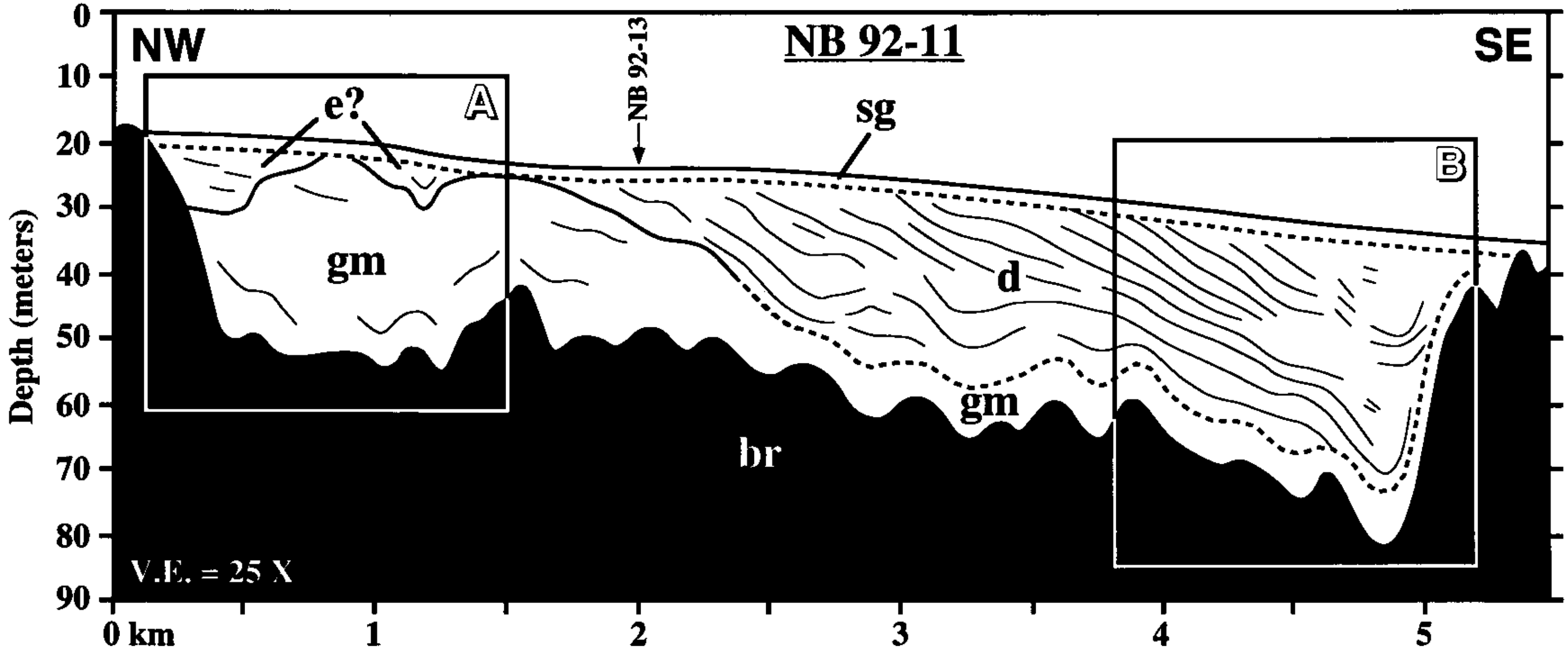


Figure 15. An axial seismic reflection profile down Narraguagus Bay showing clinoform reflectors indicative of deltaic foresets (d). The upper sand and gravel (sg) is inferred to unconformably overlie the deltaic material. Boxes indicate the position of Figures 16 and 17 (from Barnhardt, 1994, in preparation).

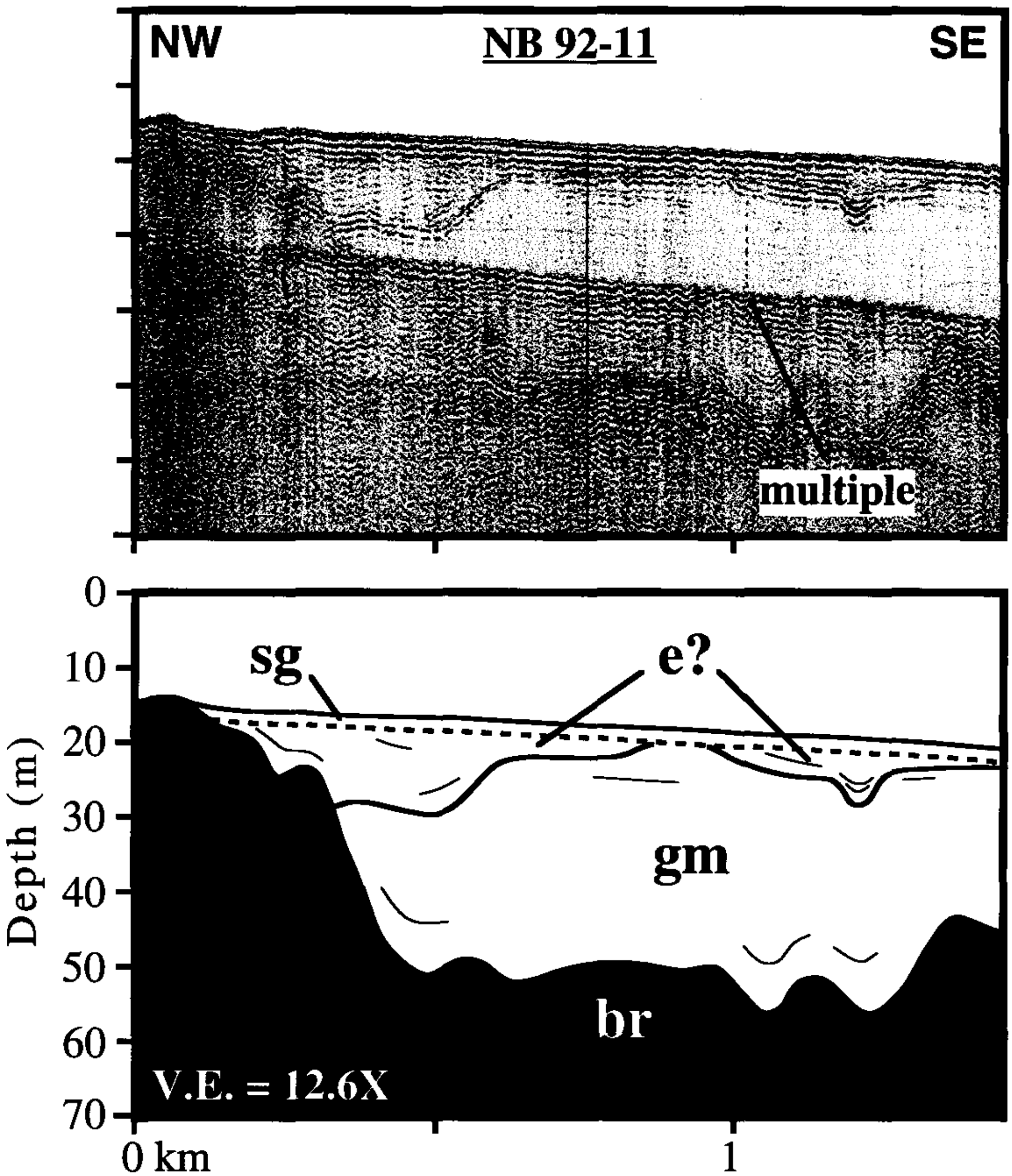


Figure 16. Detail from Figure 15 (inset A) showing the channel-filling nature of acoustic reflectors interpreted as estuarine sediment (e) (from Barnhardt, 1994, in preparation).

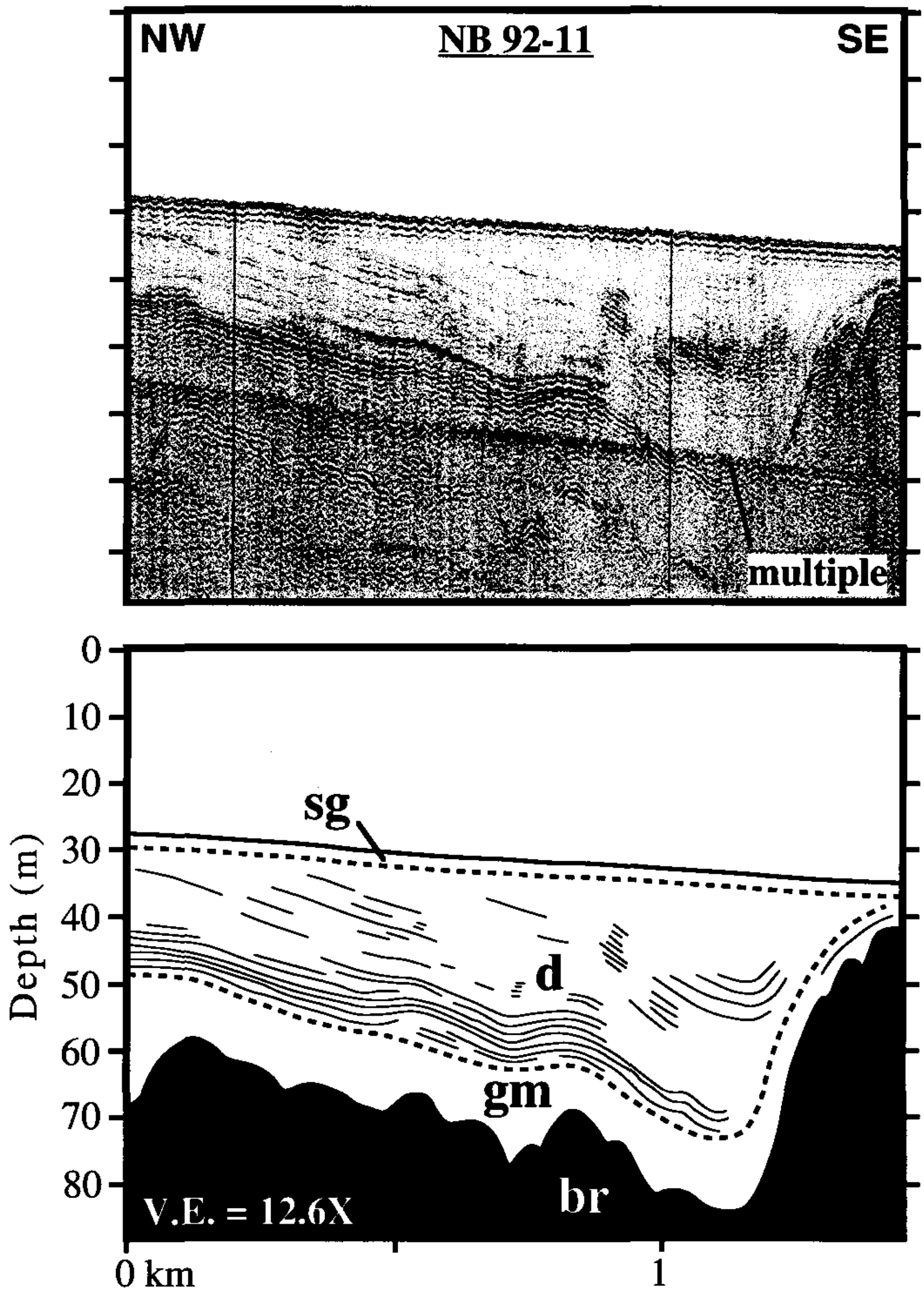


Figure 17. Detail from Figure 15 (inset B) showing the steeply dipping clinoform reflectors indicative of the inferred deltaic sediment (d) (from Barnhardt, 1994, in preparation).

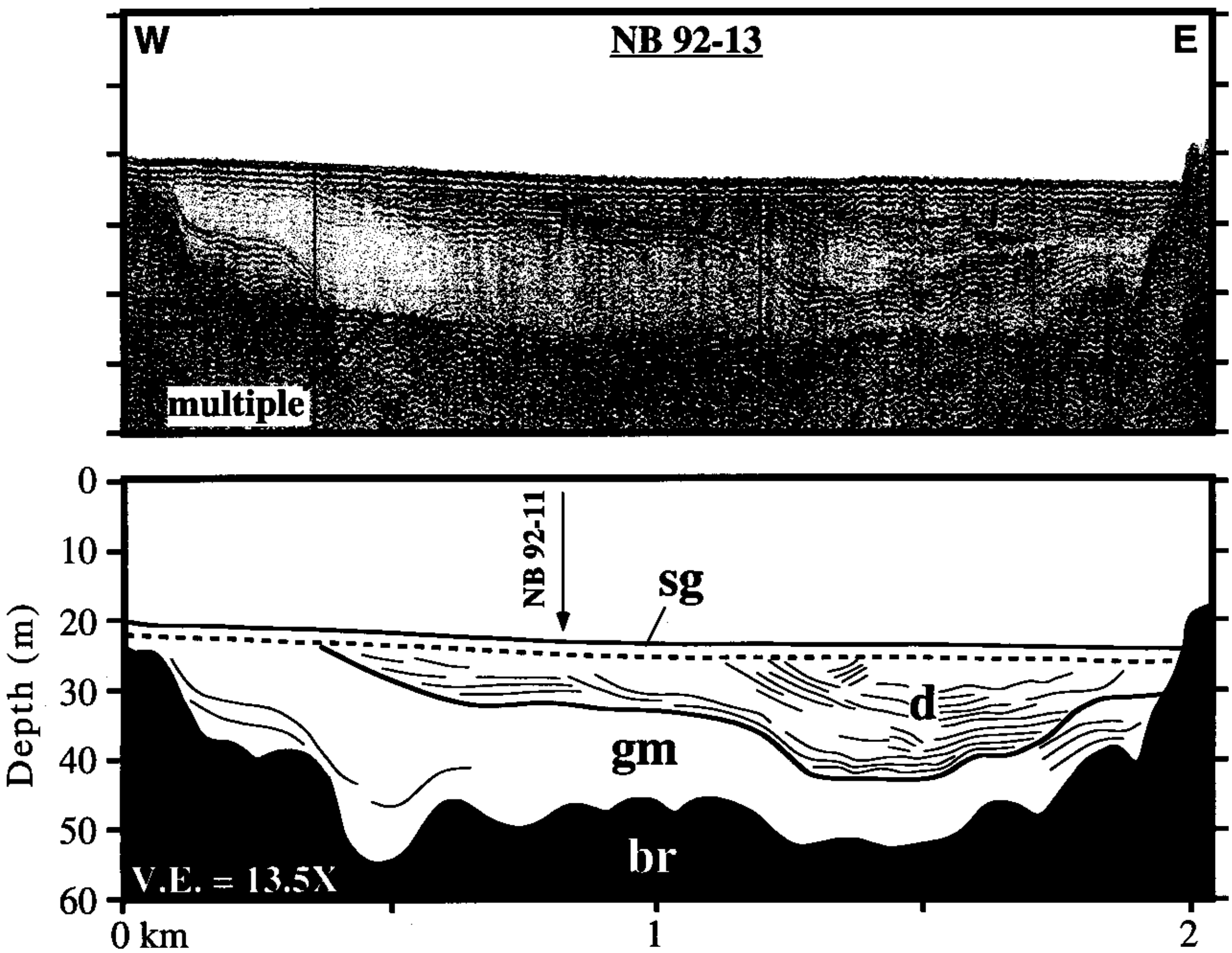


Figure 18. Clinoform reflectors indicative of deltaic foresets (d) unconformably overlie glaciomarine sediments (gm) in upper Narraguagus Bay (from Barnhardt, 1994, in preparation).

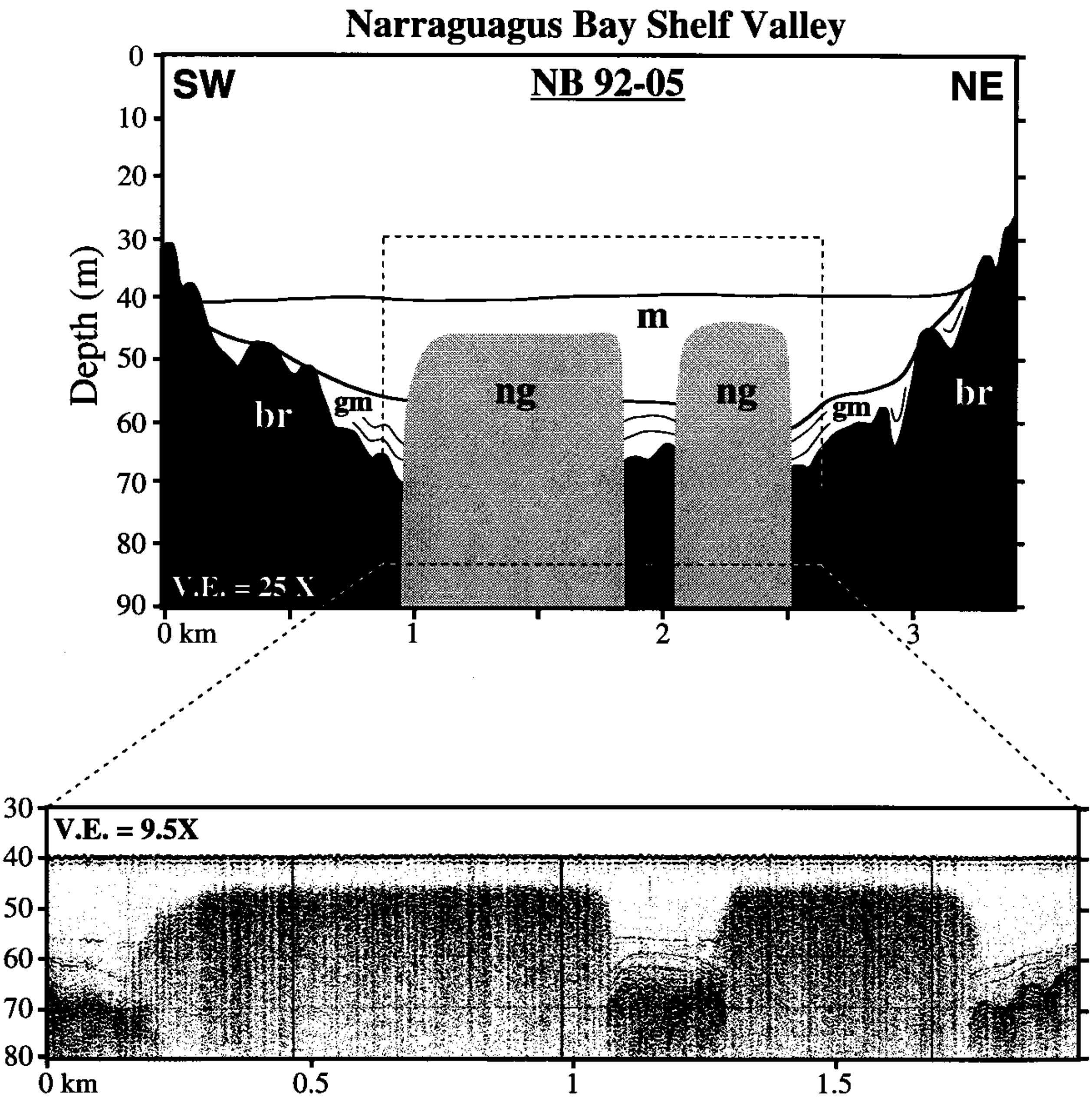


Figure 19. A seismic reflection profile normal to the Narraguagus Shelf Valley in 50 m of water. Natural gas obscures much of the record in this muddy area (from Barnhardt, 1994,in preparation).

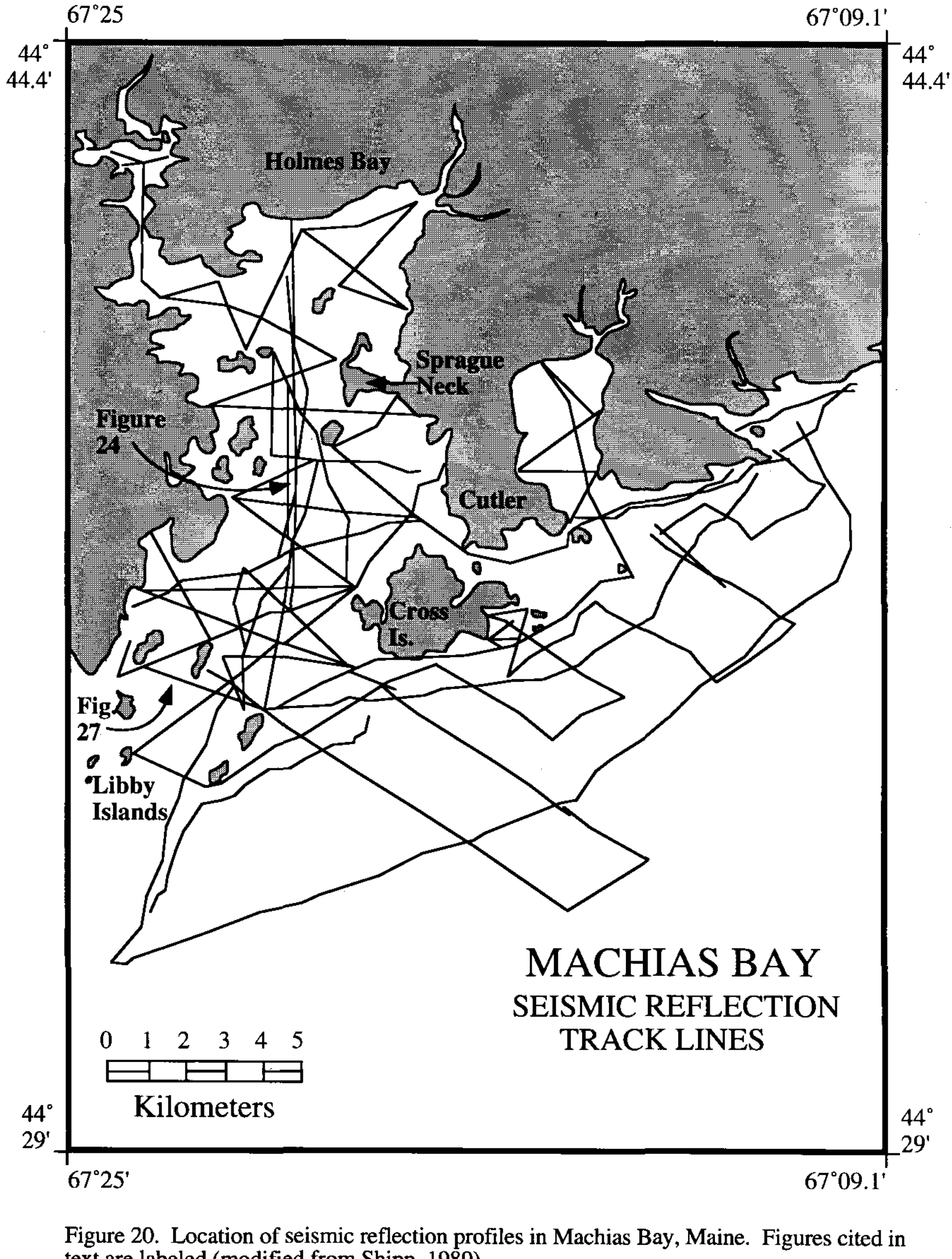


Figure 20. Location of seismic reflection profiles in Machias Bay, Maine. Figures cited in text are labeled (modified from Shipp, 1989).

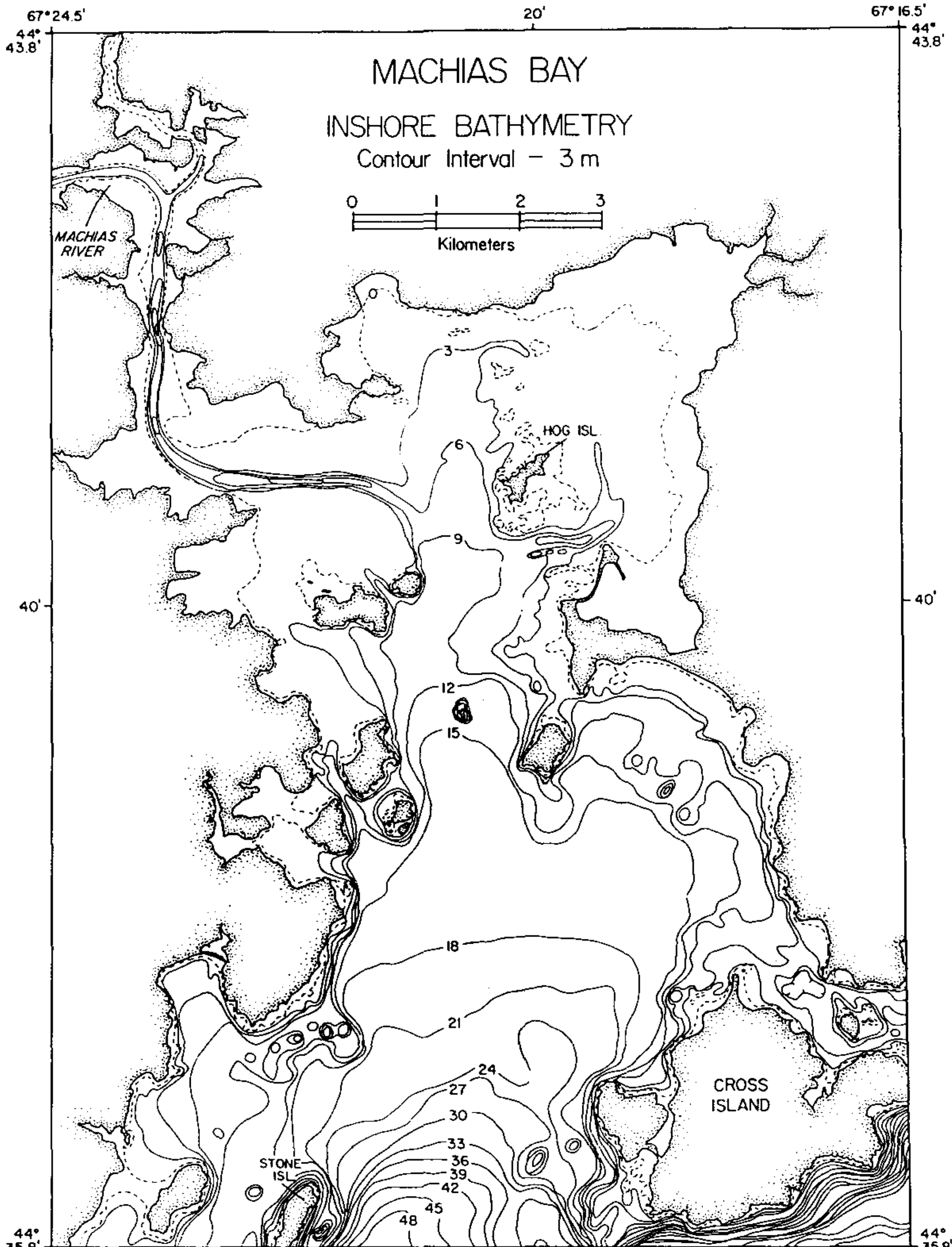


Figure 21. Bathymetric map of Machias Bay (modified by Shipp, 1989 from National Ocean Service Chart 13327).

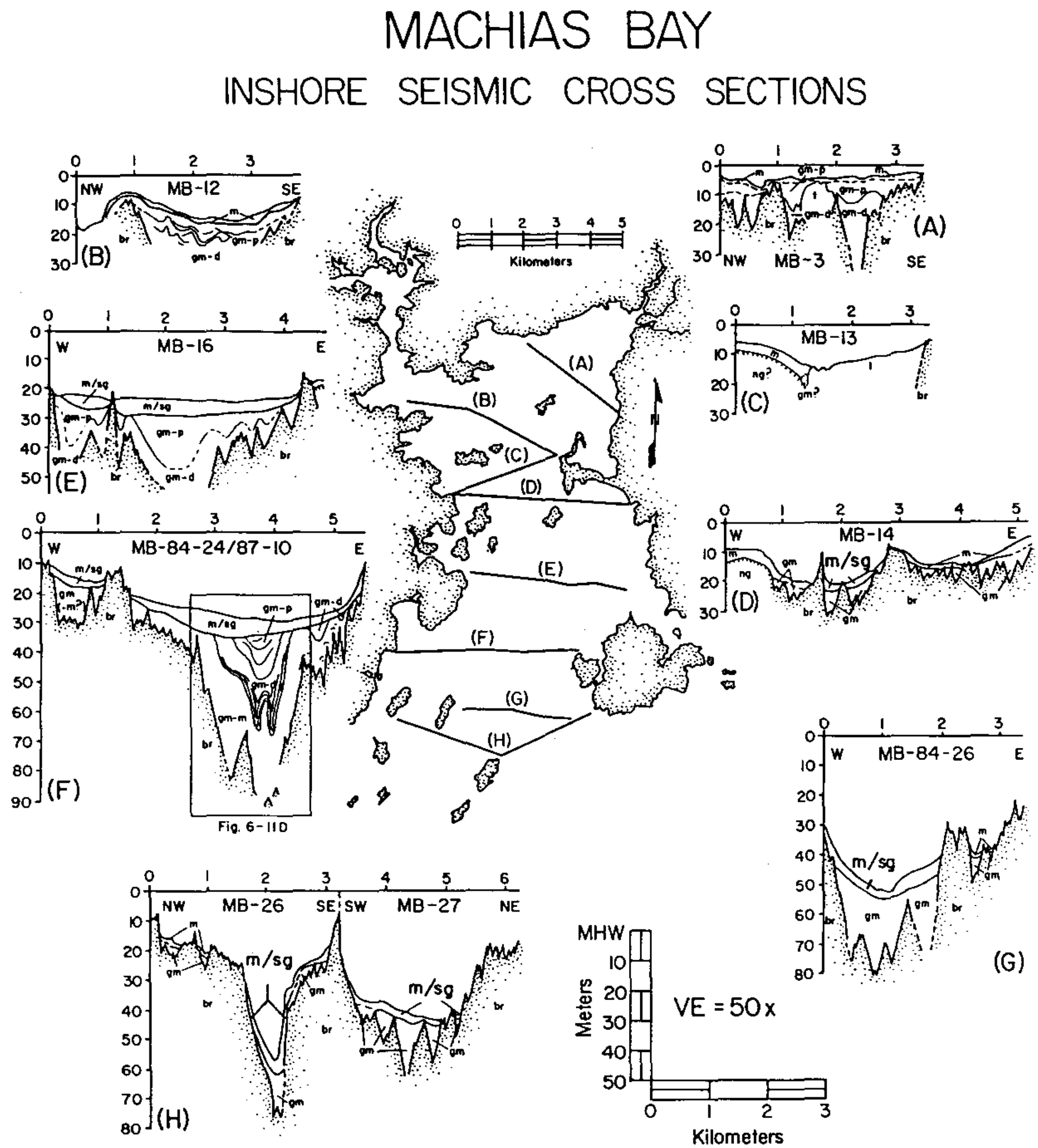


Figure 22. Interpreted seismic reflection profiles from Machias Bay (from Shipp, 1989).

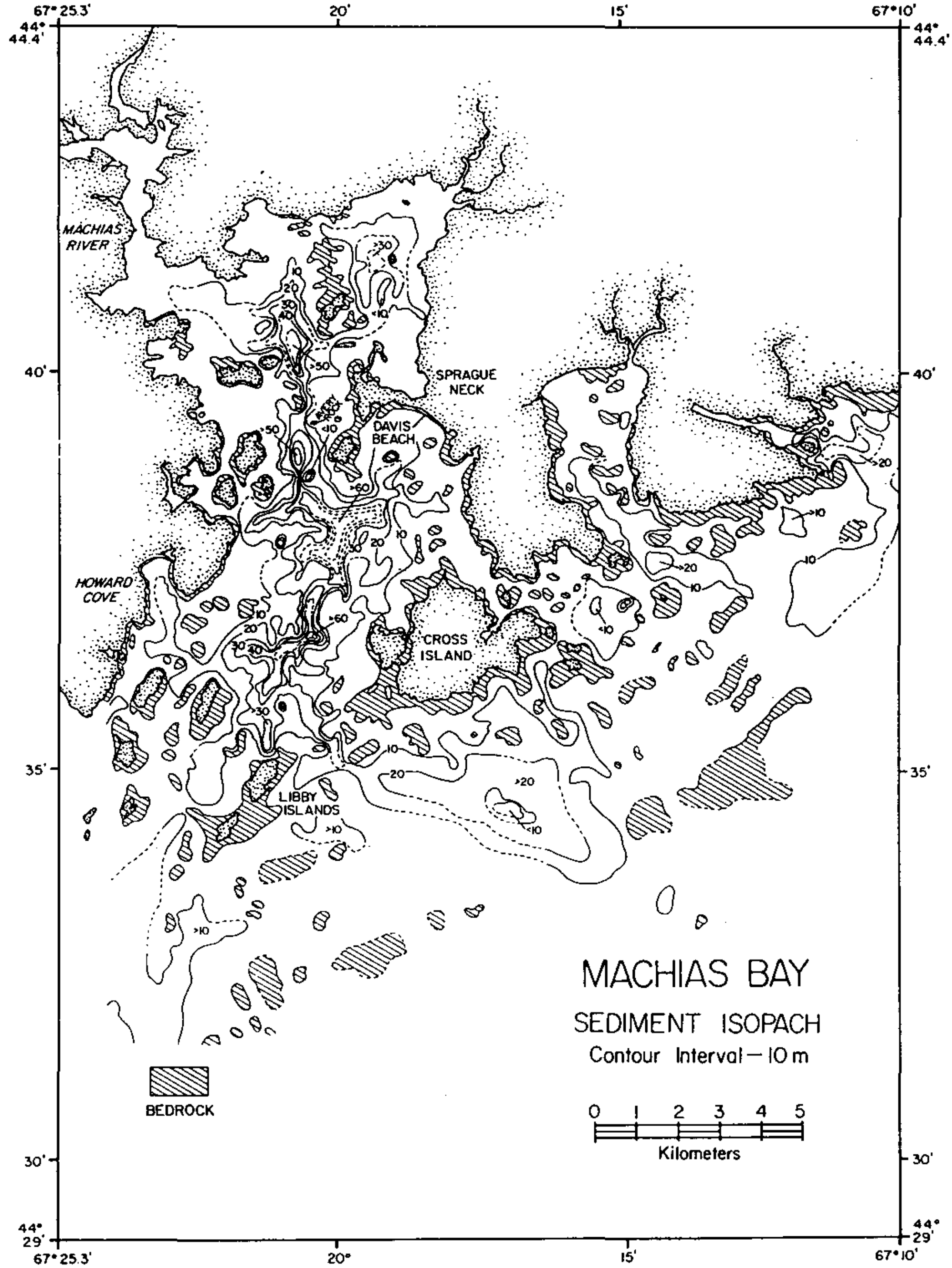


Figure 23. Sediment isopach map of Machias Bay (from Shipp, 1989).

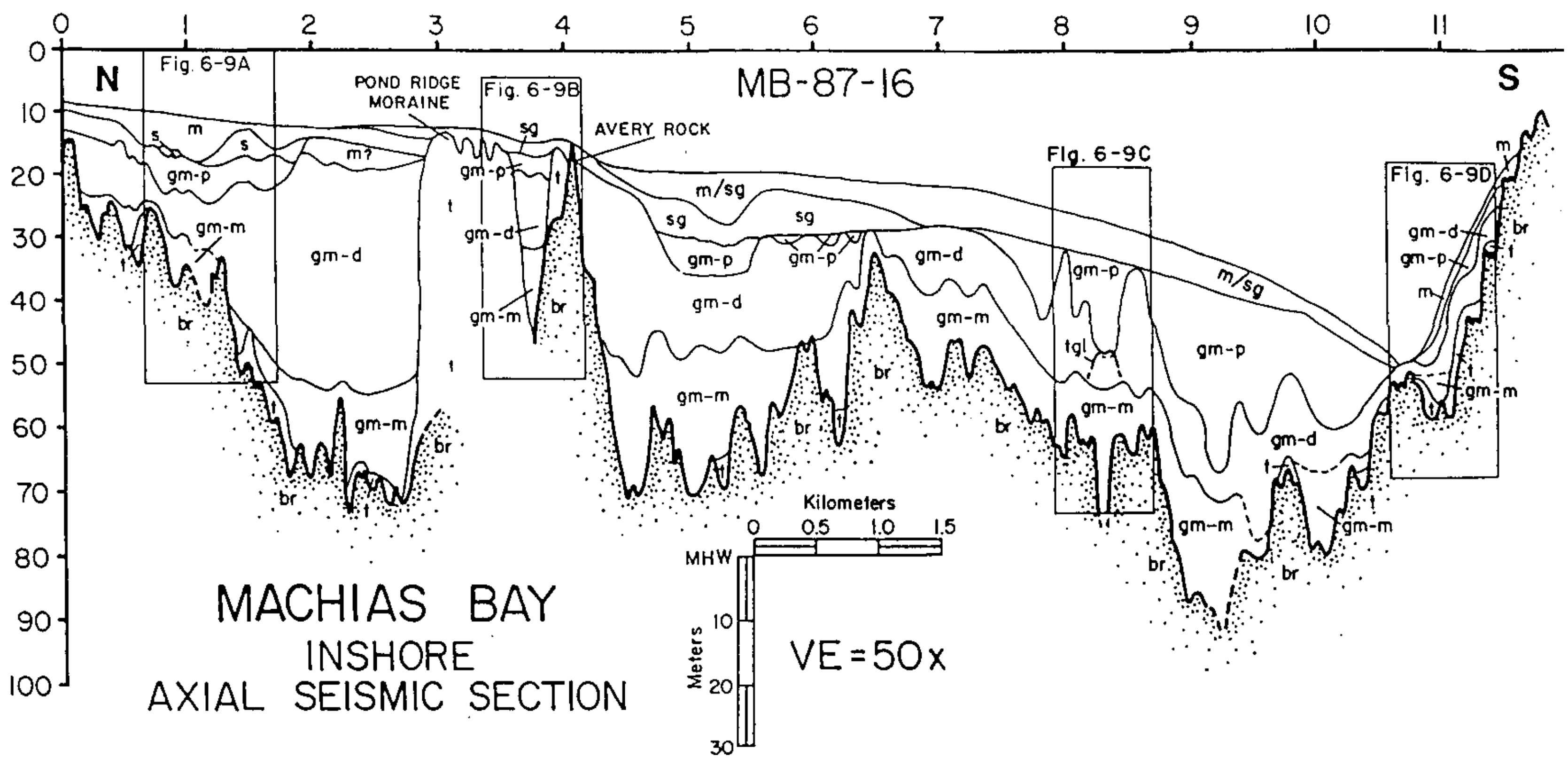


Figure 24. Axial seismic section through Machias Bay (from Shipp, 1989).

MACHIAS BAY

INSHORE AXIAL SECTION COMPOSITE

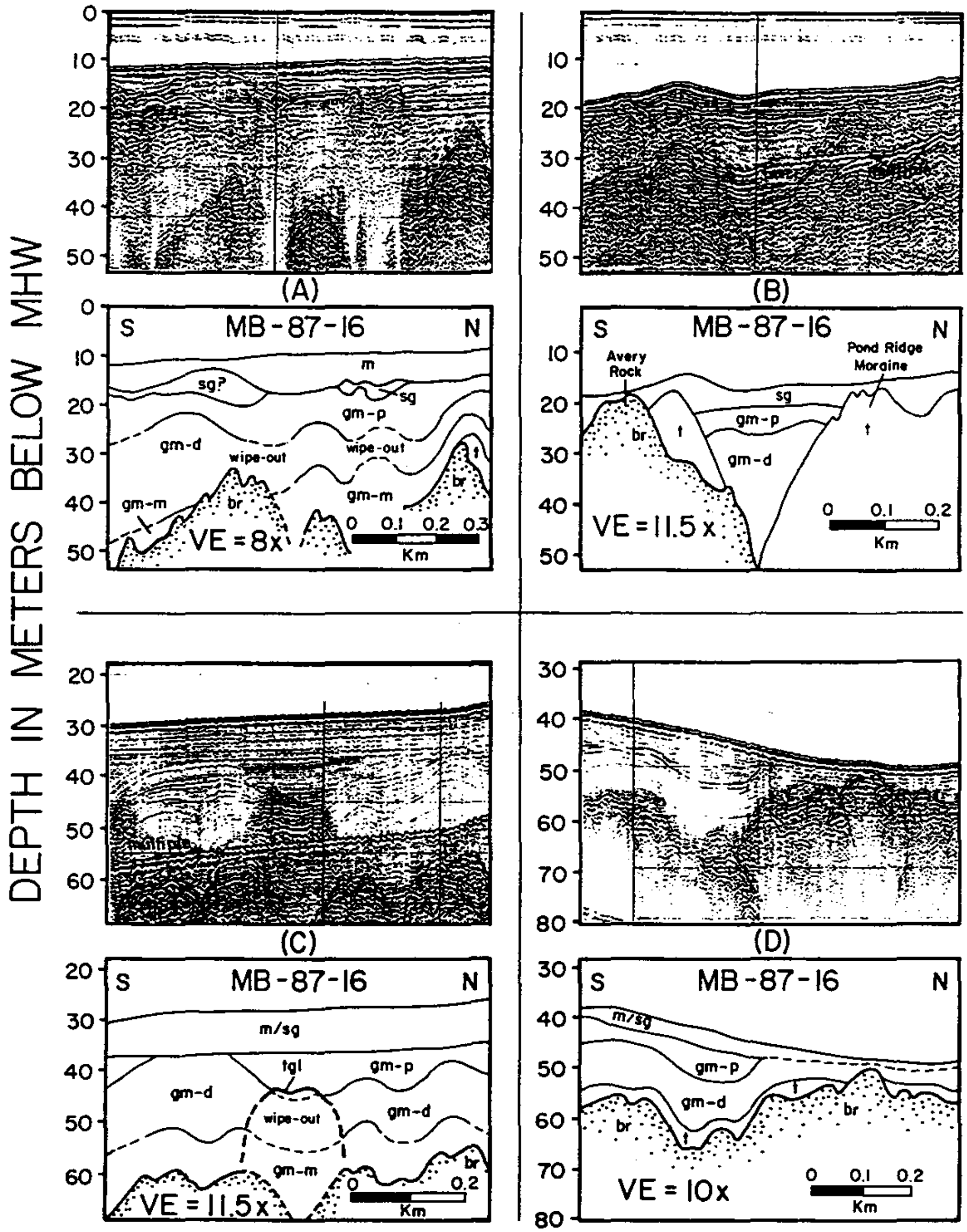


Figure 25. Original and interpreted seismic reflection records from axial seismic section through Machias Bay (from Shipp, 1989). Figures located on Figure 24.

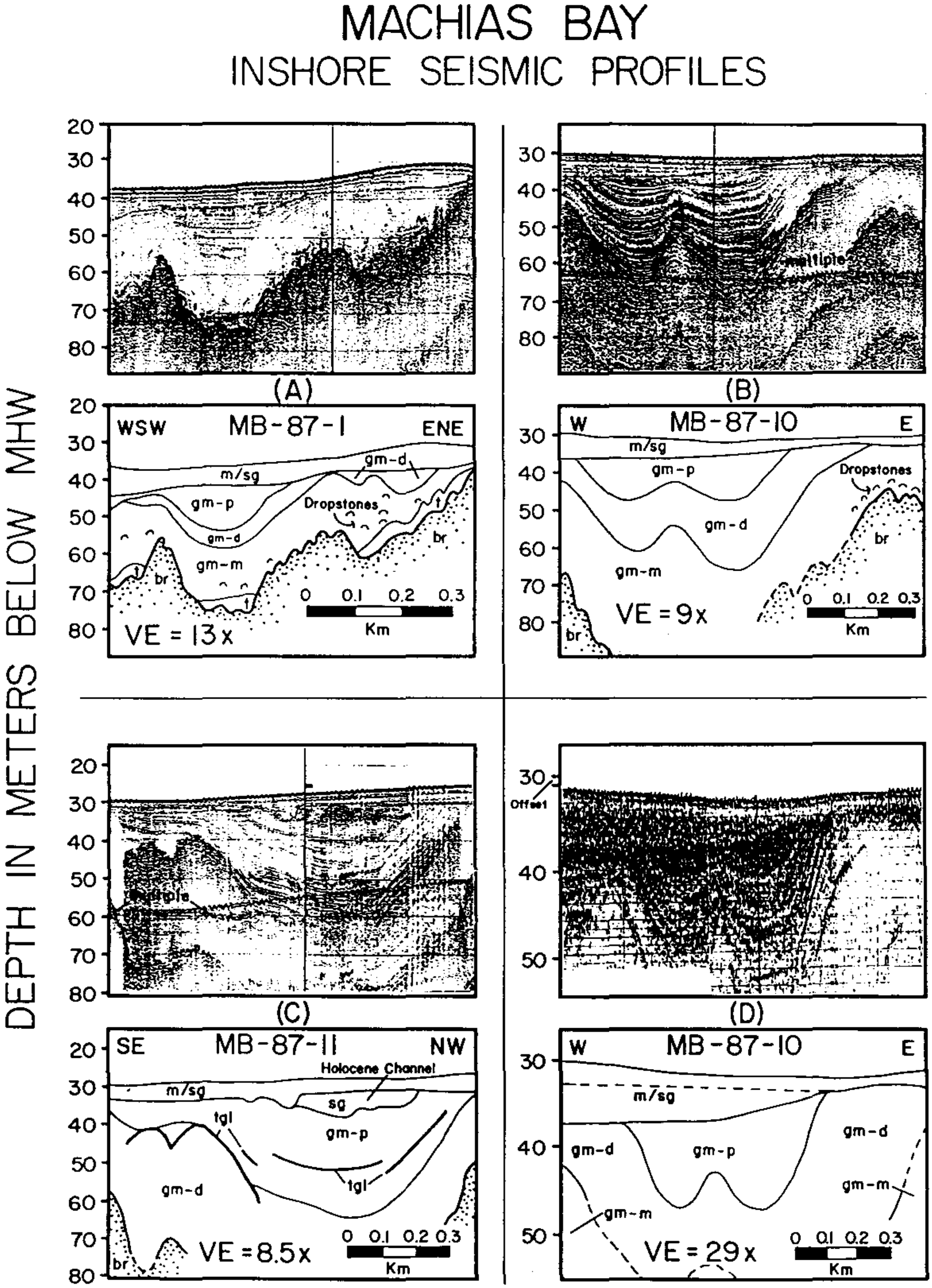


Figure 26. Interpreted and original seismic sections through Machias Bay (from Shipp, 1989).

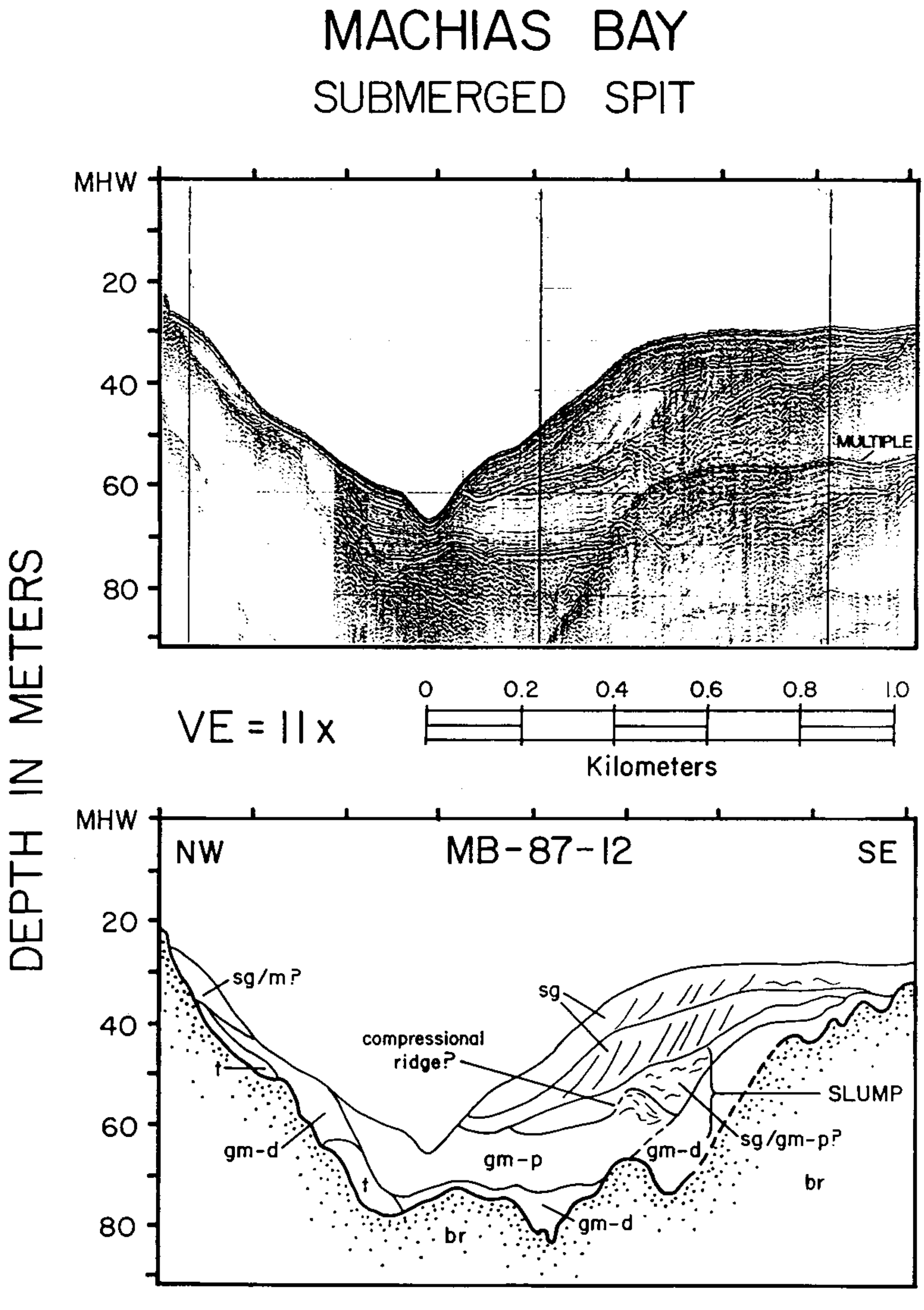
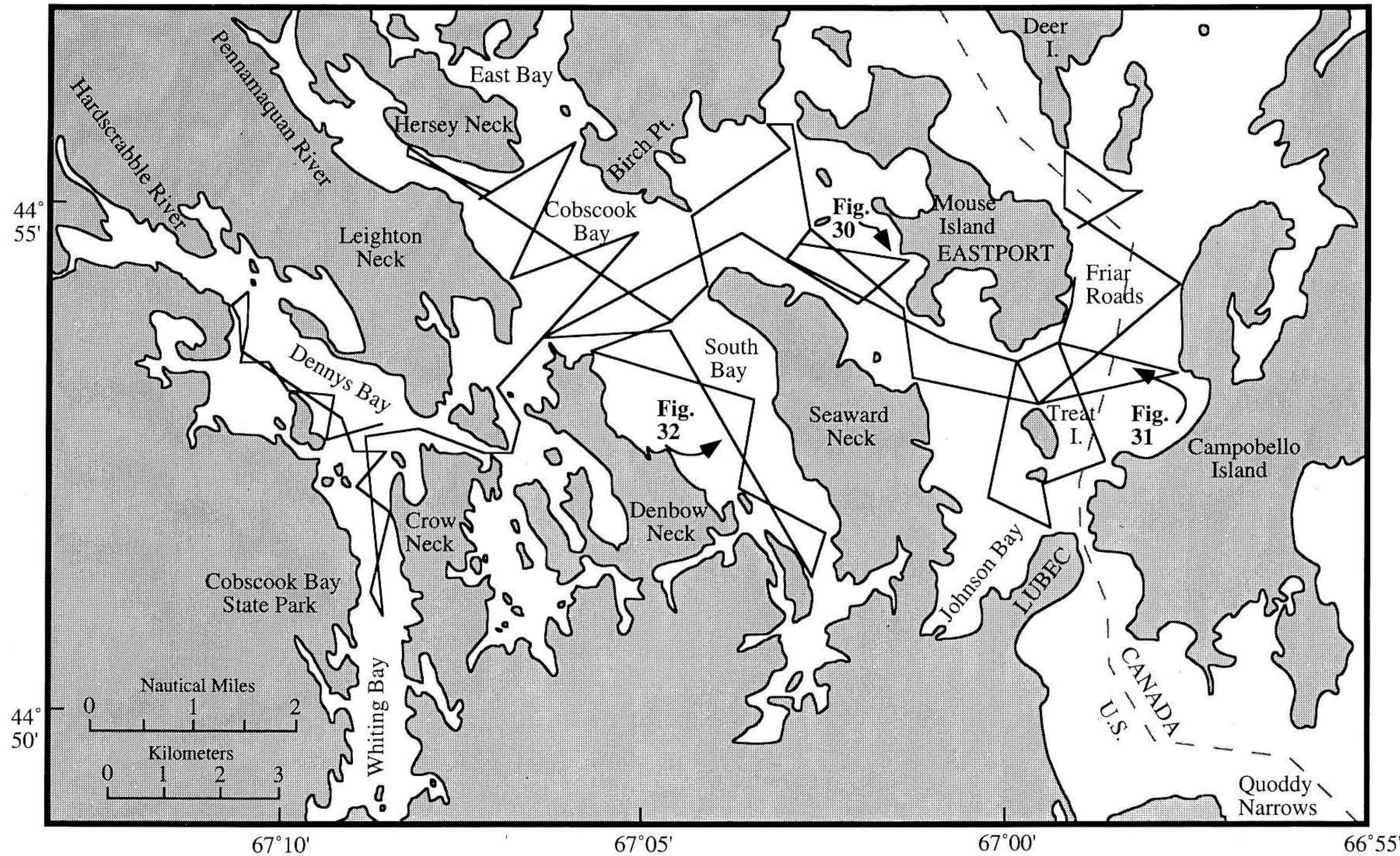


Figure 27. Interpreted seismic reflection profile over a possible drowned spit off Libby Island (from Shipp, 1989).

Figure 28. Seismic reflection profiles from Cobscook Bay (modified from Kelley et al., 1989). Locations of figures used in text are indicated.



SEISMIC REFLECTION PROFILES OF COBSCOOK BAY

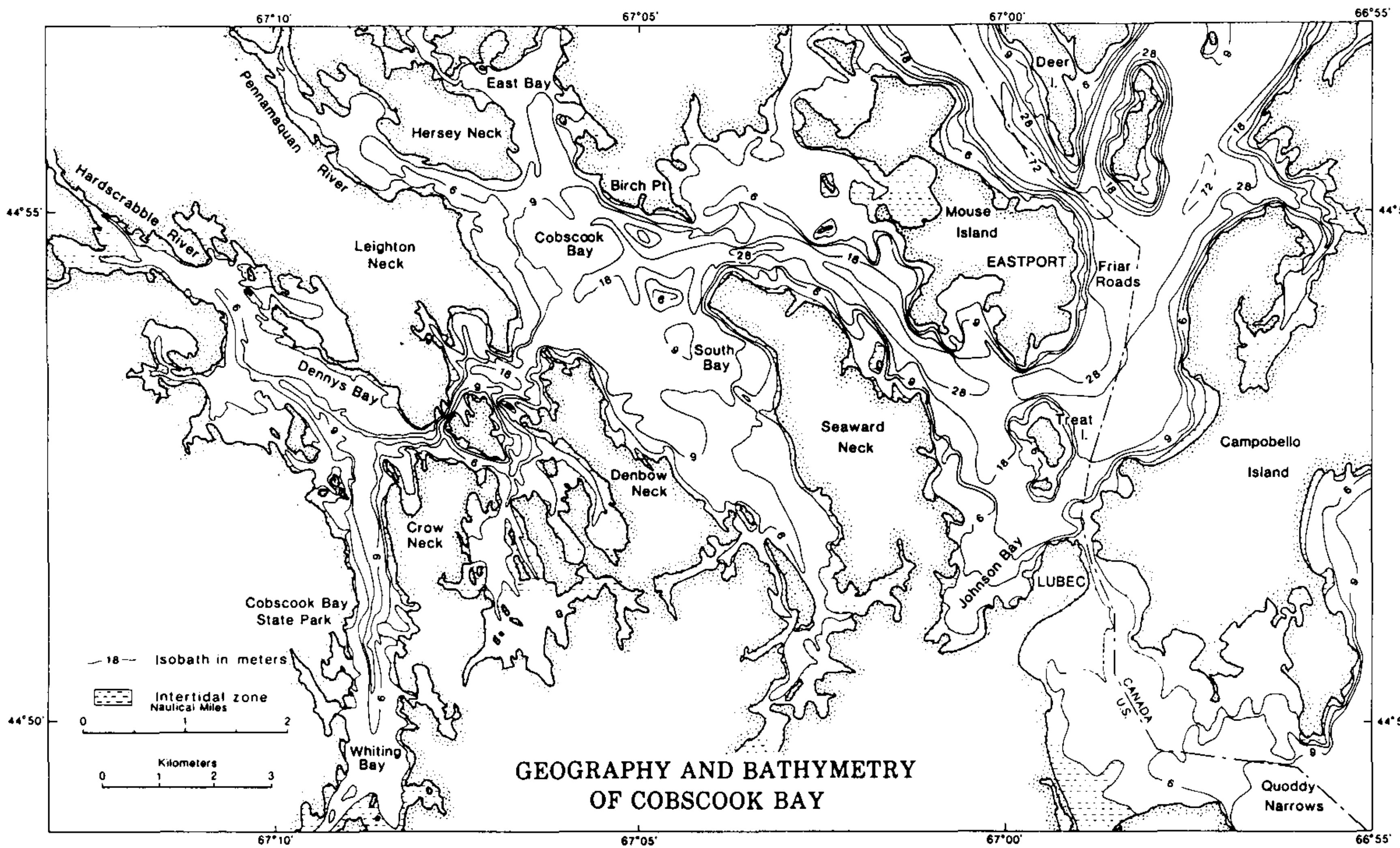


Figure 29. Bathymetry of Cobscook Bay (from Kelley et al., 1989).

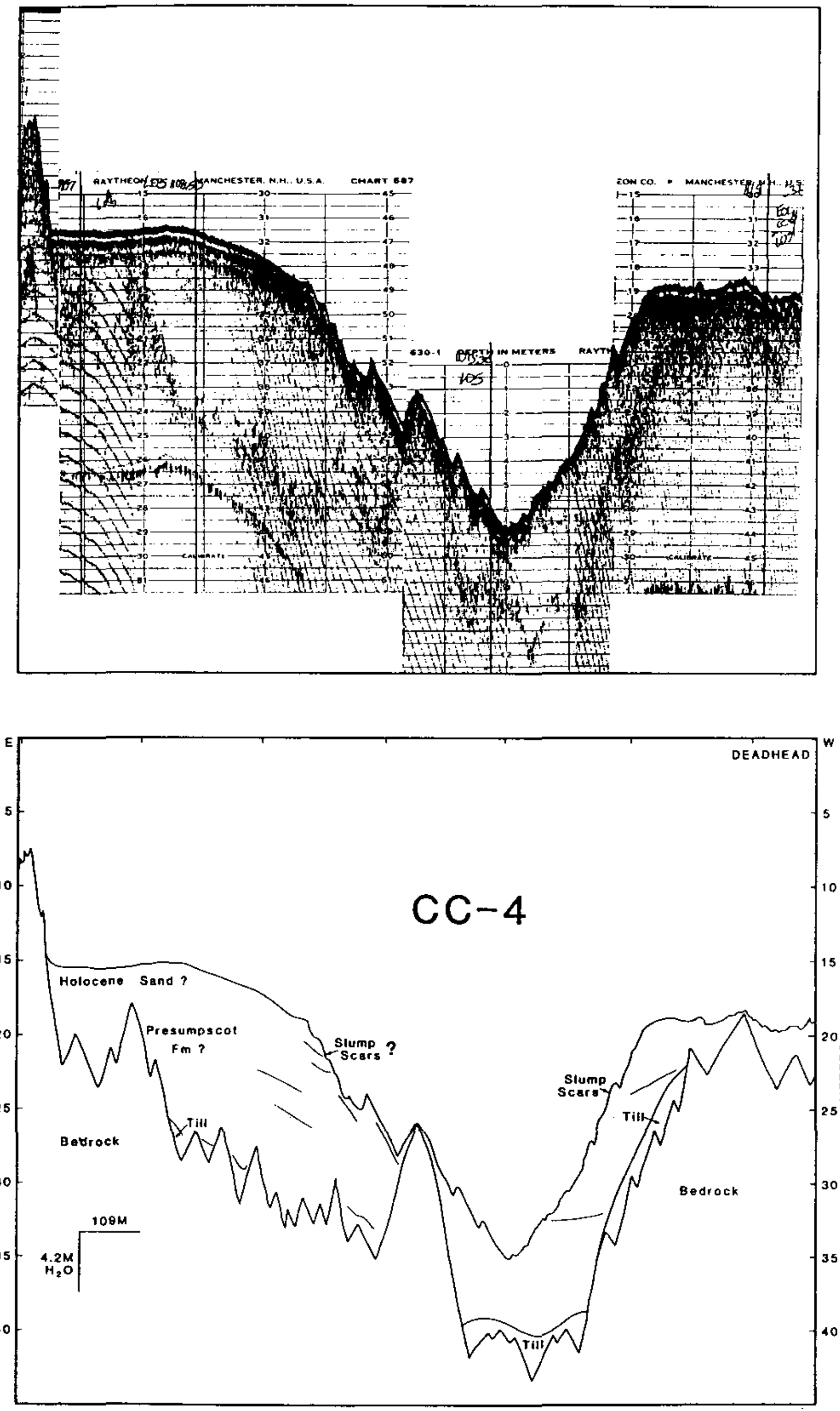
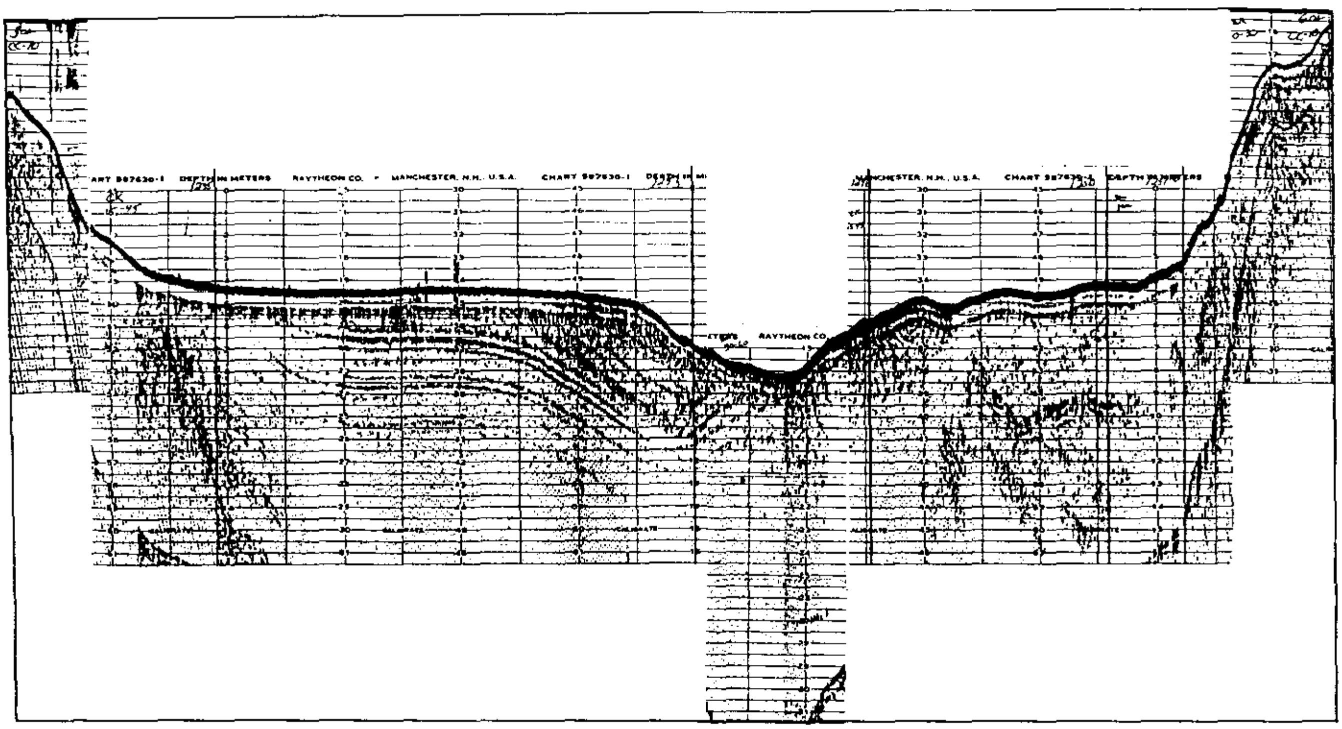


Figure 30. Seismic reflection profile from Cobscook Bay showing slump scars in presumed glaciomarine sediment. Holocene sediment may be absent here (from Kelley et al., 1989).



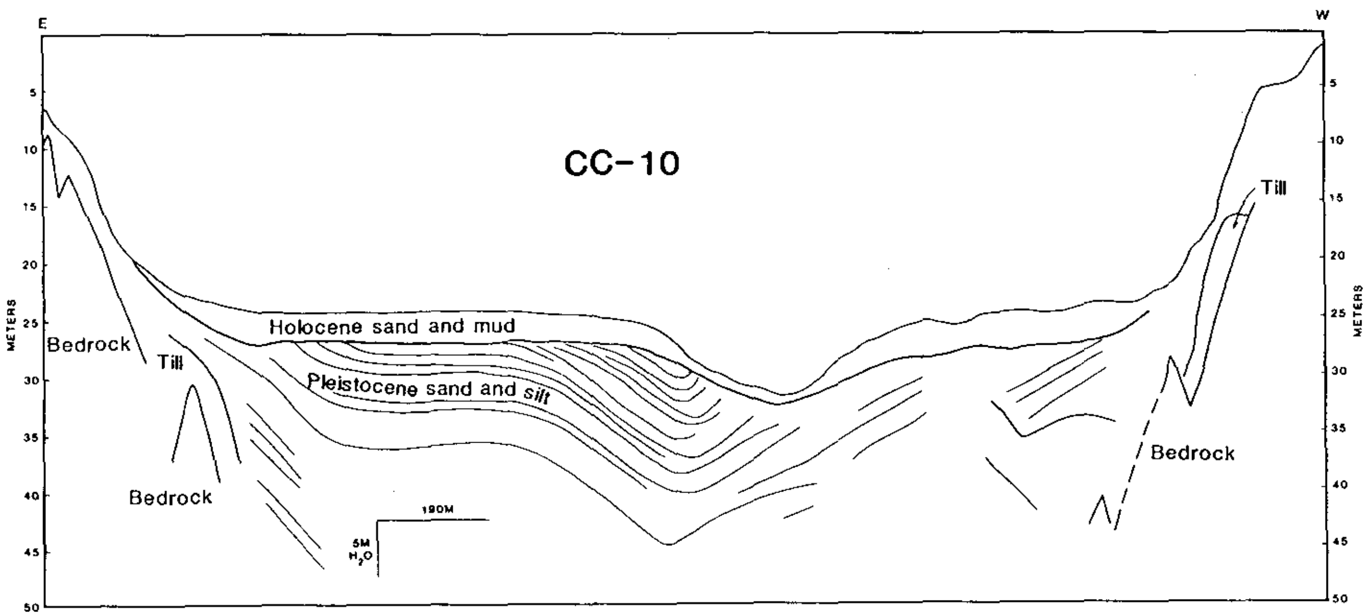
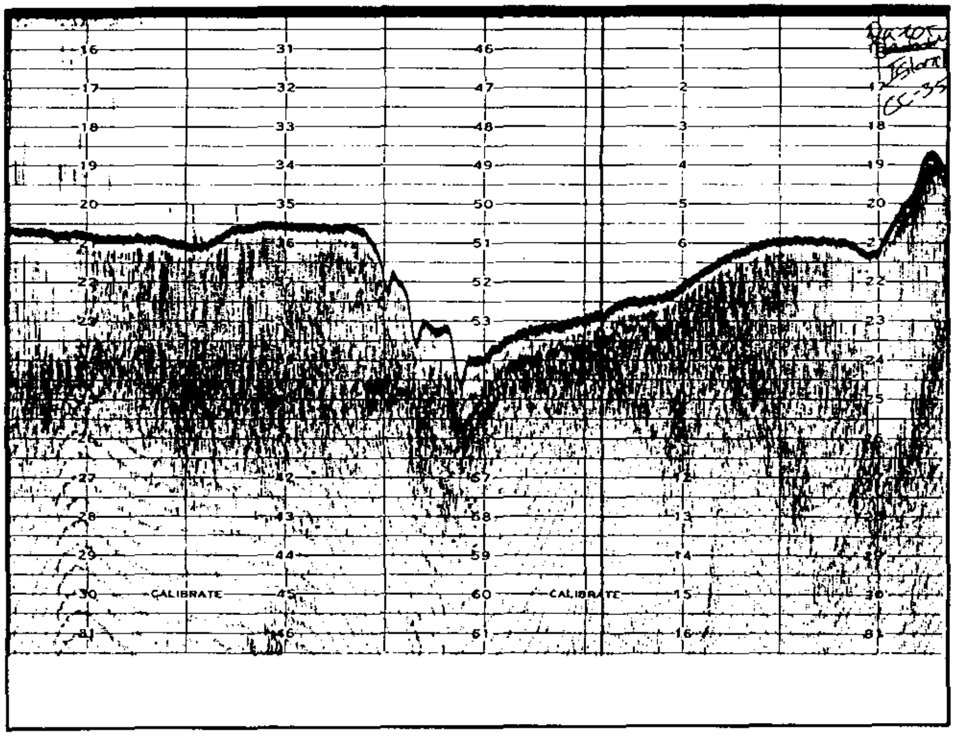


Figure 31. Cross section between Campobello Island and Eastport showing the apparent lack of Holocene sediment and eroding glaciomarine sediment (from Kelley et al., 1989).



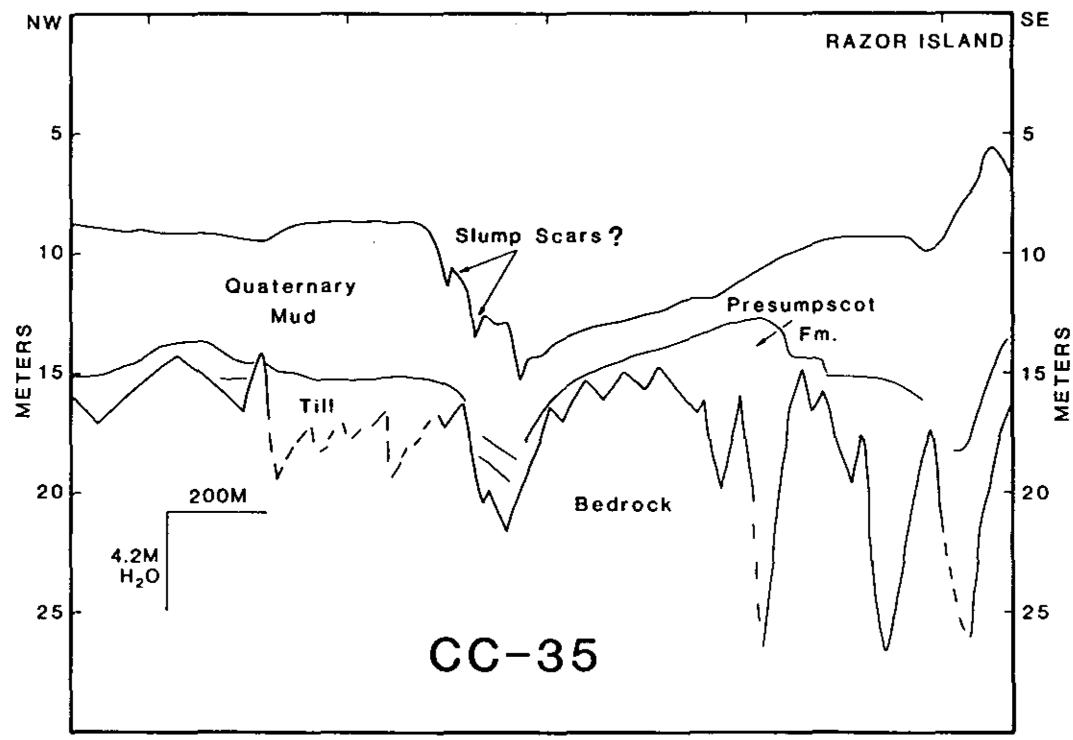


Figure 32. Seismic reflection profile across relatively thick section of Holocene sediment in a protected portion of Cobscook Bay (from Kelley et al., 1989).

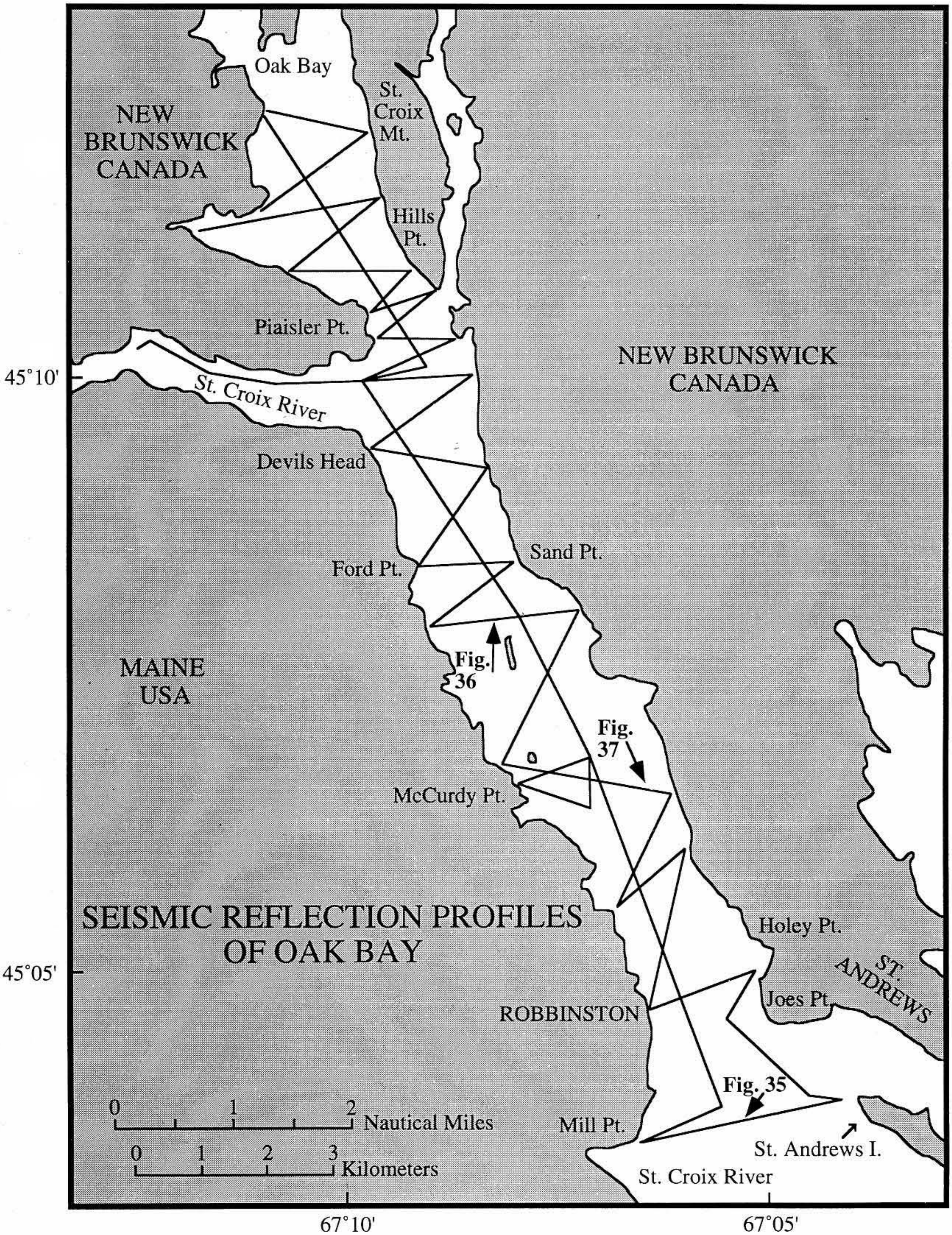


Figure 33. Location of seismic reflection profiles in Oak Bay. Location of data used in text is indicated (from Kelley et al., 1989).

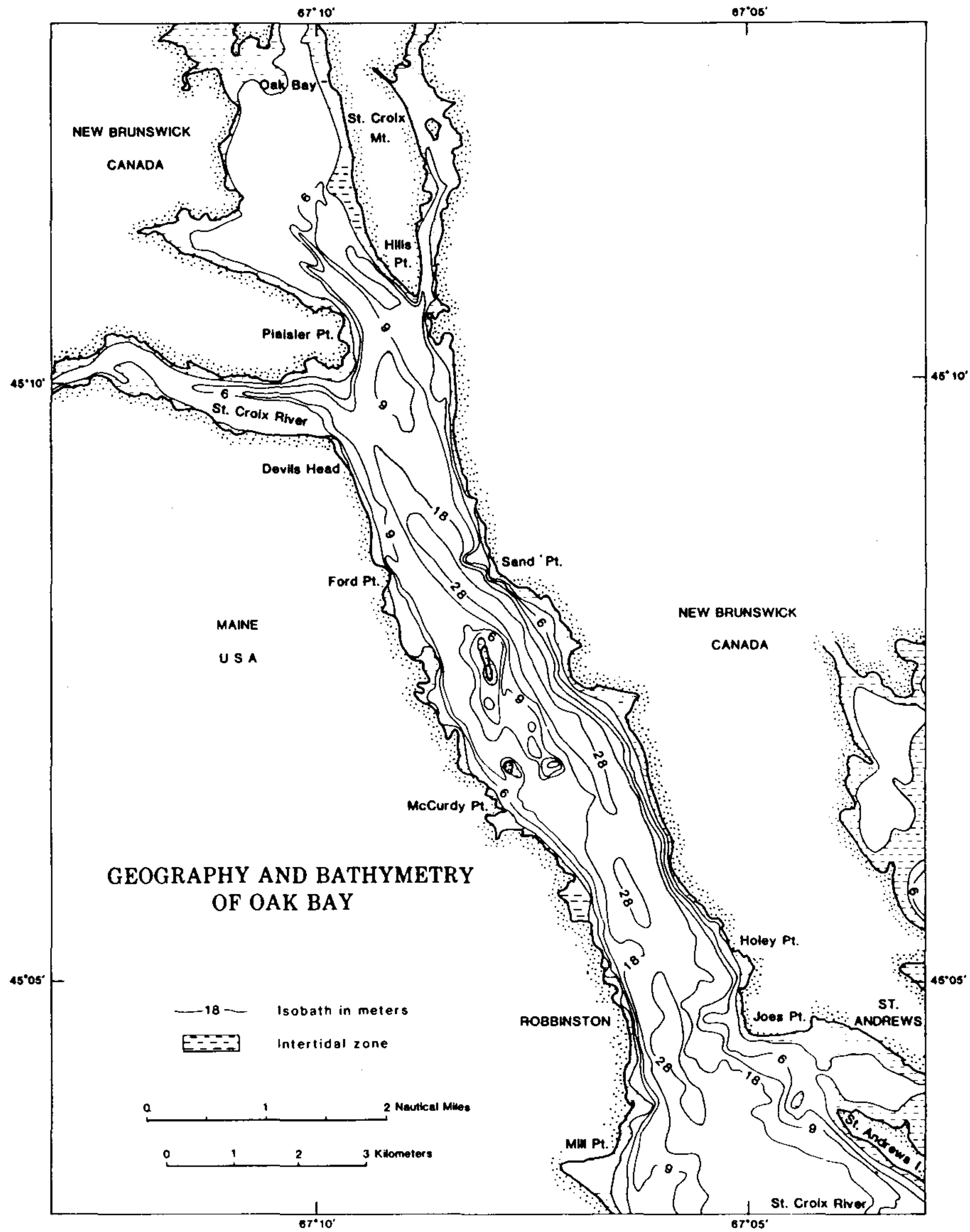


Figure 34. Bathymetry of Oak Bay (from Kelley et al., 1989).

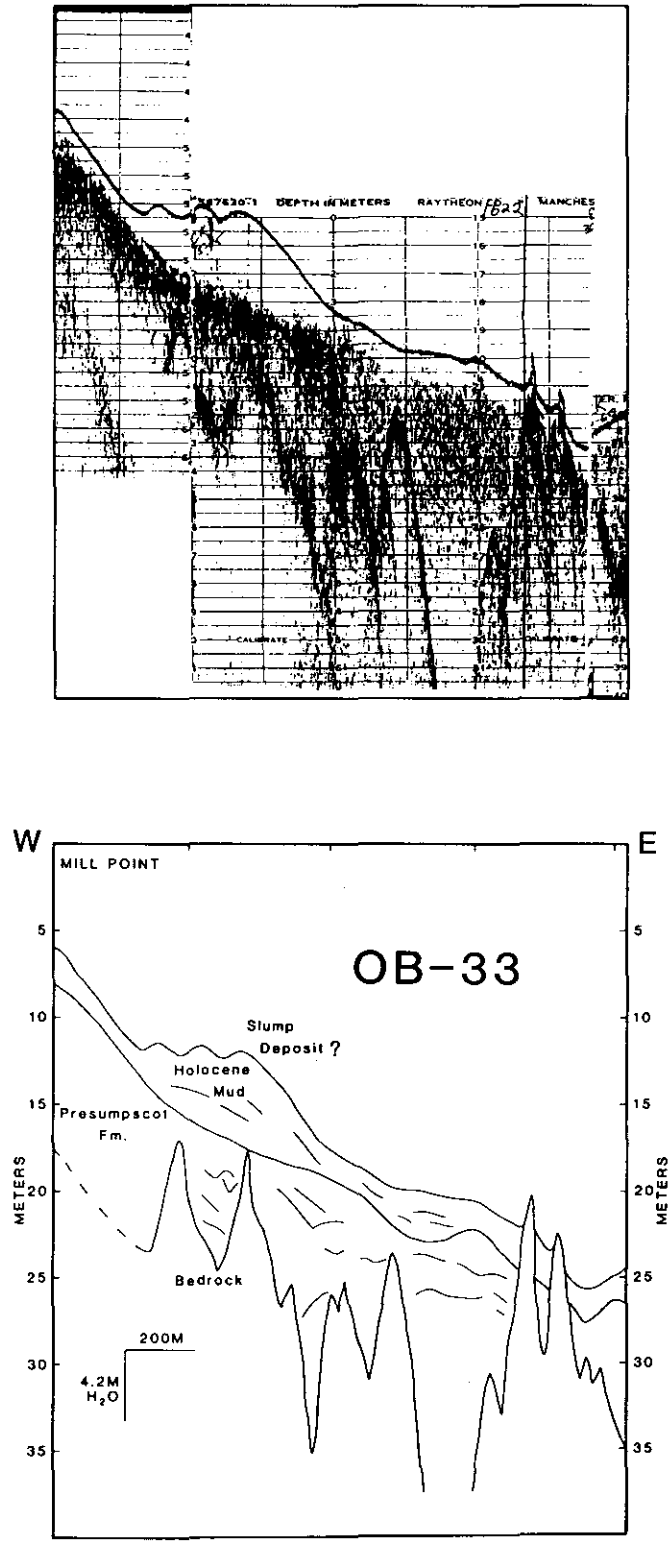


Figure 35. Seismic reflection profile extending into Oak Bay from the United States mainland (from Kelley et al., 1989). An apparent slump deposit occurs over the glaciomarine sediment.

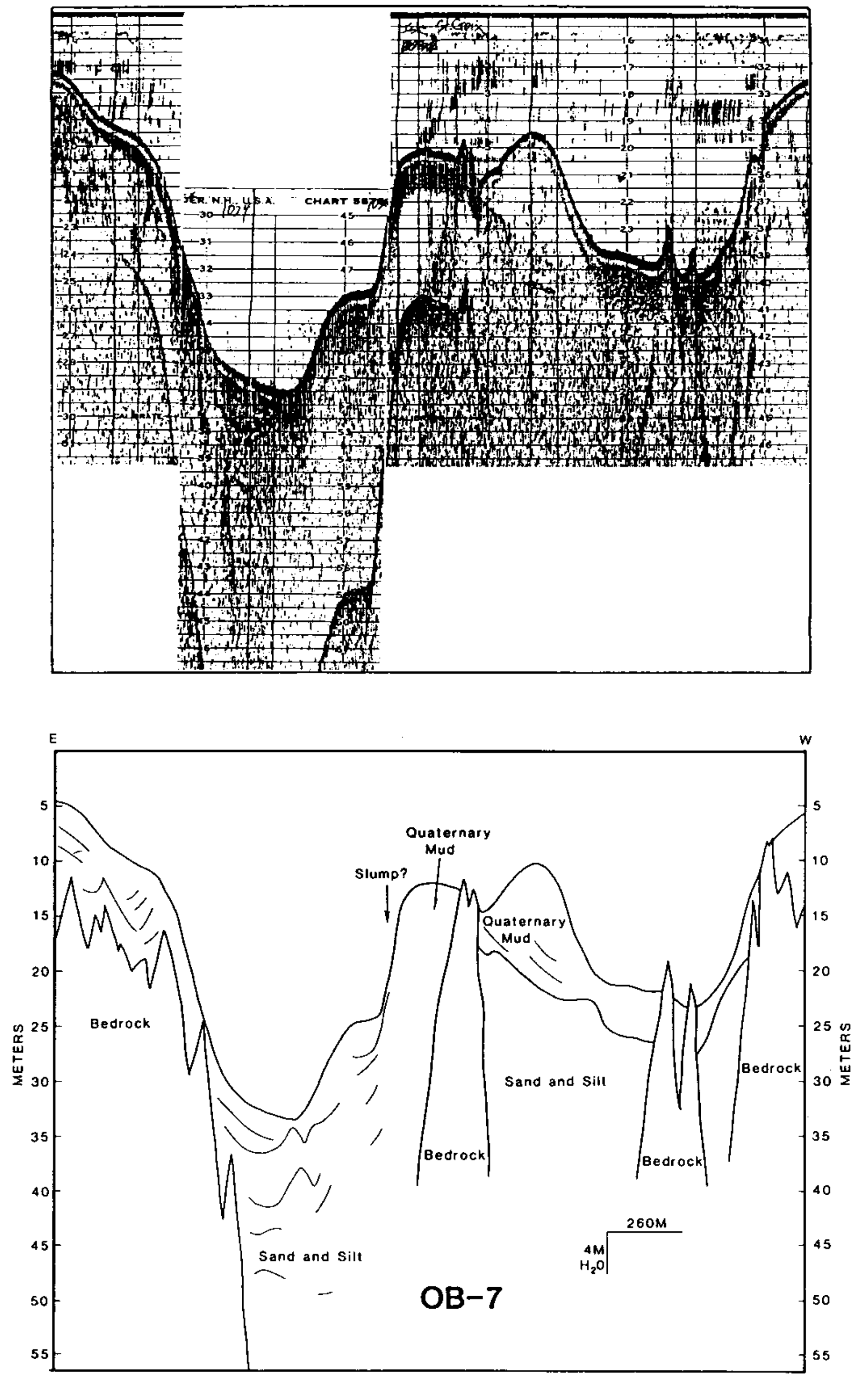


Figure 36. Extreme bedrock relief and a strongly reflecting surface obscur the seismic record from central Oak Bay (from Kelley et al., 1989).

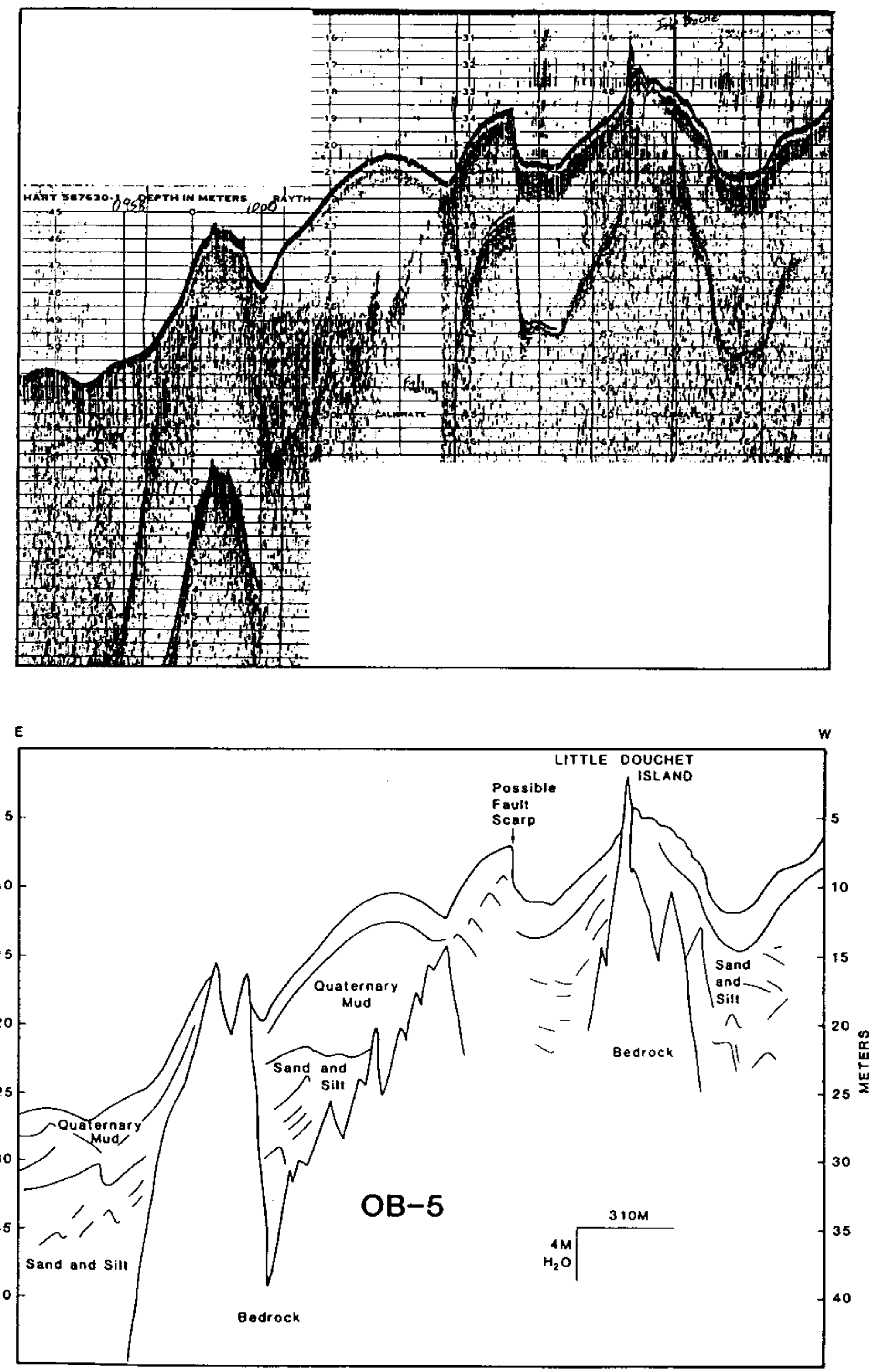


Figure 37. Holocene mud appears to rest over a strong seismic reflector marking the transgressive unconformity (from Kelley et al., 1989).

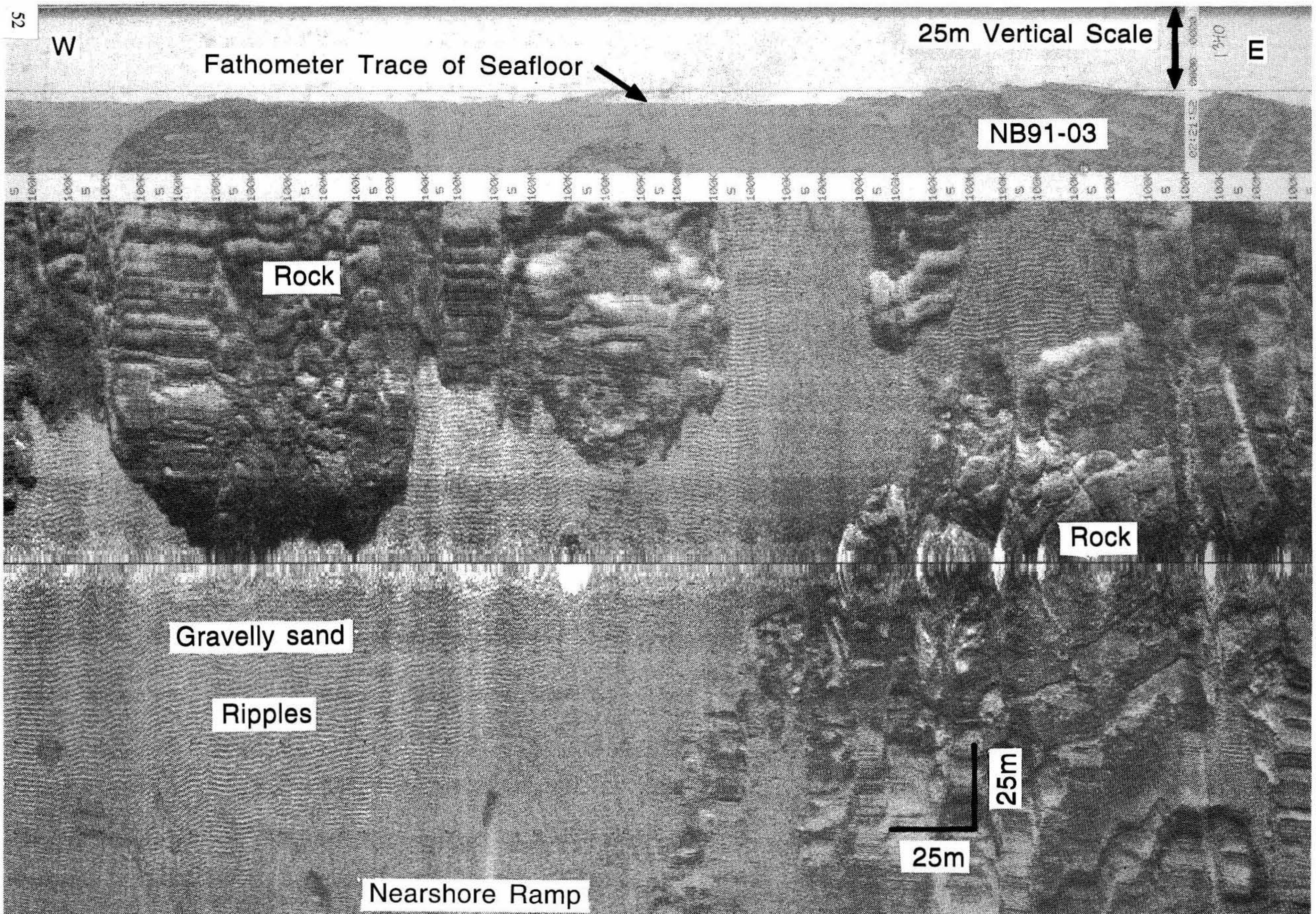


Figure 38. Side-scan sonar image from line NB91-03 of the Narraguagus Bay Nearshore Ramp. Time mark 1340 on the right margin of the image is located at 13589.9, 31782.1 LORAN-C or approximately 44° 27.9' N, 67° 47.8' W. Course 285° mag.

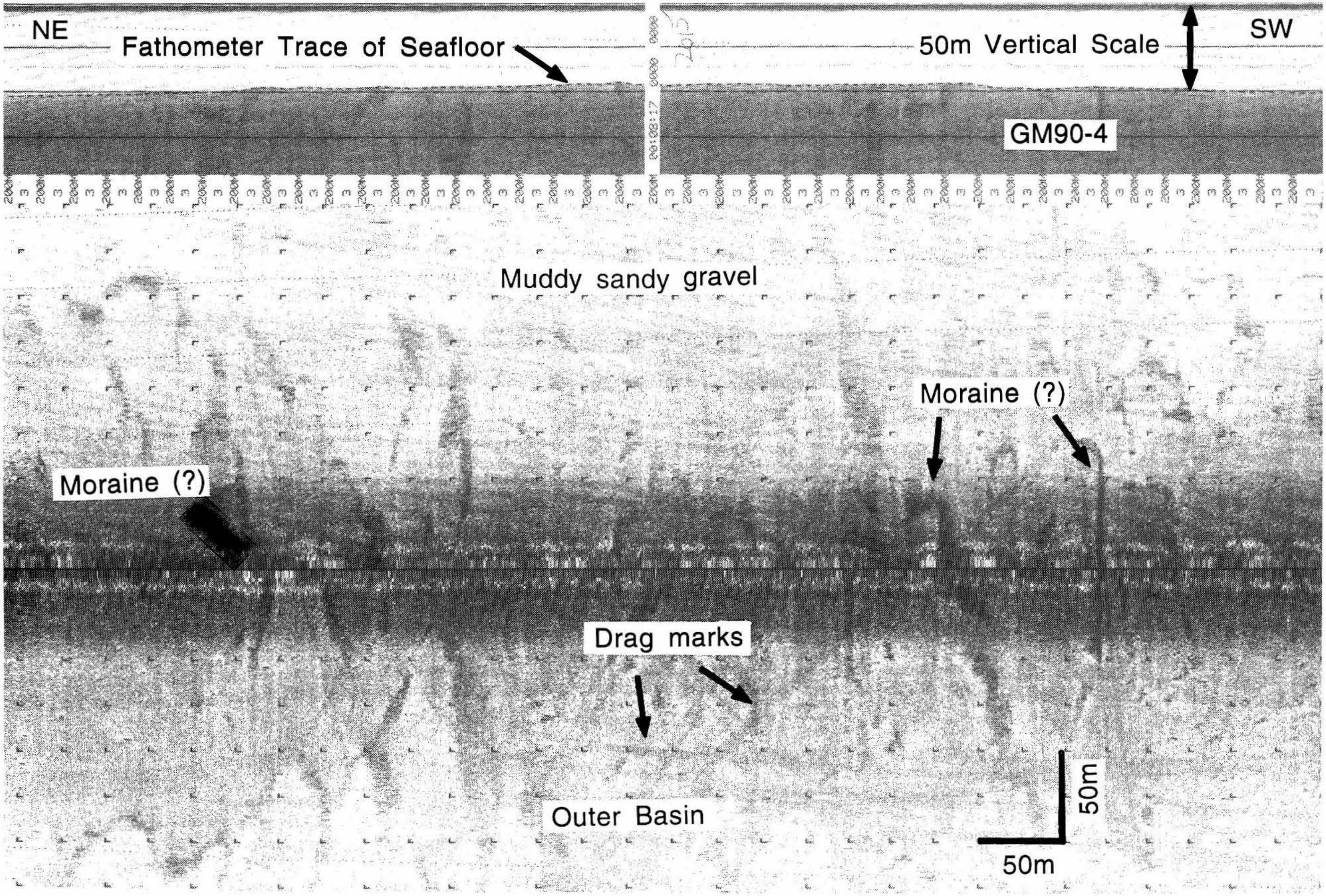


Figure 39. Side-scan sonar image from line GM90-4 (13722.2, 31619.7 LORAN-C position; 44° 35.0' N, 67° 10.6' W) in the Murr Basin. Water depth is about 80 meters. Numerous drag marks from fishing can be seen crossing coarse ridges. The event mark at the image center corresponds to the 2015 mark in Figure 40. Track heading 55° magnetic.

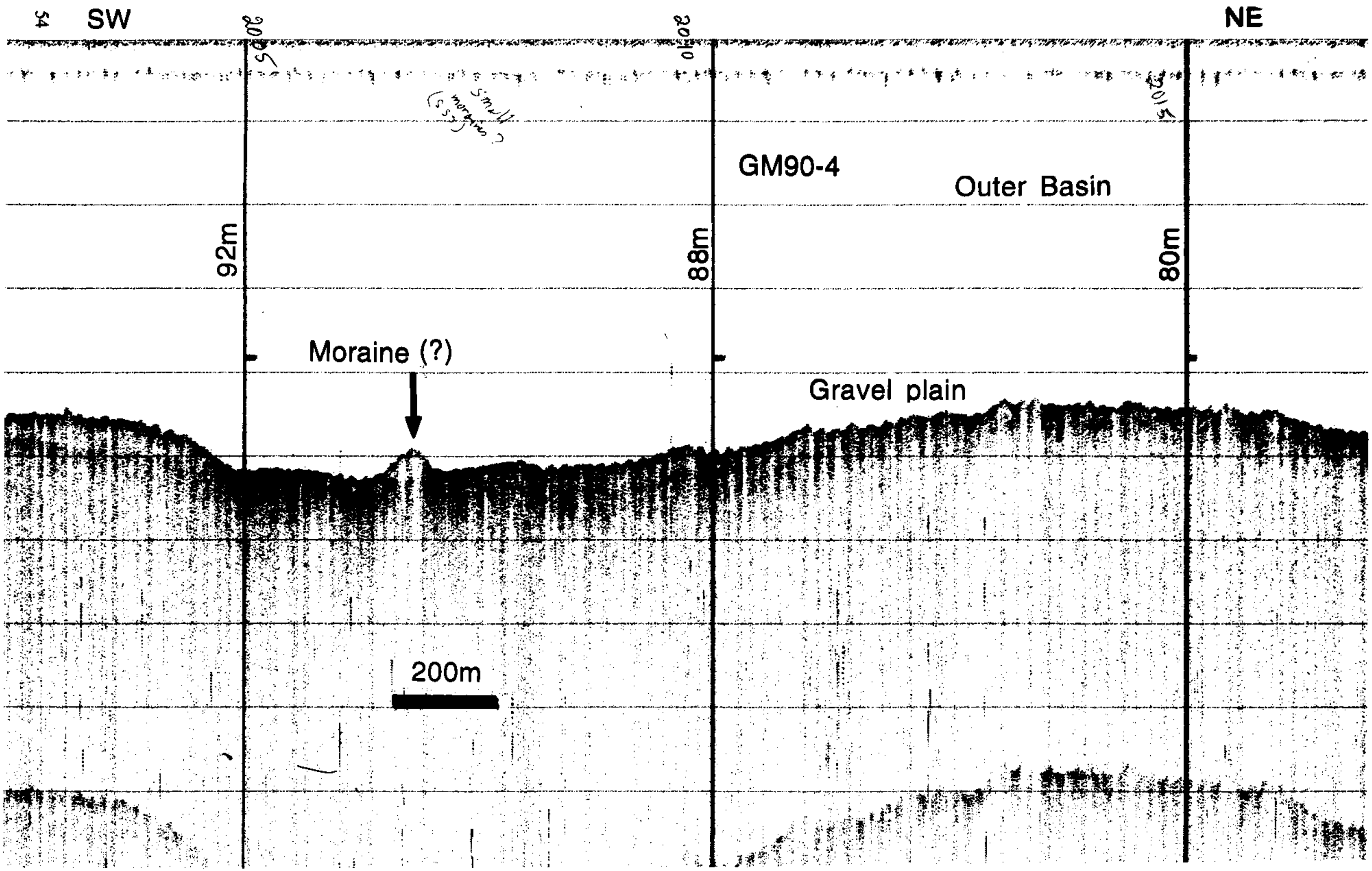


Figure 40. Seismic reflection profile from line GM90-4 in the Murr Basin. Position of 2015 event mark is given in the Figure 39 caption. One large and numerous smaller ridges could be moraines. Acoustic penetration is minimal suggesting a till or bedrock surface. The Murr Basin has a relief of 10 - 20 meters on the muddy, sandy gravel plain.

PLATES INCLUDED AS FOUR SEPARATE MAPS WITH THIS REPORT:

Plate 1. Offshore Geophysical Tracklines and Sediment Samples

Seismic reflection tracklines
Side-scan sonar tracklines
Simultaneous seismic reflection and side-scan sonar tracklines
Bottom sediment sample locations

Plate 2. Inner Continental Shelf Bathymetry

20 meter contour interval from 10 meters
From National Ocean Service 1:100,000 bathymetric maps

Plate 3. Inner Continental Shelf Surficial Geology

msG	=	Muddy, sandy gravel
mG	=	Muddy gravel
gms	=	Gravelly, muddy sand
M	=	Mud
Br	=	Bedrock

Plate 4. Physiographic Provinces

NB	=	Nearshore Basin
NR	=	Nearshore Ramp
SV	=	Shelf Valley
OB	=	Outer Basin
RZ	=	Rocky Zone

Geomorphology and Sedimentary Framework of the Inner Continental Shelf of Downeast Maine

by Stephen M. Dickson, Joseph T. Kelley and Walter A. Barnhardt

Maine Geological Survey
DEPARTMENT OF CONSERVATION
Walter A. Anderson, State Geologist

1994
Open-File No. 94-11

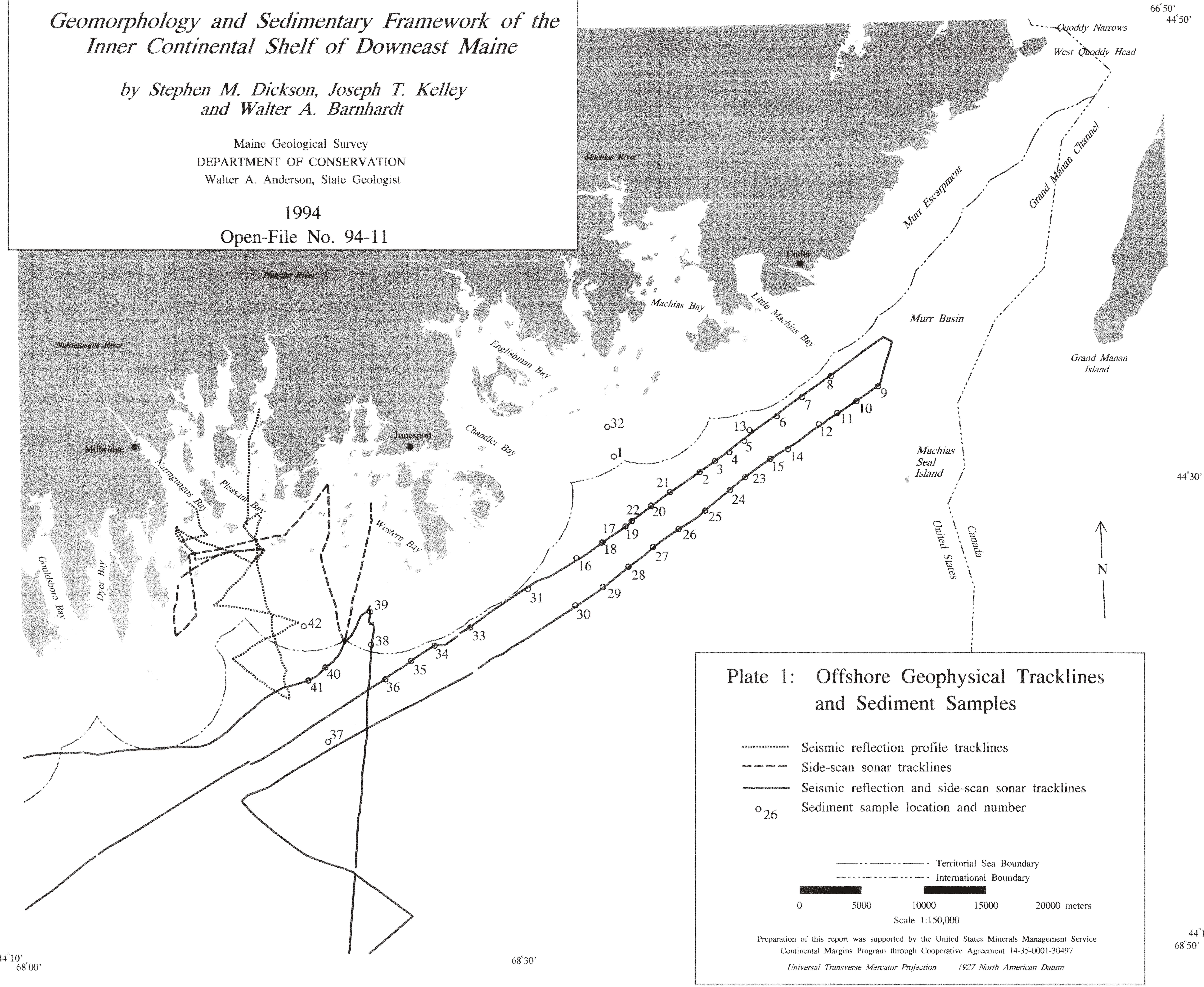


Plate 1: Offshore Geophysical Tracklines and Sediment Samples

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Universal Transverse Mercator Projection 1927 North American Datum

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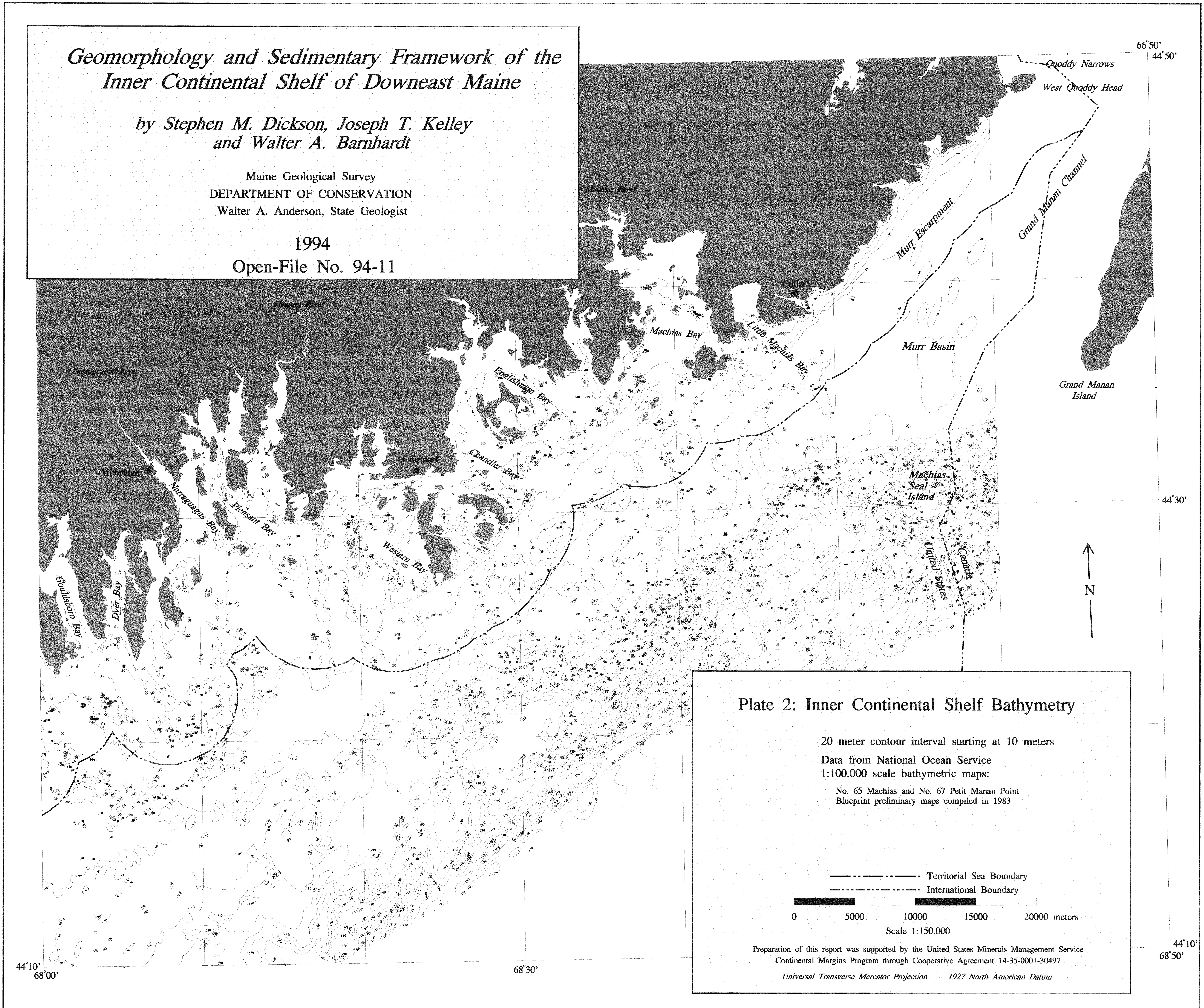

Plate 2: Inner Continental Shelf Bathymetry

20 meter contour interval starting at 10 meters
Data from National Ocean Service
1:100,000 scale bathymetric maps:

No. 65 Machias and No. 67 Petit Manan Point
Blueprint preliminary maps compiled in 1983

Territorial Sea Boundary
International Boundary

0 5000 10000 15000 20000 meters
Scale 1:150,000

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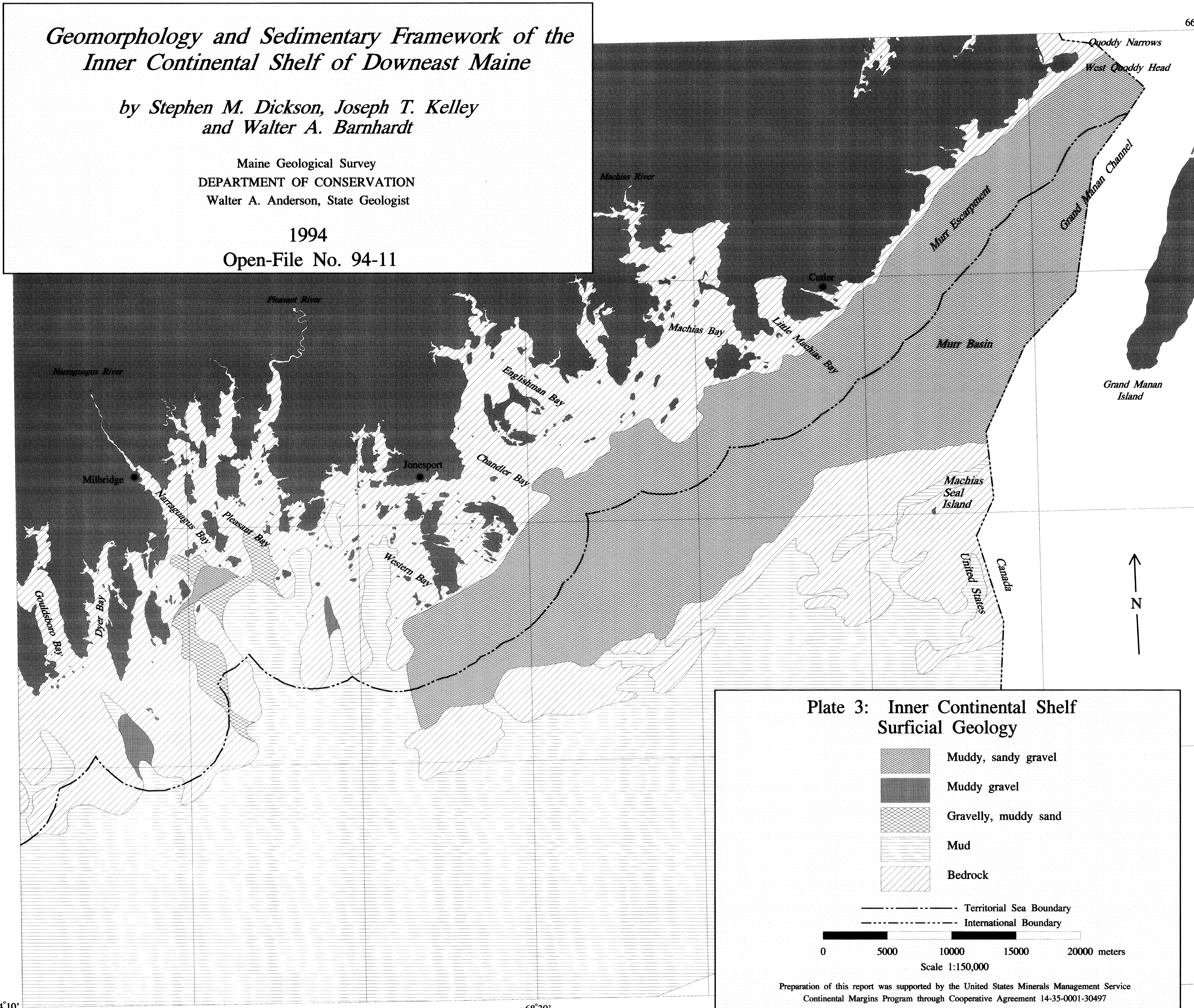

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Universal Transverse Mercator Projection *1927 North American Datum*

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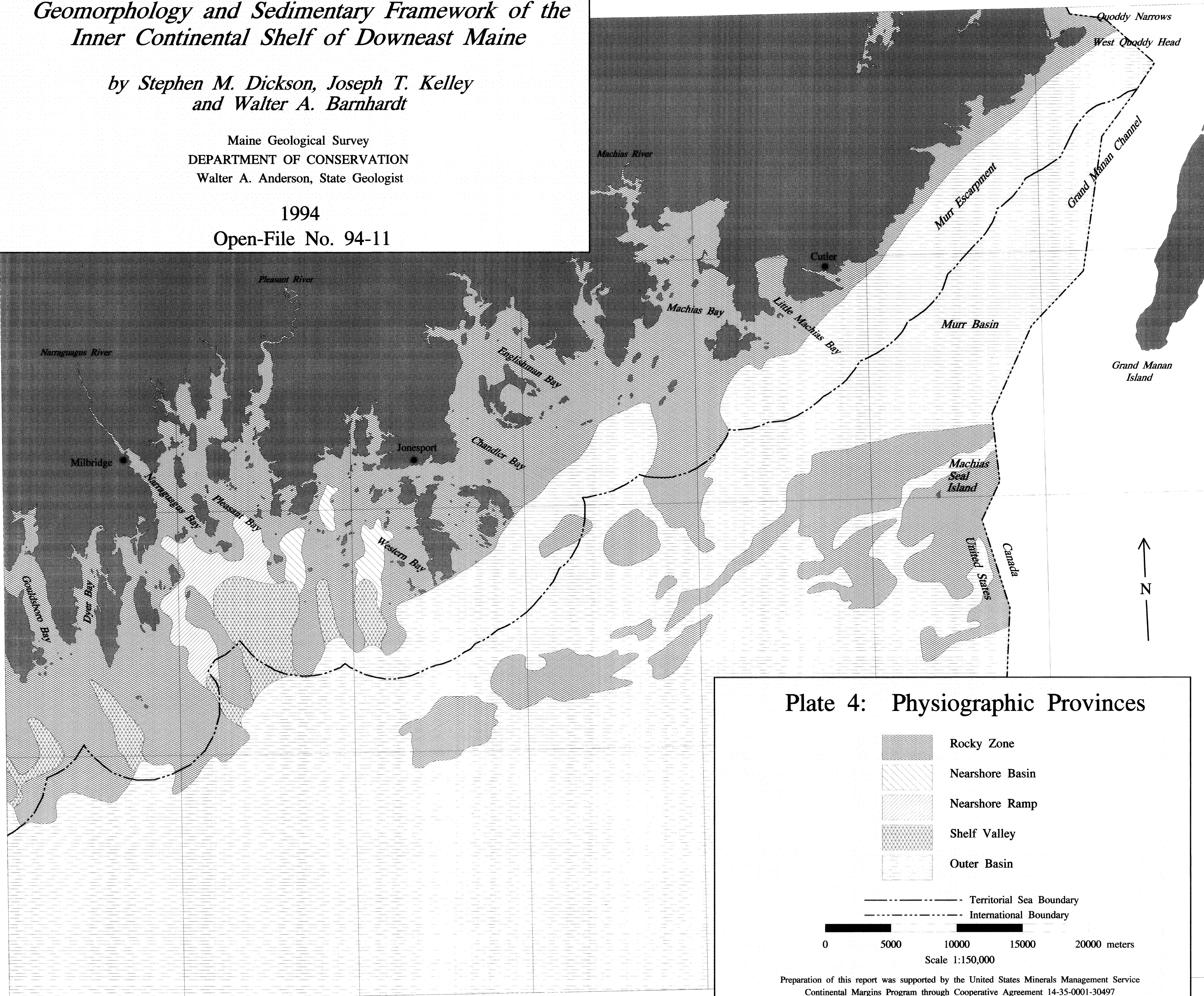

Plate 4: Physiographic Provinces

- Rocky Zone
- Nearshore Basin
- Nearshore Ramp
- Shelf Valley
- Outer Basin

Territorial Sea Boundary
International Boundary

0 5000 10000 15000 20000 meters
Scale 1:150,000

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