U.S. DEPARTMENT OF THE INTERIOR
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# GEOPHYSICAL INVESTIGATION OF THE NEARSHORE GEOLOGIC FRAMEWORK, EASTERN CASCO BAY - REID STATE PARK, MAINE: DATA ANALYSIS AND IMPLICATIONS FOR LATE QUATERNARY COASTAL EVOLUTION

by

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# INTRODUCTION

Stratigraphic and evolutionary models of barrier coasts rely heavily on an understanding of the antecedent topography and sea-level history of the region, and preservation potential of barrier and estuarine facies (Belknap and Kraft, 1981; Davis and Clifton, 1987). This is particularly true along structurally-controlled and fluvially-supplied settings, such as the peninsular coast of Maine. Mapping of the nearshore basement topography is one of the primary tasks in determining the distribution and relative elevation of former valley divides and drainage courses at various times during late Quaternary. Changes in accommodation space available for deposition of fluvial and coastal sediments in a regime of fluctuating sea level can also be evaluated. The present study consists of 105 km of high-resolution shallow seismic-reflection surveys and was conducted in two legs (September of 1996 and 1997). Nearshore seismic profiles (primarily < 20 m water depth) were used for mapping the basement morphology and sediment thickness along coastal Sagadahoc County, south-central Maine. The study area extends from the New Meadows Valley eastward to western border of the Sheepscot River valley (Fig. 1). The goal of this investigation was to extend the previously collected seismic-reflection data on the inner shelf (Kelley *et al.*, 1987, 1992; Belknap *et al.*, 1989; Belknap and Shipp (1991); Barnhardt *et al.*, 1997) in an onshore direction, where this information can be integrated with high-resolution Ground-Penetrating Radar (GPR) profiles obtained from the adjacent barriers (Buynevich *et al.*, 1996). In addition, seismic profiling of the New Meadows River paleovalley was undertaken in order to map the Quaternary sediment fill and investigate the possibility of a regressive fluvial-deltaic origin for the western lobe of the Kennebec River Paleodelta.

The tasks of this study were to: 1) investigate the nearshore basement morphology;
2) determine the total sediment thickness in different physiographic regions;
3) map the former valleys of the Kennebec-Androscoggin River system and determine the nearshore paleodrainage pathways; 4) examine the role of antecedent topography in controlling the patterns of sediment dispersal and onshore sediment reworking and barrier formation during the later stages of Holocene transgression.

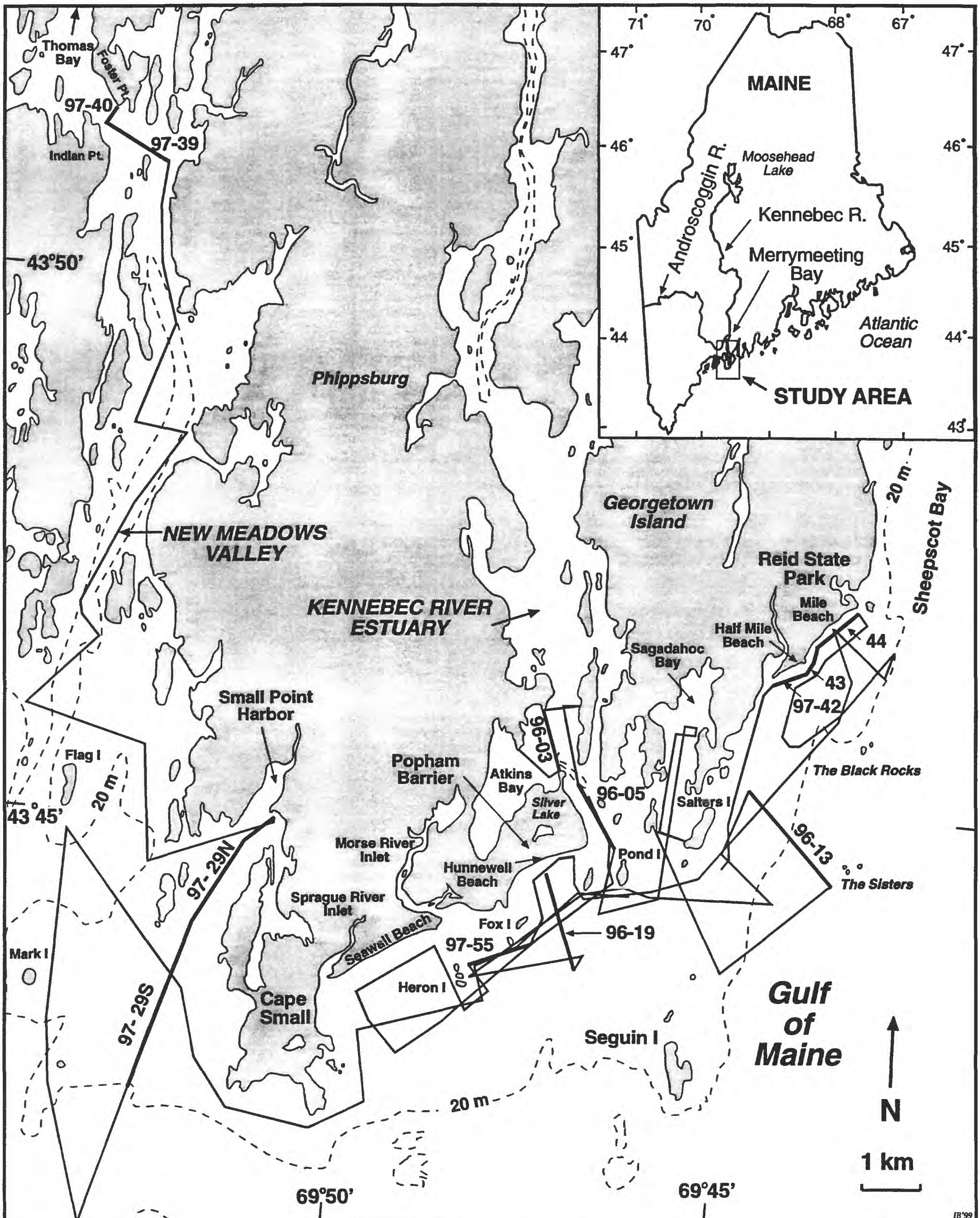


Figure 1. Location of the study area and 1996-97 seismic coverage. Transects shown as figures are numbered.

## PREVIOUS WORK

In the past 50 years a number of seismic-stratigraphic, geomorphic, and evolutionary studies have been carried out in the northwestern Gulf of Maine. Seismic investigations of the Maine inner shelf in the period of 1957-1986 are summarized in Kelley *et al.* . (1987, Table 1). Since that time Belknap *et al.*. (1987, 1989), Kelley *et al.*. (1989a, b, c), Kelley and Belknap (1988, 1989), Belknap and Shipp (1991), and Shipp *et al.* . (1989, 1991) have conducted extensive seismic studies, which together with vibracore and side-scan sonar data were used to formulate Late Quaternary seismic-stratigraphic and evolutionary models. In their study along the south-central inner shelf region between eastern Casco Bay and Pemaquid Point, Belknap *et al.* (1989) identified a large lobate sand deposit on the inner shelf as the Kennebec River Paleodelta (KRP) and described three major buried channels:

1) a basinward extension of the Kennebec River channel along the west flank of Salters-Seguin Island bedrock ridge;
2) a valley underlying Atkins Bay and Popham State Park, and
3) a seaward extension of Sprague River valley (Fig. 2A).

The switching of the Kennebec River channel near its present mouth was suggested to be responsible for large nearshore sand accumulations (Belknap *et al.* , 1989). Due to depositional character of the gently sloping KRP, it is classified as the nearshore ramp physiographic region of the inner shelf, bordered by the New Meadows shelf valley on the west and by Sheepscot shelf valley to the east (Kelley *et al.*, 1989a; 1992).

More recently, Barnhardt (1994) and Barnhardt *et al.* (1997) used geophysical and vibracore data to reconstruct the Late Quaternary evolution of the south-central inner shelf of Maine in response to relative sea-level change. The Kennebec River Paleodelta was subdivided into the east, south, and west lobes. The formation of the lobes took place during regressive, regressive-lowstand, and transgressive phases, respectively, with corresponding shoreline groups located at 30-40 m, 50-60 m, and 20-30 m depths (Barnhardt *et al.*, 1997; Fig. 2B). This research has also led to the present classification of seismic facies and construction of the offshore depth-to-bedrock and total sediment thickness maps (Barnhardt *et al.*, 1997). This report extends the existing seismic coverage onshore and discusses the implications of nearshore geologic framework for sediment dispersal patterns and evolution of coastal accumulation forms.

A

B

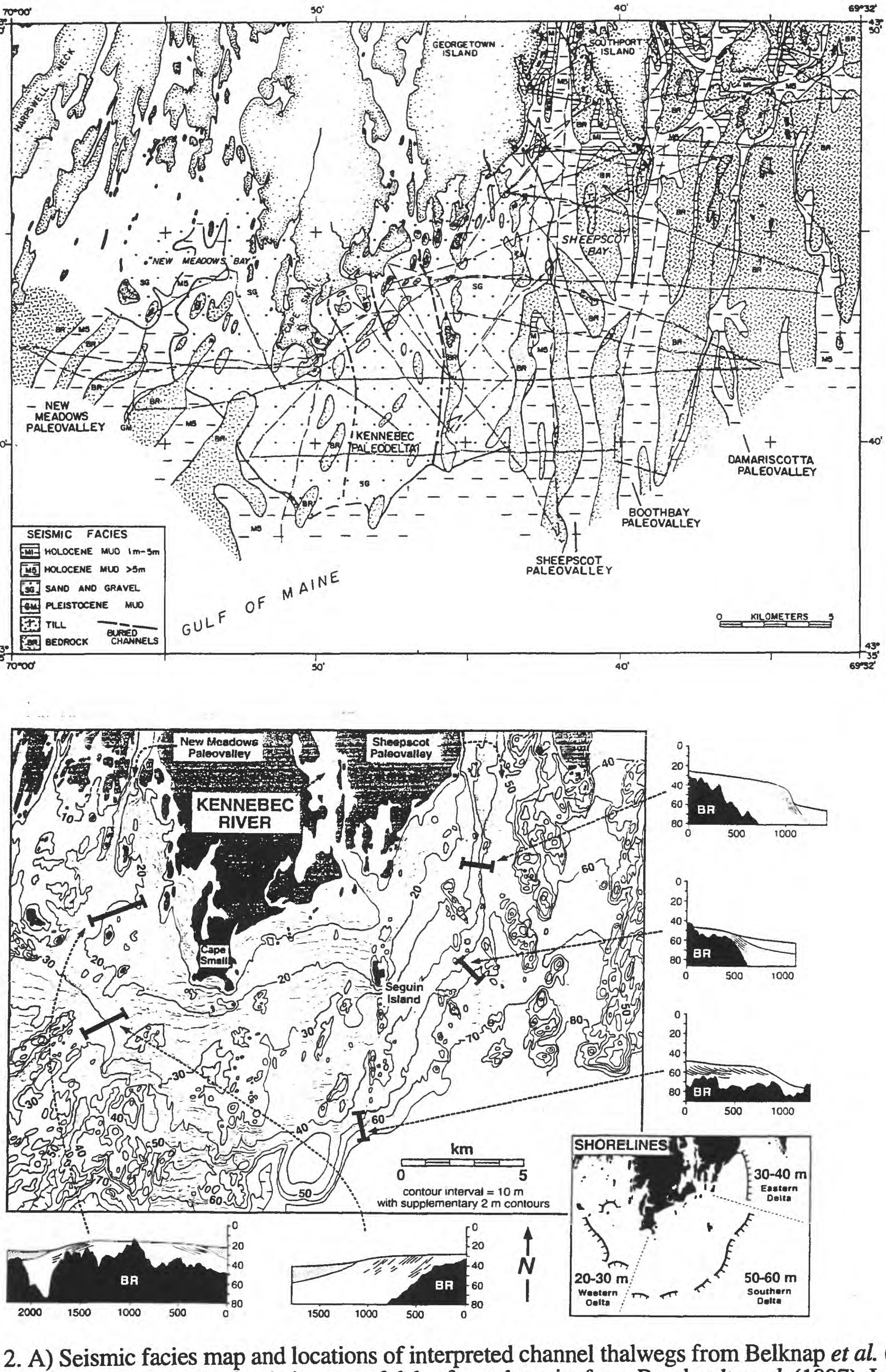


Figure 2. A) Seismic facies map and locations of interpreted channel thalwegs from Belknap *et al.* (1989). B) Offshore bathymetry and seismic images of delta-front deposits from Barnhardt *et al.* (1997). Inset shows the depths of shorelines associated with the three lobes of the Kennebec River Paleodelta.

## METHODS

In September of 1996 and 1997, 62 seismic-reflection profiles having a total length of 105 km were collected in the study area (Fig. 1). The equipment was mounted on a small boat to accommodate shallow water depths (3-20 m). An ORE Geopulse power supply was used to drive a transducer towed on a catamaran approximately 15 meters behind the survey vessel. The output power was set at 175 Joules at a fire rate of 0.5 seconds. A Benthos 10 element streamer was towed adjacent to the catamaran with a separation of 7-10 m. Incoming signals were routed through a Geopulse 5210A receiver which applied 20-30 DB of gain and TVG as required. Filters were set at 0.5 - 2.5 kHz, and data recorded on an EPC-9800 thermal printer. Positioning information was provided by a Rockwell Precision Lightweight GPS Receiver (PLGR) using P-Code. The navigational accuracy with this system is better than 5 meters.

## RESULTS

The study region was subdivided into four compartments. The results of seismic investigations for each compartment from west to east are presented below. Our description of seismic facies follows the classification of Barnhardt (1994). Depth to acoustic basement and thickness of overlying sediment were determined based on a velocity of 1500 m/s.

### New Meadows Valley - Small Point Harbor

Seismic profiles taken from Foster Point down the New Meadows valley show sediment fill varying in thickness from 3 to 25 m in the valley axis, with thinner, typically convex-upward drapes on the valley sides (Fig. 3). Where shallow areas adjacent to the valley are dominated by mudflats, the signal is attenuated by accumulations of natural gas. Longitudinal profiles taken in this area show 3-10 m thick channel fill with several discontinuous internal reflectors and flood-oriented to symmetrical bedforms on the modern floor of a 45 m deep channel (all bedrock depths are reported in meters below mean high water - MHW). Farther downstream, where the valley is deepest there is typically less than 10 m of sediment fill in the thalweg and thin sediment drape on the banks. Strong surface return and massive to slightly stratified signature of the valley fill suggest relatively high sand content in these deposits, with possible occurrence of glaciomarine sediment (facies GM) at the bottom of the sequence. Areas east and north of Flag Island are dominated by bedrock ledges with thin (< 3 m) sediment cover and apparent extensive natural gas areas in

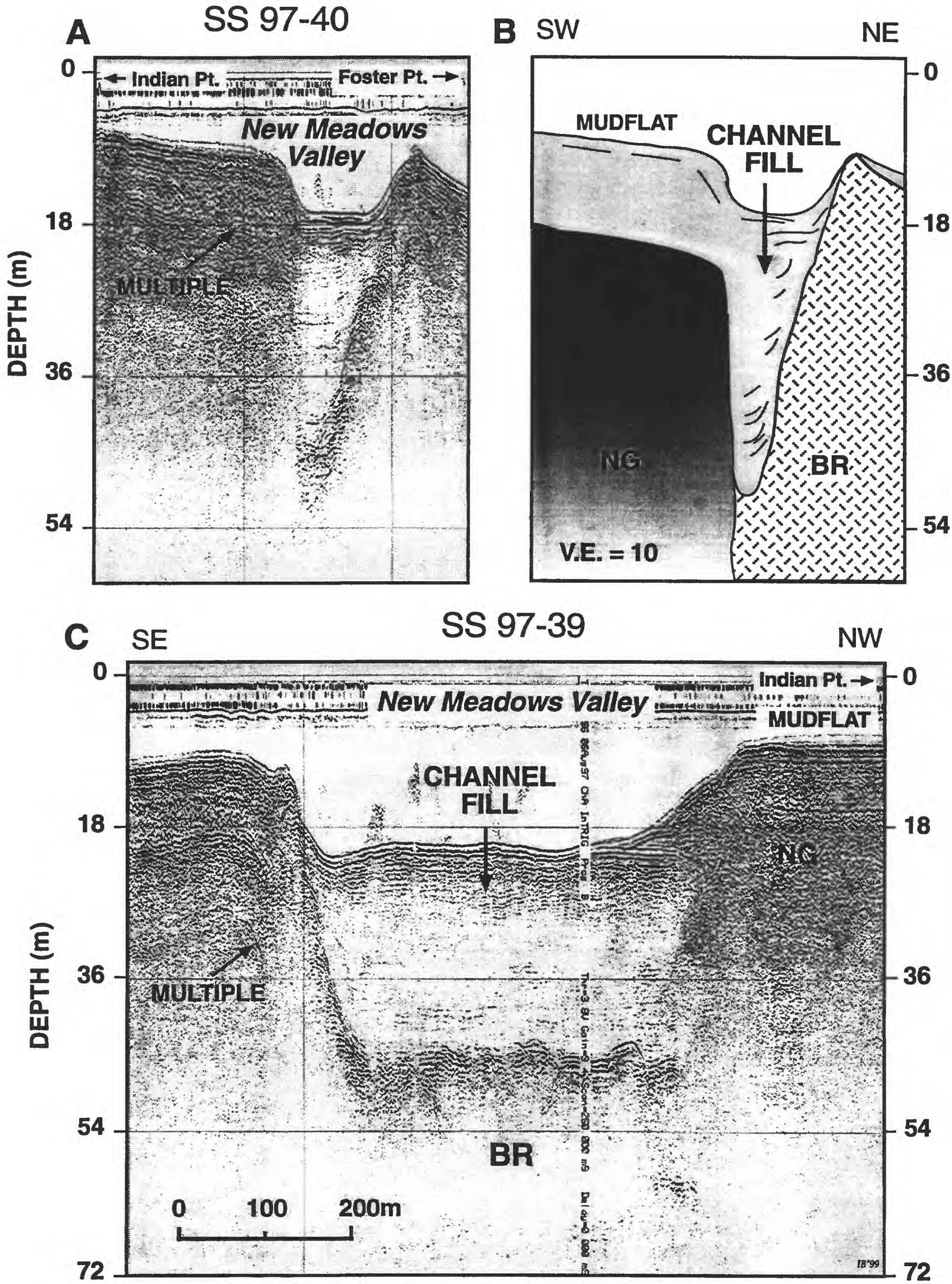


Figure 3. Seismic-reflection profiles across the New Meadows valley seaward of Thomas Bay. A) Original record and B) Interpretation of line SS 97-40. C) Annotated record SS 97-39. A thick valley fill is characteristic for this valley. Locations of all seismic transects are shown in Figure 1.

the adjacent mudflat regions. Figure 4 shows a comparison the depth to bedrock and sediment thickness for the New Meadows valley and the western delta region (south of Flag Island) measured on seismic profiles at 300 m intervals .

Transects taken across the western delta lobe show a smooth-topped, sandy deposit with a relatively steep landward slope between Flag and Mark Islands (the - 20 m shoreline of Barnhardt *et al.*, 1997). On the landward side, this deposit is backed by areas of gas-charged deposits that extend upstream beneath the mudflats. At the entrance to Small Point Harbor, a small buried channel is overlain by a 5 m-thick unit with landward-dipping cross-beds (Fig. 5). In the central portion of the harbor, a convex-upward attenuation signal suggests presence of natural gas (facies NG) (Fig. 6). The head of the harbor is characterized by an irregular bedrock surface which is exposed at several locations along the Flat Point barrier shoreface. The overall sediment thickness in the harbor varies from 2 to 10 m in the structural lows.

**Cape Small - Kennebec River Estuary**

Along the eastern margin of Cape Small, a 50 m deep channel with over 40 m of sediment continues from the Sprague River Inlet (Fig. 1) and its marsh-filled valley into a shelf paleovalley identified by Belknap *et al.* (1989) and Barnhardt *et al.* (1997). The valley is cut into metasandstones, metapelites, and granulites of Cape Elizabeth Formation, with fine-grained schists of the Diamond Island Formation underlying the throat of the Sprague River Inlet and exposed along its western margin (Osberg *et al.*, 1985). The differences in resistance to erosion of these lithologies are likely responsible for a greater depth of the western portion of the valley. Seaward of Seawall Beach, the stratigraphy of Belknap *et al.* (1989) describes glaciomarine facies overlain by thick sand and gravel (SG) sequence with several channel forms. Barnhardt (1994) and Barnhardt *et al.* (1997) reinterpret the upper unit as estuarine facies (E) separated from a relatively thin (0.5 -3.0 m) SG unit above by shoreface ravinement unconformity.

Farther east, a 50 m deep bedrock depression, located seaward of Popham State Park, can be traced into a structural low in the offshore direction, between Heron and Fox Islands (Fig. 7 and 8). This region was also proposed by Belknap *et al.* (1989) to be the location of one of the Kennebec River paleo-channels (Fig. 2A). In a landward direction, this depression extends beneath the Atkins Bay, and branches into two valleys at its junction with the present Kennebec River channel. At this point, the valleys shoal to about 35 m,

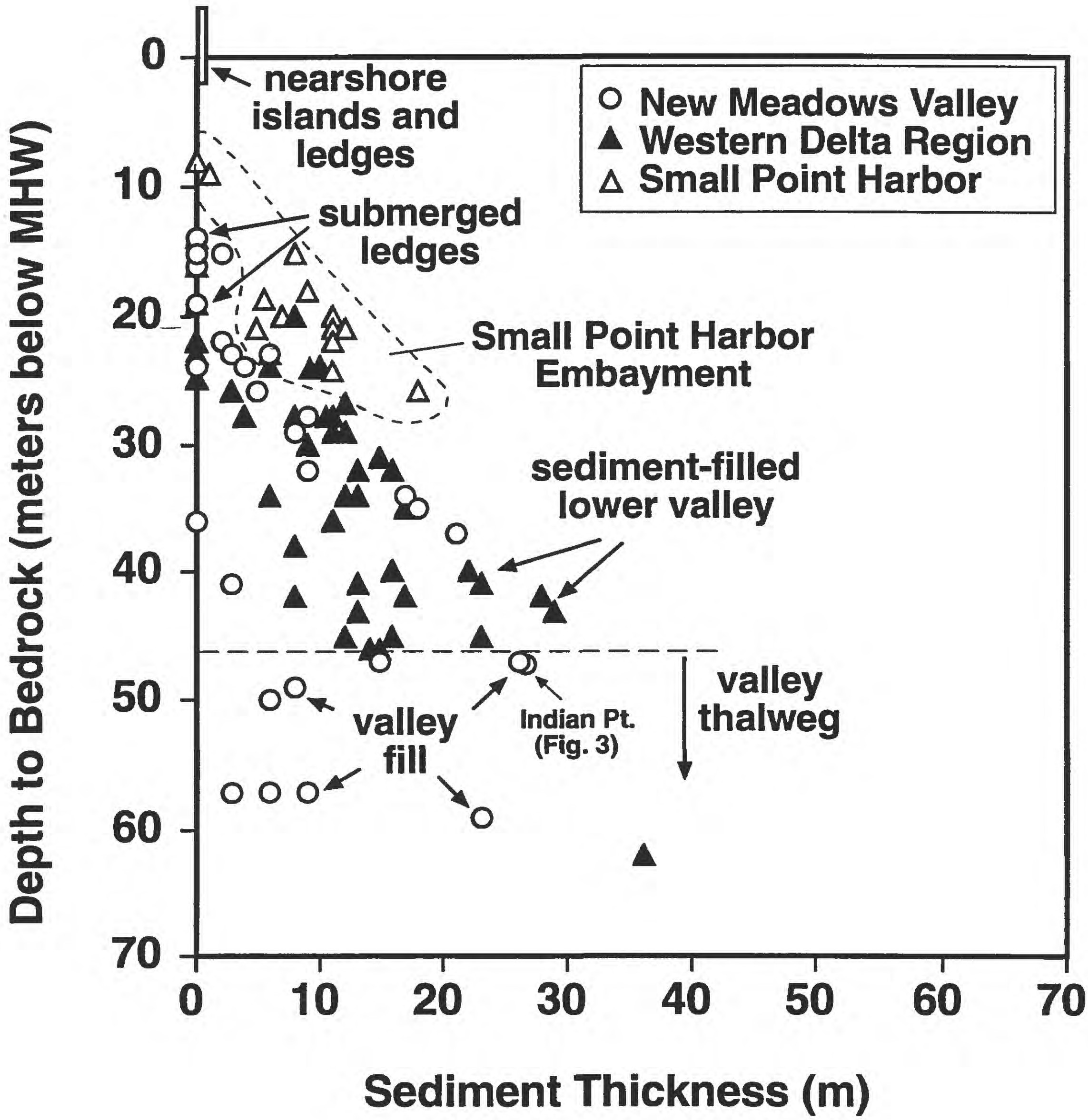


Figure 4. Plot of depth to acoustic basement vs. overlying sediment thickness for New Meadows valley (Indian Point to Flag Island), the western delta region (south of Flag Island), and Small Point Harbor (Fig. 1 for location). Note the relatively shallow basement depths below the delta and up to 25 m of sediment fill in the upstream valley thalweg.

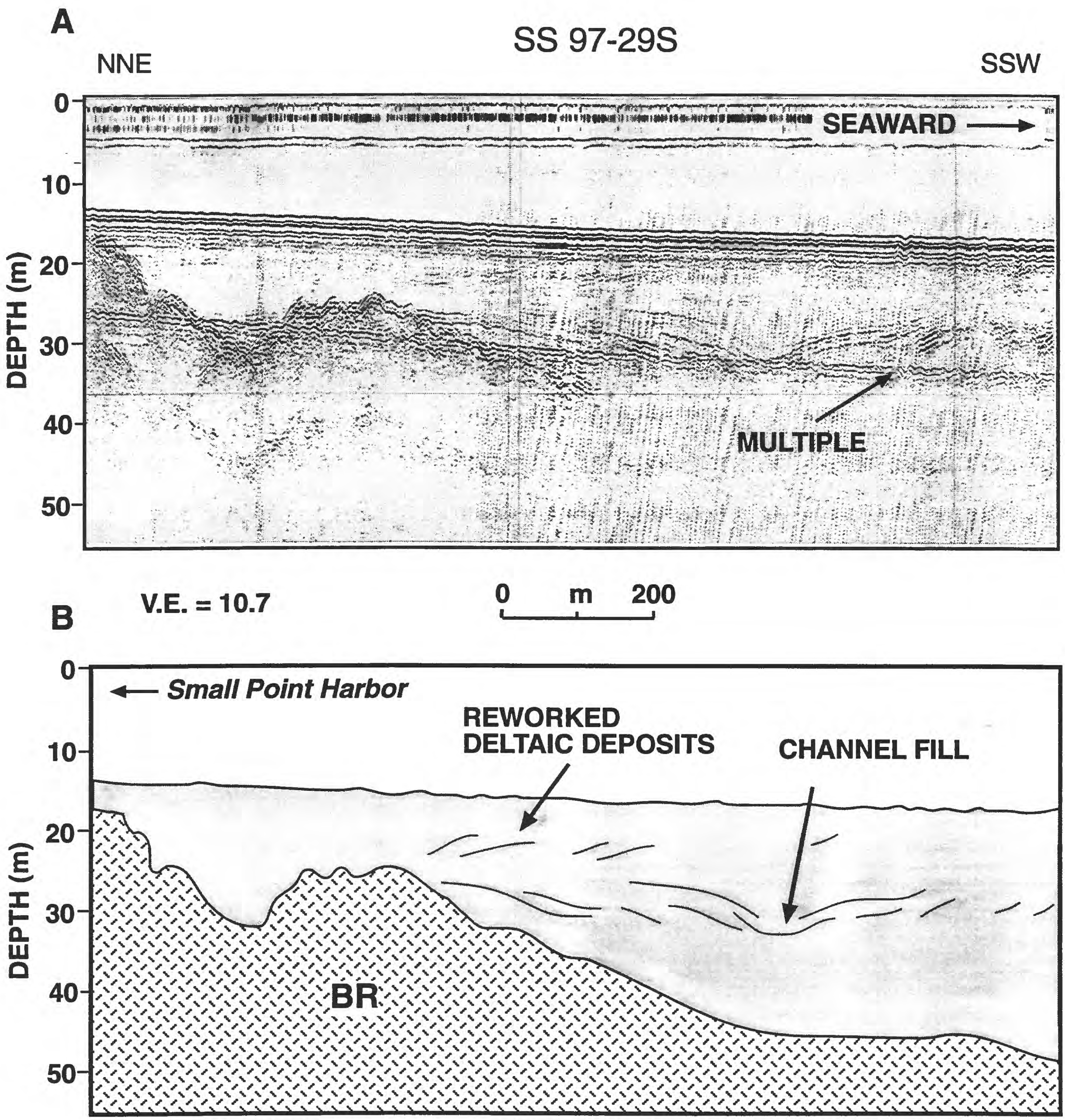


Figure 5. Subsurface geology of the east portion of the western delta. A) Original data and B) interpretation of line SS 97-29S. The landward-dipping reflectors indicate reworking of the deltaic deposits during transgression.

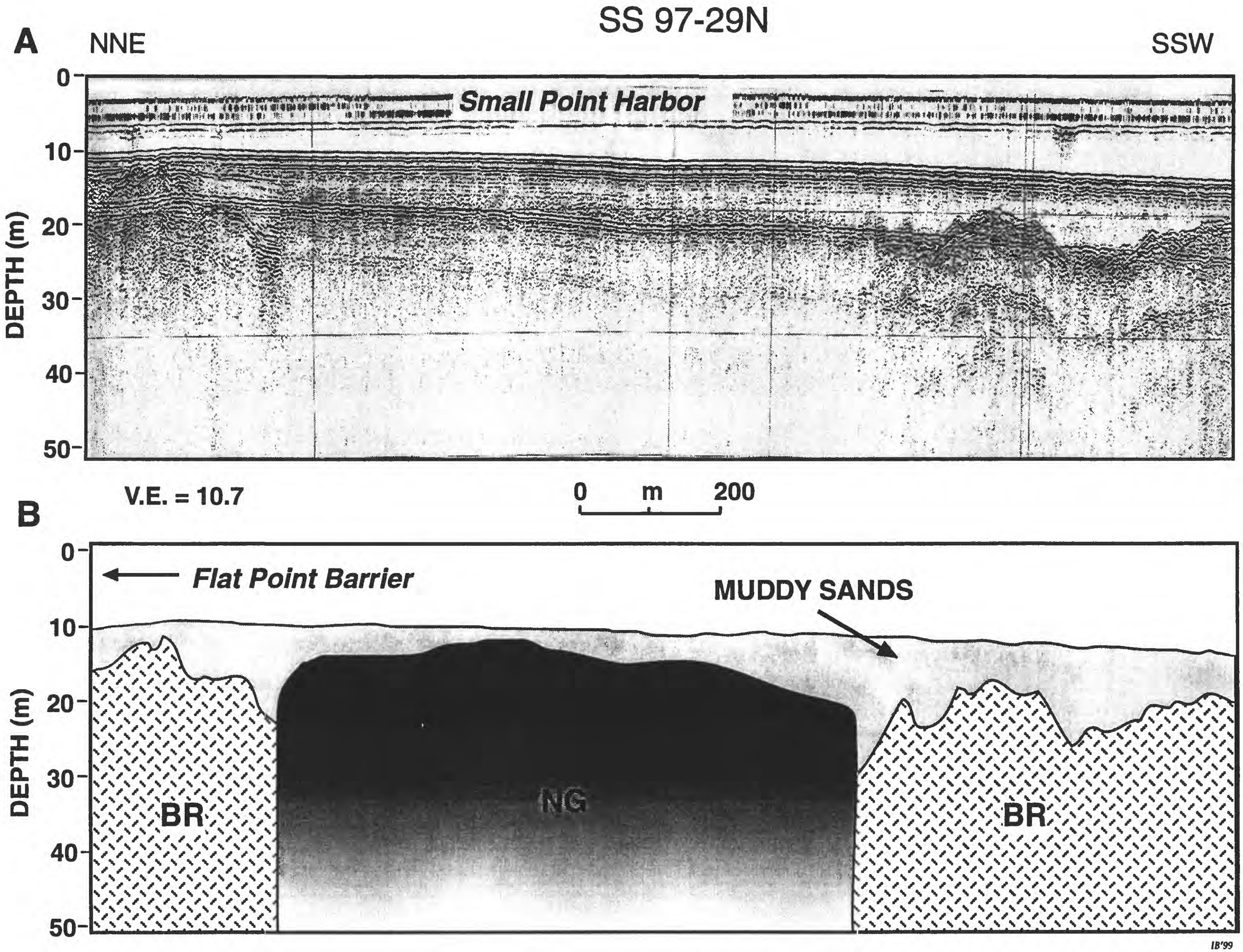


Figure 6. Analog record (A) and interpretation (B) of line SS 97-29N taken along the axis of the Small Point Harbor. Signal wipeout due to natural gas in the central portion of the embayment suggests fine-grained nature of the sedimentary deposit. The surficial sediments in this area are fine to very fine silty sands.

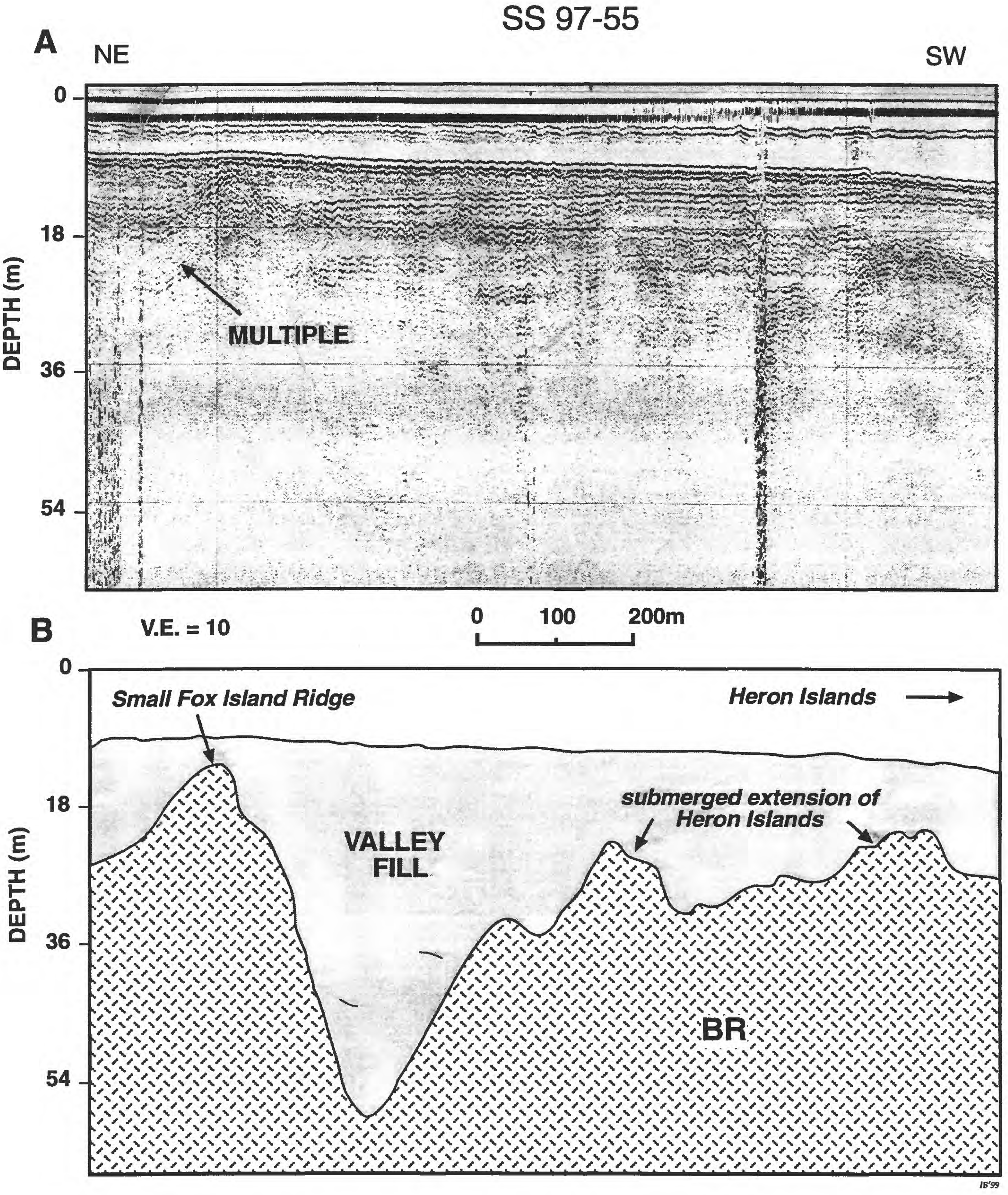


Figure 7. Original data (A) and interpretation (B) of shore-parallel seismic profile SS 97-55 showing a thick valley fill just seaward of Atkins Bay.

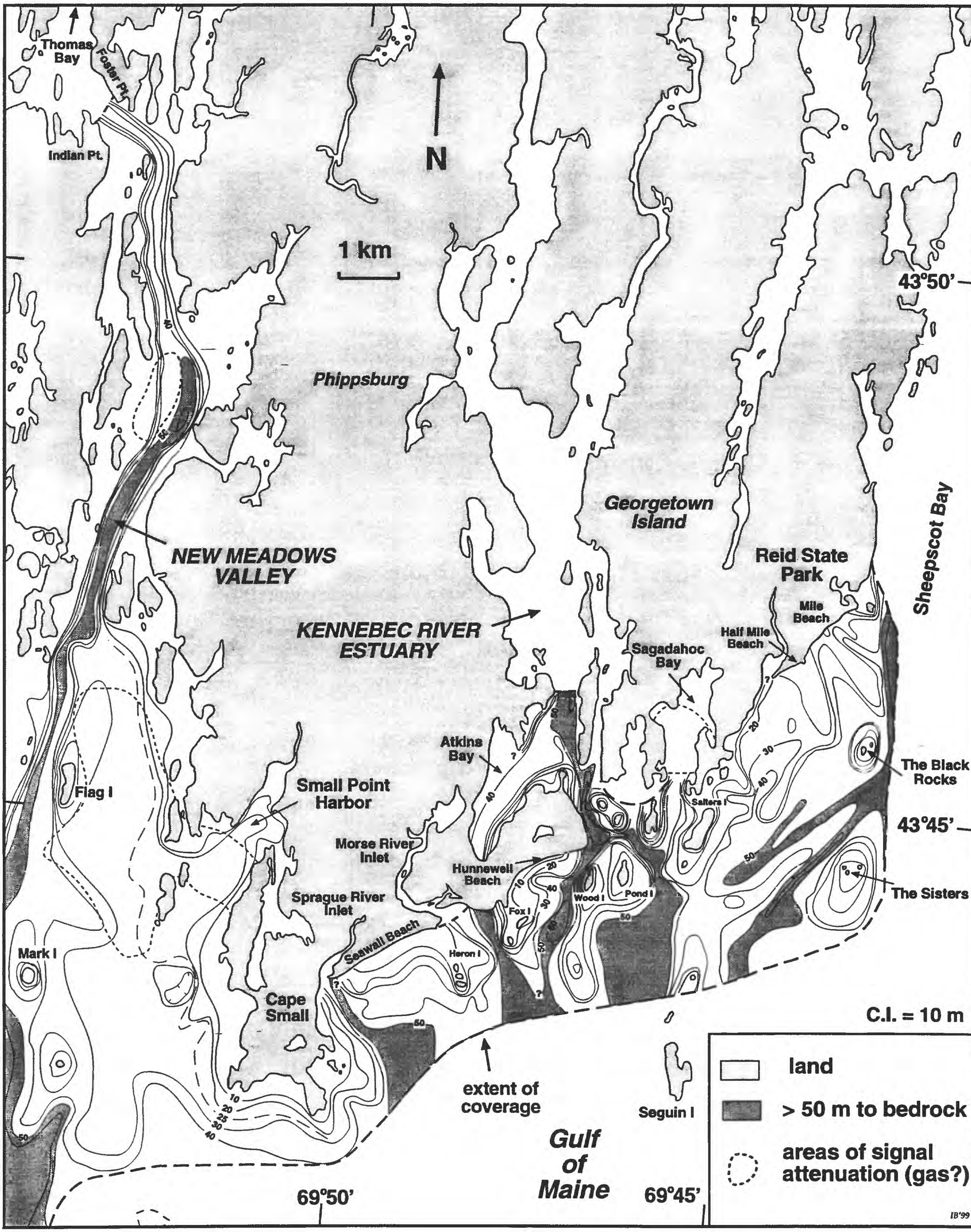


Figure 8. Contour map showing depth to acoustic basement (in meters). Also shown are areas of seismic signal attenuation, possibly due to presence of natural gas in fine-grained sediments.

and are filled with 10-15 m of stratified fluvial and estuarine sediments (Fig. 9). A series of large bedforms characterizes the present channel bottom.

Another bedrock-controlled valley can be traced from the mouth of the Kennebec River estuary beneath the Wood Island tombolo, extending in a southwesterly direction in front of the Hunnewell Beach (Figs. 8 and 10). This bedrock surface reaches a depth of over 60 m seaward of the Silver Lake depression (Fig. 1), and possibly connects to the main Kennebec shelf valley under eastern Hunnewell Beach. Under the edge of Pond Island Shoal, sediment fill attains a thickness of 55 m (Fig. 11). Here, the bedrock surface ascends steeply in a seaward direction where it crops out at Jackknife Ledge. Landward of the structural low, basement rises to within 5 m below the Hunnewell Beach shoreface (~ 10 m below MHW). Onshore GPR records and cores indicate that the bedrock is over 10 m deep under the barrier and southern and central portions of the Silver Lake, and rises steeply around the periphery of the lake into the granitic headlands of Sabino and Rockledge. The contact between pegmatitic granite and underlying schist exposed along the western shore of the lake suggests that preferential erosion of the schist is likely responsible for the Silver Lake depression.

The main Kennebec River valley was shown by Belknap *et al.* (1989)and Barnhardt *et al.* (1997) (Figs. 2A and 10) to extend seaward from Pond Island along a north-south structural trend, with depressions of over 70 m west of Seguin Island and at the paleodelta edge. The landward extension of this valley is characterized by a number of structural highs and lows. The bedrock sill between Wood and Pond Islands is less than 30 m deep and is not part of the main paleovalley (Fig. 8). Farther upstream, the bedrock descends abruptly to over 65 m just seaward of the Fort Popham outcrop. This depression is filled with over 40 m of sediment, the modern surface of which has been molded into 10-15 m high, sandy, ebb-oriented transverse bars (Fig. 12).

### Stage and Sagadahoc Bays

The bedrock underlying the Stage and Sagadahoc Bays (Fig. 1), and Heal Eddy to the west, consists of metapelites of Diamond Island Formation, with adjacent ridges and peninsulas composed of Spring Point Formation metavolcanics (Osberg *et al.*, 1985). The differential resistance to erosion of these lithologies is likely responsible for the present coastal physiography. Bedrock basement under Stage Bay, located seaward of the Sagadahoc Bay, is up to 40 m deep and joins the main Kennebec River paleovalley in a

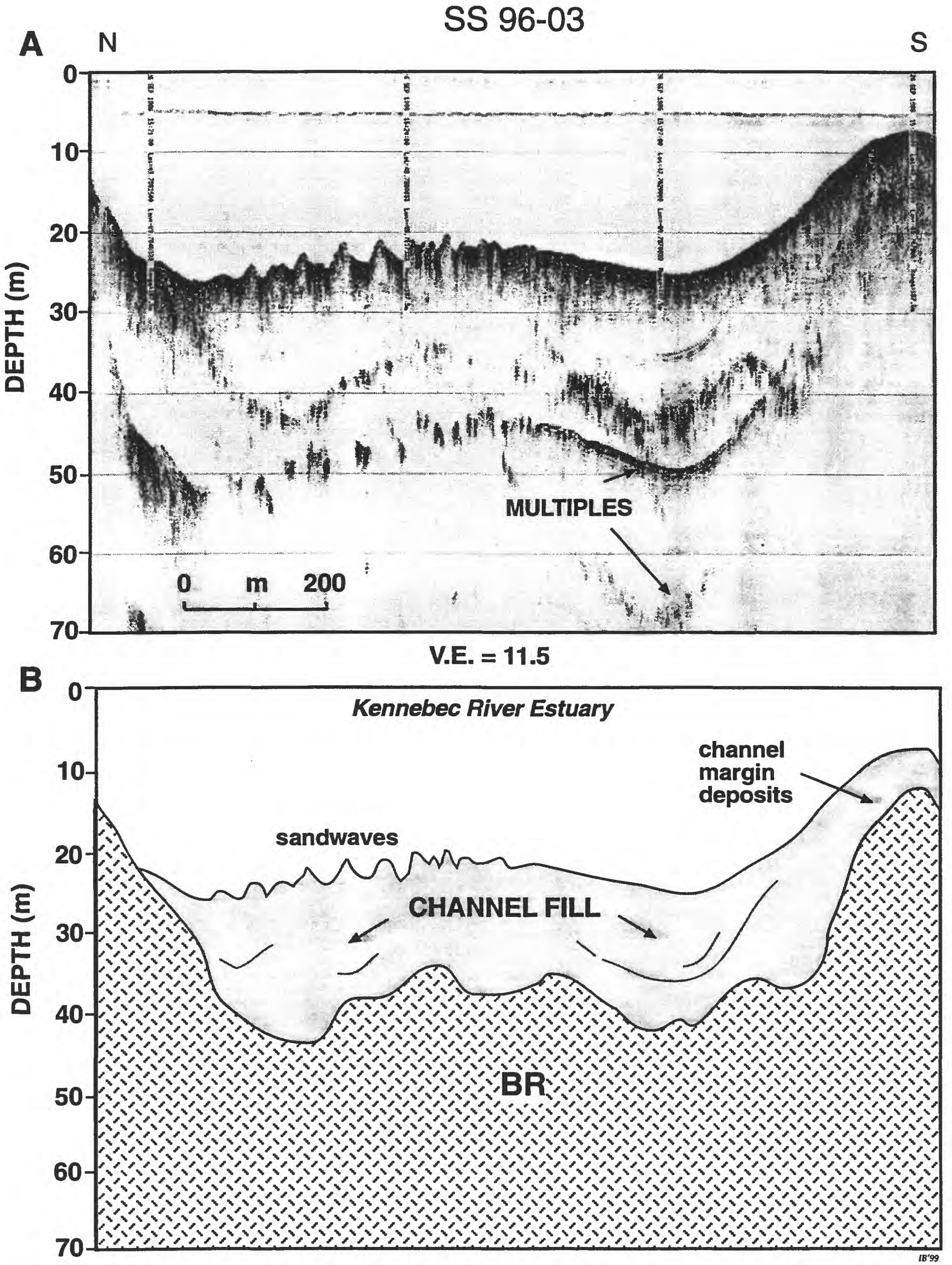


Figure 9. A) Original record and B) Interpretation of transect SS 96-03 taken across the mouth of Atkins Bay at the junction with the Kennebec River Estuary. Note the two channel fill structures in the paleotopographic lows.

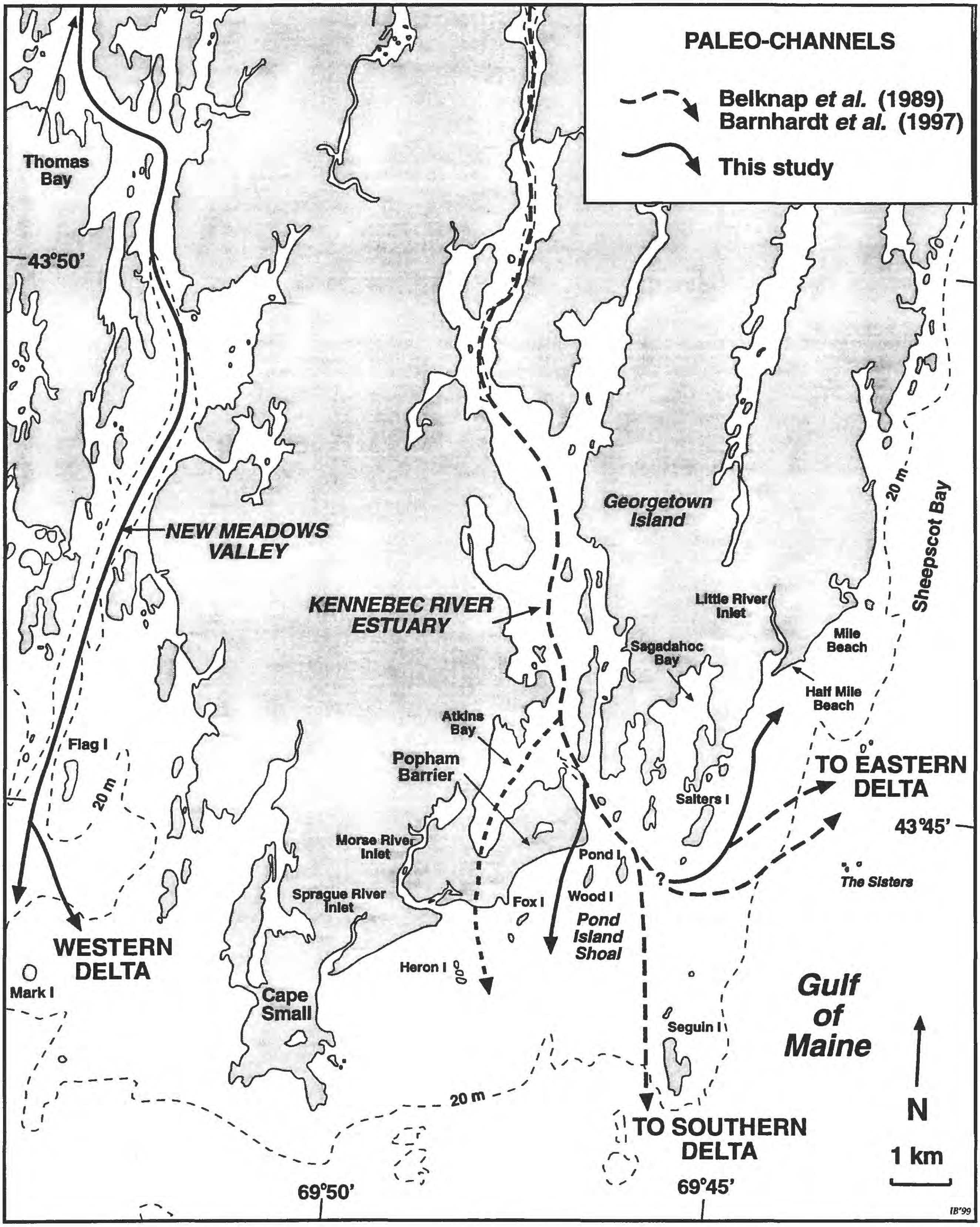


Figure 10. Locations of primary paleo-channels, longshore distributaries, and valleys terminating in bedrock in a landward direction. These valleys extend offshore into the shelf valleys leading to regressive and lowstand deltaic deposits. The landward portion of Sprague River valley was not a site of active channel (compare to Fig. 2A).

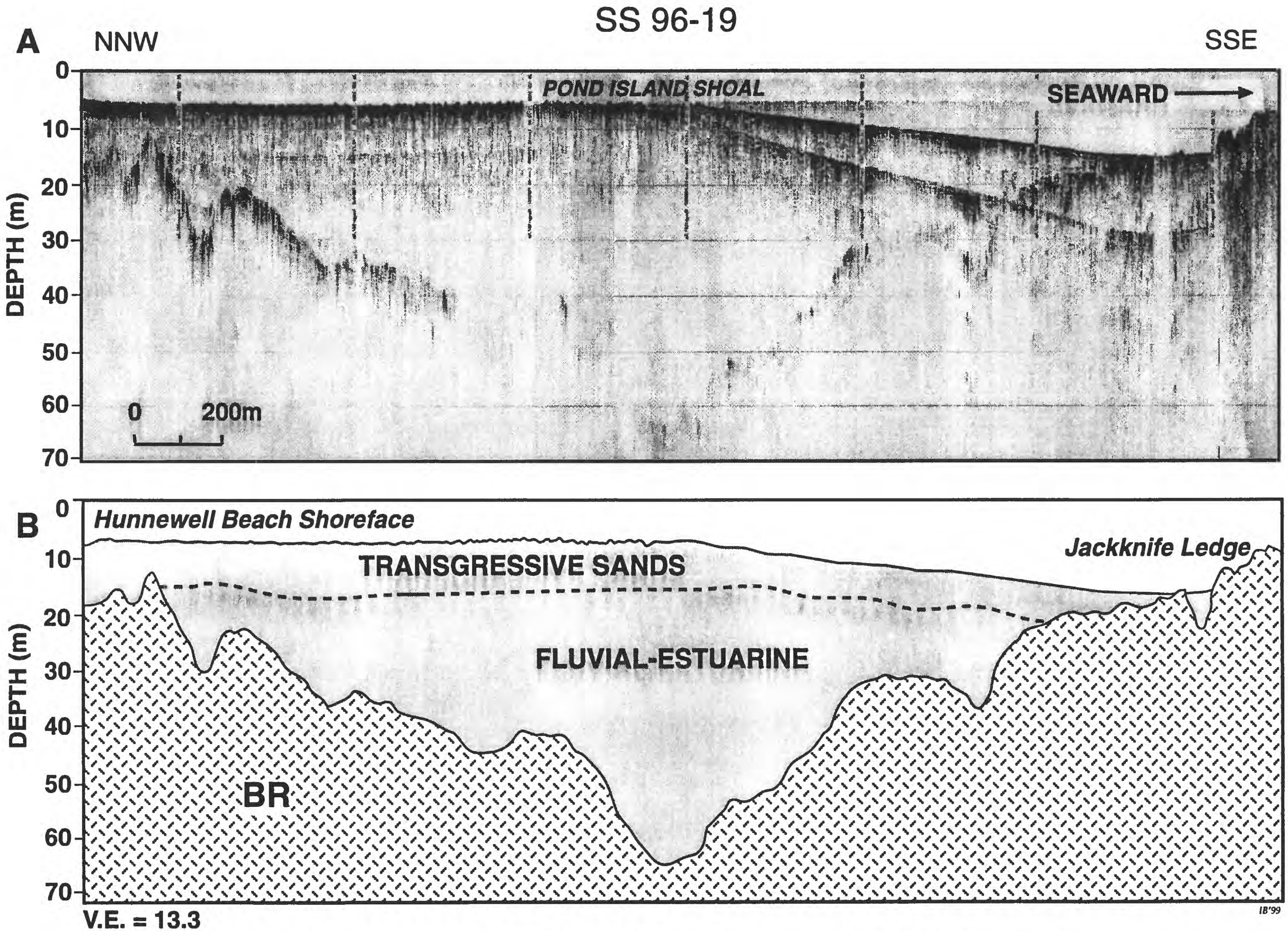


Figure 11. Shore-normal transect SS 96-19 (A) and its interpretation (B) showing a deep basement trough that extends from the main Kennebec River valley beneath the shoreface and was a likely conduit for fluvial sediment. The bedrock under the shoreface becomes shallower in a landward direction.

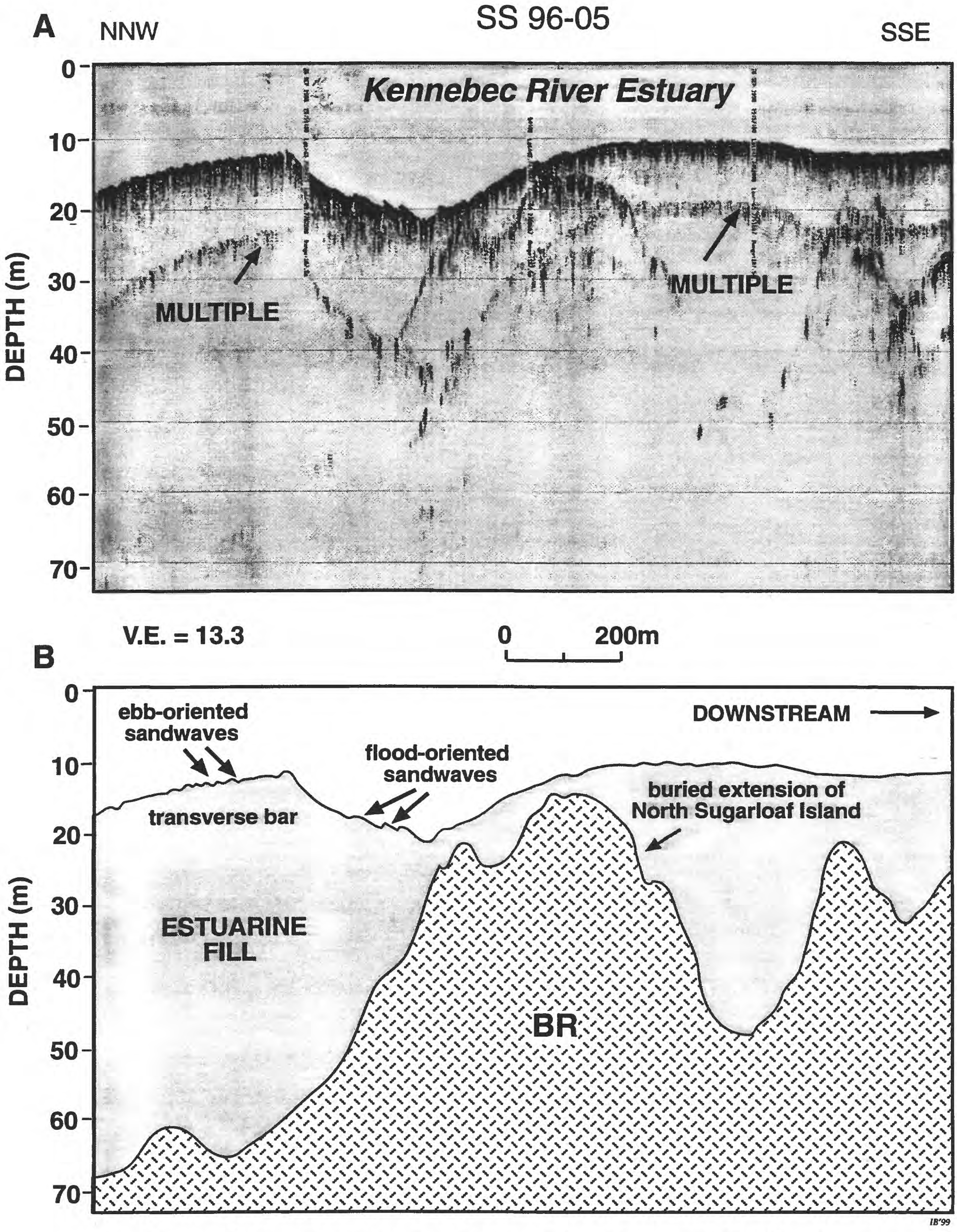


Figure 12. Channel-parallel seismic transect taken at the mouth of the Kennebec River estuary. Large-scale ebb-oriented bedforms indicate the present-day downstream sediment movement of sediment.

seaward direction. It is overlain by glaciomarine sediment and capped by 5-15 m of Holocene sandy deposits.

In contrast to the coast immediately west of the Kennebec River, which is characterized by large barrier complexes, Sagadahoc Bay has only a few short and narrow welded barriers concentrated along its western side. Refraction-seismic profiles conducted in the bay in 1952 by the U.S. Geological Survey revealed an increase in depth to bedrock from about 10 m at the head of the bay to over 60 m halfway to the low tide line (Bradley, 1957). Bradley described a "sill or knob" rising to within 20-25 m below the surface of the tidal flat, with deeper basement in a landward, and somewhat shallower basement in a seaward direction. The uniform velocities of the seismic waves above the basement were interpreted to be a result of homogeneity of sediment fill, with textural characteristics similar to those of modern muddy sands of the tidal flats (Bradley, 1957). In addition to these observations, localized areas of signal attenuation, suggesting the presence of natural gas in fine-grained sediments, were mapped under the subtidal portion of the bay.

**Salters Island - Reid State Park**

East of Salters Island, three bedrock valleys were mapped along a NW-SE transect (Fig. 8 and 10). In a landward direction, the valleys reach maximum depths of 55-58 m, 42-46 m, and 36-40 m. They contain 15-30 m thick stratified sediment fills, which onlap the valley sides (Fig. 13). The interfluves are draped with 2-15 m of sediment. The two seaward valleys emanate from the main Kennebec River paleovalley through a -35 m bedrock sill described by Barnhardt (1994), and continue eastward to the eastern delta lobe (Barnhardt *et al.*, 1997).

A number of shore-normal and shore-parallel transects obtained in the shoreface and shallow offshore areas of Reid State Park show that bedrock below and seaward of the Mile Beach is relatively deep (12-30 m; Fig. 14). In contrast to Mile Beach, the nearshore bedrock along the Half Mile Beach is shallow (3-20 m) with numerous exposures forming offshore islands and ledges (e.g., Little River Ledges, Sloop Ledges). These ledges are part of structural ridges which were traced for over 15 km offshore in seismic profiles by Belknap *et al.* (1989). The morphological difference between the offshore areas of the two barrier segments is also indicated on the plot of sediment thickness versus depth to bedrock measured along seismic transects (Fig. 15).

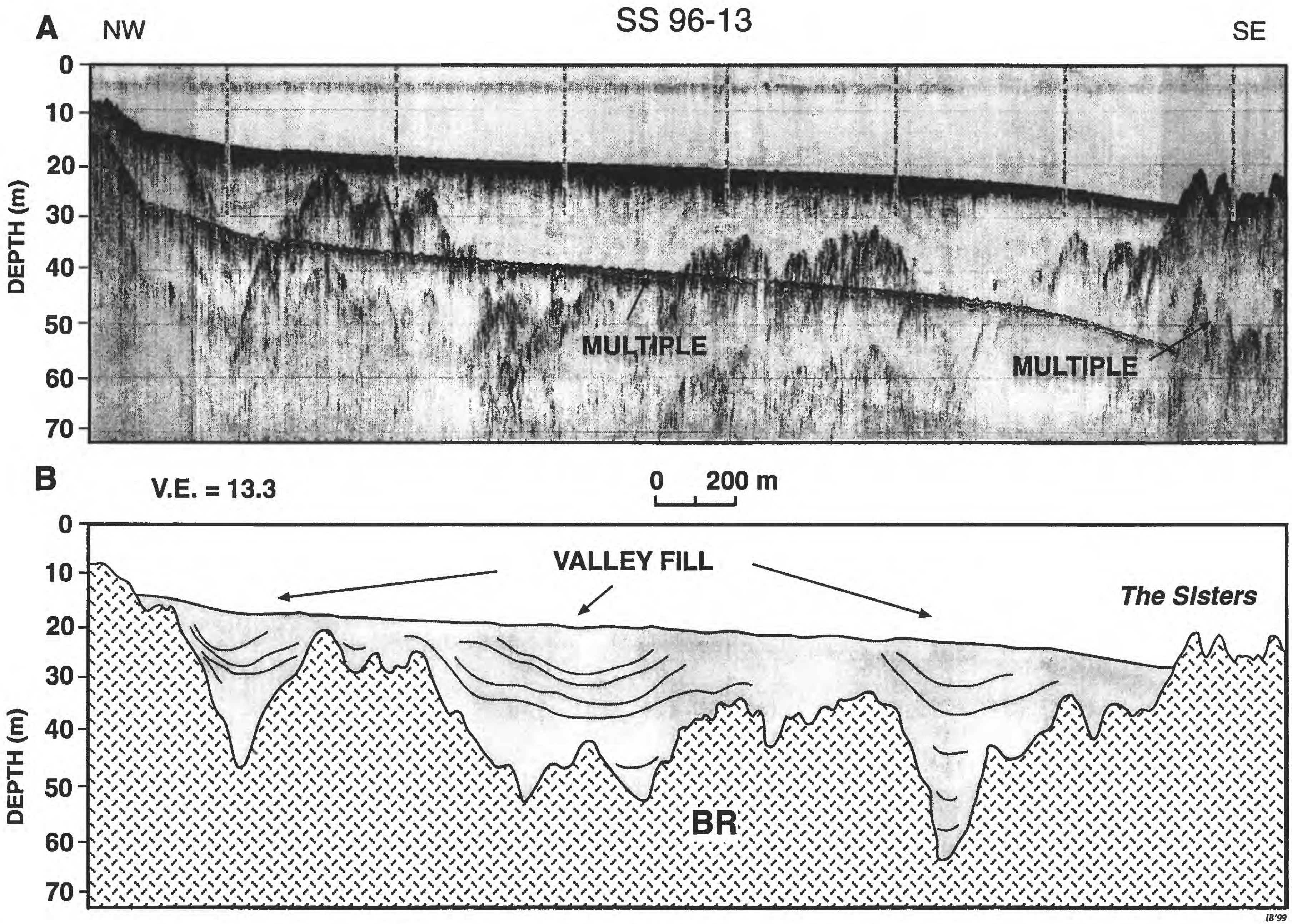


Figure 13. Analog record (A) and interpretation (B) of the shore-normal transect SS 96-13 showing three sediment-filled valleys between the offshore ledges of The Sisters and the Georgetown Island. These valleys acted as longshore conduits to the eastern delta. See Figure 10 for interpreted channel positions.

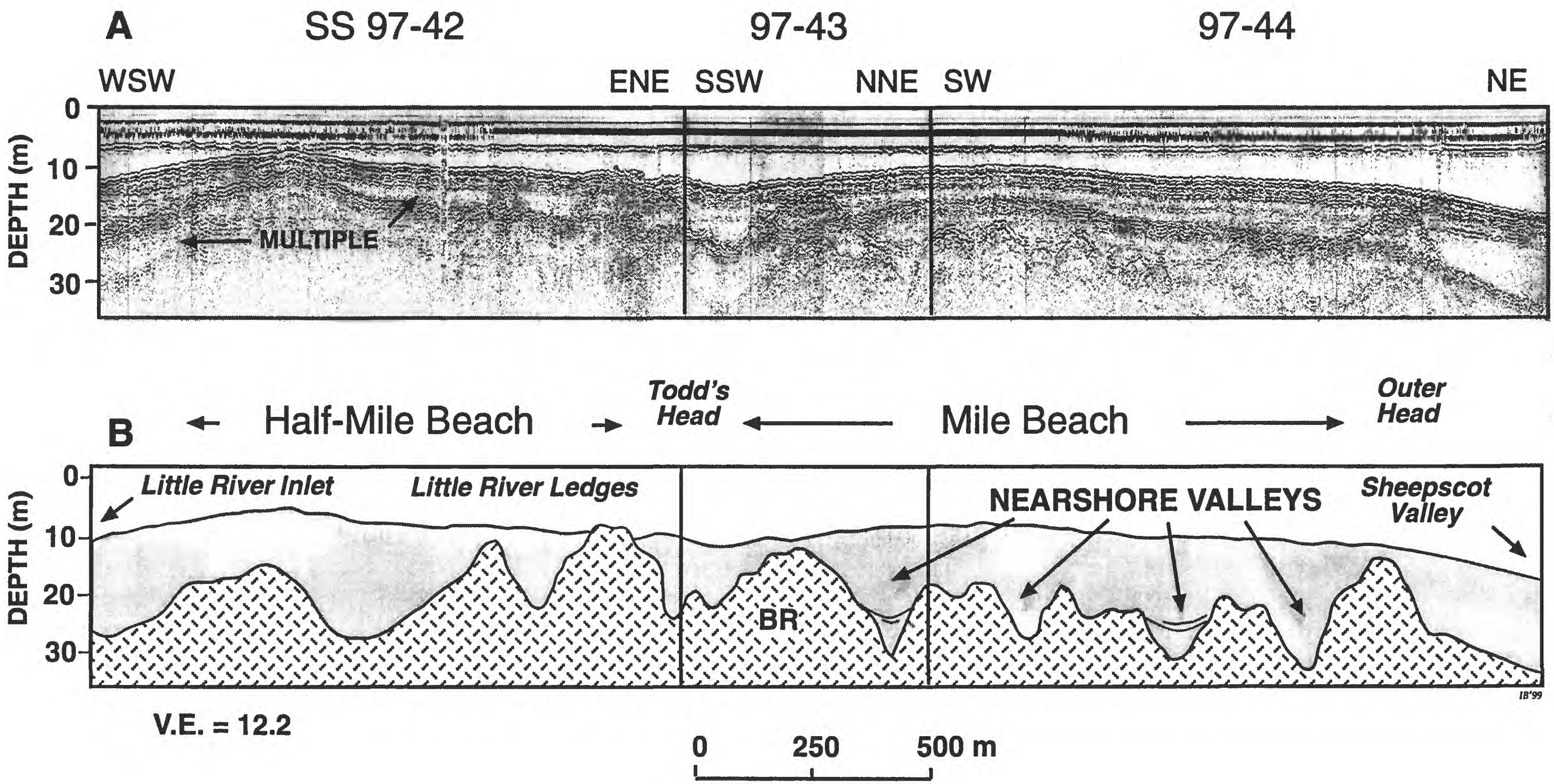


Figure 14. A sequence of shore-parallel seismic transects (A) and their interpretation (B) showing irregular basement morphology and stratified valley-fill deposits under the Mile Beach shoreface. Most basement lows extend for only a short distance in a landward direction. See Figure 1 for location.

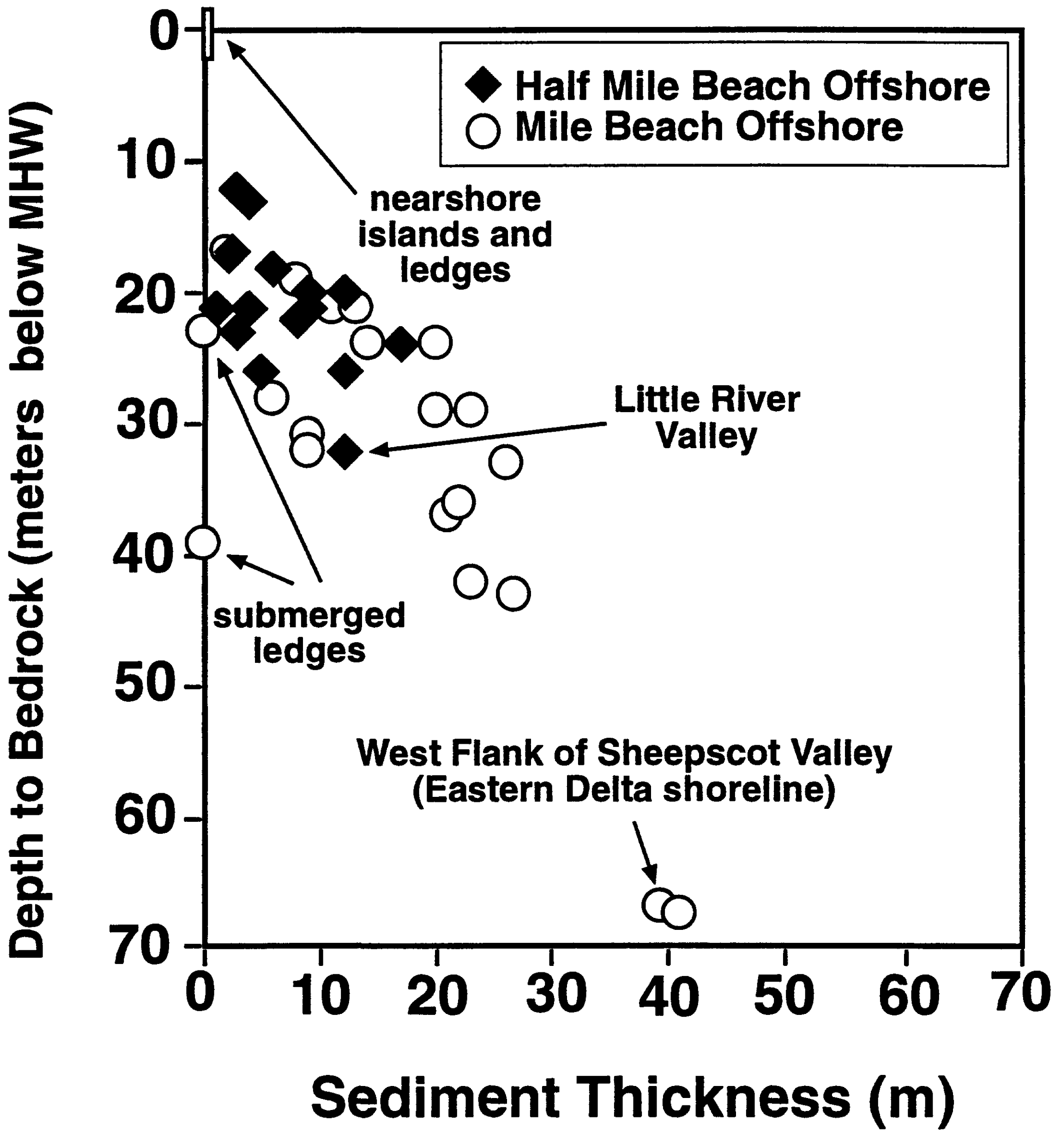


Figure 15. Depth to acoustic basement vs. sediment thickness in the nearshore region of Reid State Park. Note the overall deeper basement and thicker sedimentary sequence seaward of Mile Beach compared to Half Mile Beach.

# DISCUSSION

## Nearshore Basement Morphology and Drainage Patterns

The results of our study are summarized in a structure-contour map of the nearshore area and New Meadows valley (Fig. 8). This new information provides detailed coverage of the nearshore paleotopography and revises the regional paleo-drainage framework. Combined with the existing offshore database (Belknap *et al.* , 1989; Barnhardt *et al.* , 1997), these data sets present a regional picture of the inner shelf geology and drainage pathways. Because nearshore paleotopography exerts the primary control on sediment dispersal patterns, fluvial depocenters, and the subsequent onshore reworking of shelf sediments in response to Holocene transgression, the present study has important implications for the Late Quaternary evolution of this coastal region.

The New Meadows River valley has been proposed as a possible passageway for the Androscoggin River drainage (Kelley and Hay, 1986; Belknap *et al.*, 1989). However, a bedrock ridge between the present Androscoggin River channel and New Meadows valley at +20 m elevation precluded drainage through this valley once sea level fell below this elevation. Drainage of the Androscoggin through the Brunswick sand plain into Maquoit or Middle Bays has also been suggested by Kelley and Hay (1986) based on analysis of deranged river systems and fluvial sediments underlying thick mudflat facies in Maquoit Bay. Although there may have been temporary drainage through these areas, there are no apparent significant accumulations of coarse-grained sediment in Casco Bay at these possible outlets.

In a recent study of the evolution of the Brunswick sand plain, Crider *et al.* (1997) and Crider (1998) demonstrated that Thomas Bay valley (Fig. 1), which is located along the eastern edge of the sand plain and connects to the New Meadows valley at its southern end, has been partially incised. Ground-penetrating radar profiles and outcrop studies show that channel cut-and-fill structures extend northward from Thomas Bay to the main channel of the Androscoggin River. At least 15 m-thick fluvial sequence was removed by incision during rapid regression. This provides a constraint on the minimum volume of sediment deposited downstream of the Thomas Bay valley with continuing sea-level fall. In another recent study, Kniskern (1998) analyzed the mineralogy of the coarse-grained sand fraction of surficial sediments in south-eastern Casco Bay (western lobe of the Kennebec River

Paleodelta; Barnhardt *et al.*, 1997). Using major mineral and rock fragment content of 73 samples, she concluded that the surface sands closely resembled the sediment composition of samples from the present Androscoggin River (Kniskern *et al.*, 1998), as well as fluvial facies of Thomas Bay and Lisbon Falls proglacial submarine fan located 20 km upstream of the bay. The western lobe samples did not compare closely to those of the present Kennebec River (Kniskern, 1998). Thus, an alternative depositional model presented here envisions drainage of ancestral Androscoggin River through Thomas Bay into the lower New Meadows valley depositing a delta (Fig. 10).

This interpretation of the western lobe deposit may also have implications for the timing of the early stages of paleodelta deposition, possibly prior to 11.0 ka B.P. (Buynevich *et al.*, 1999). Sometime during the regression the Androscoggin River drainage must have switched to the present Kennebec River valley and sediment began to be delivered to the nearshore and eastern delta by ca. 11.0 ka B.P. (Barnhardt, 1994).

The results of this study, along with evidence from Barnhardt (1994) and Barnhardt *et al.* (1997), also suggest that the upper portion of the Sprague River paleovalley did not contain an active fluvial channel. It was filled during the Holocene transgression by estuarine, tidal flat, and salt marsh sediments. The seaward portion of this valley may have received fluvial sediment from the main Kennebec paleovalley to the east through a number of smaller bedrock passages. The Morse River valley also terminates in bedrock in a landward direction, which suggests that it was not a site of an active fluvial distributary channel. Both Sprague and Morse River valleys were filled with fine-grained marine and backbarrier sediments through the course of Holocene transgression.

The Atkins Bay paleovalley between Heron and Fox Islands was the most likely conduit for sediment from the Kennebec River to the landwardmost passage of the Sprague River valley. After formation of the Popham State Park barrier across Atkins Bay, only large-magnitude spring freshets contributed to the infilling of the bay. Another deep valley branching from the main Kennebec River mouth between Rockledge and Wood Island and continuing below the Pond Island Shoal must have served as a conduit for fluvial sediment (Figs. 8 and 10). It probably reconnected seaward to the main Kennebec valley, one of the Sprague River valley passages, or both (Barnhardt *et al.*, 1997).

Three bedrock valleys east of Salter Island containing thick stratified channel fill deposits, are part of the regressive fluvial distributary framework which fed the eastern lobe of the Kennebec River Paleodelta prior to emergence of the -35 m bedrock pass described by Barnhardt *et al.* (1997). The drainage through these channels probably occurred simultaneously with the discharge through the main Kennebec River channel. Coarse-grained channel fill and eastern paleodelta lobe deposits provided ready sediment source for the Reid barrier complex (Figs. 10 and 14).

A relationship between maximum valley depths and drainage patterns is shown in Figure 16. Major fluvial conduits are associated with deepest valleys (New Meadows River valley, Kennebec River valley and its nearshore distributaries), whereas the maximum nearshore depths of the valleys terminating in bedrock in a landward direction are much shallower (Upper New Meadows valley, Sprague River Inlet, Morse River Inlet, and Little River Inlet). The deep areas offshore of Mile Beach are part of the Sheepscot Bay valley. Although the deepest portions of the valleys were mostly filled in with till and glaciomarine sediment (Belknap *et al.*, 1989), these trends show the overall structural control on the regional drainage patterns (Figs. 8 and 10).

## Implications For Barrier Origin and Development

In areas where the offshore deltaic sands are the only sediment source in a region (e.g., New Meadows paleodelta), wave reworking of the upper coarse-grained fluvial units likely contributed much of the sediment to coastal accumulation forms (i.e., Small Point Harbor barriers). In other areas, structural trends have resulted in the relative proximity of shore-parallel bedrock valleys to the present-day coast. Sediment delivered through these valleys not only contributed to the formation of the eastern delta lobe (Barnhardt *et al.* , 1997), but also provided a ready supply of coarse material for barrier development during the late stages of the Holocene transgression (e.g., Reid State Park barrier complex; Buynevich and FitzGerald, 1999). Finally, where there has been a continuous supply of fluvial sediment to the nearshore during the transgression, such as in the vicinity of the main Kennebec River channel, a combination of onshore reworking and westerly longshore transport resulted in largest nearshore sand accumulations in this coastal compartment (e.g., Pond Island Shoal, Popham and Seawall barriers and their shoreface; Belknap *et al.*, 1989; FitzGerald *et al.*, 1994, Buynevich *et al.*, 1999).

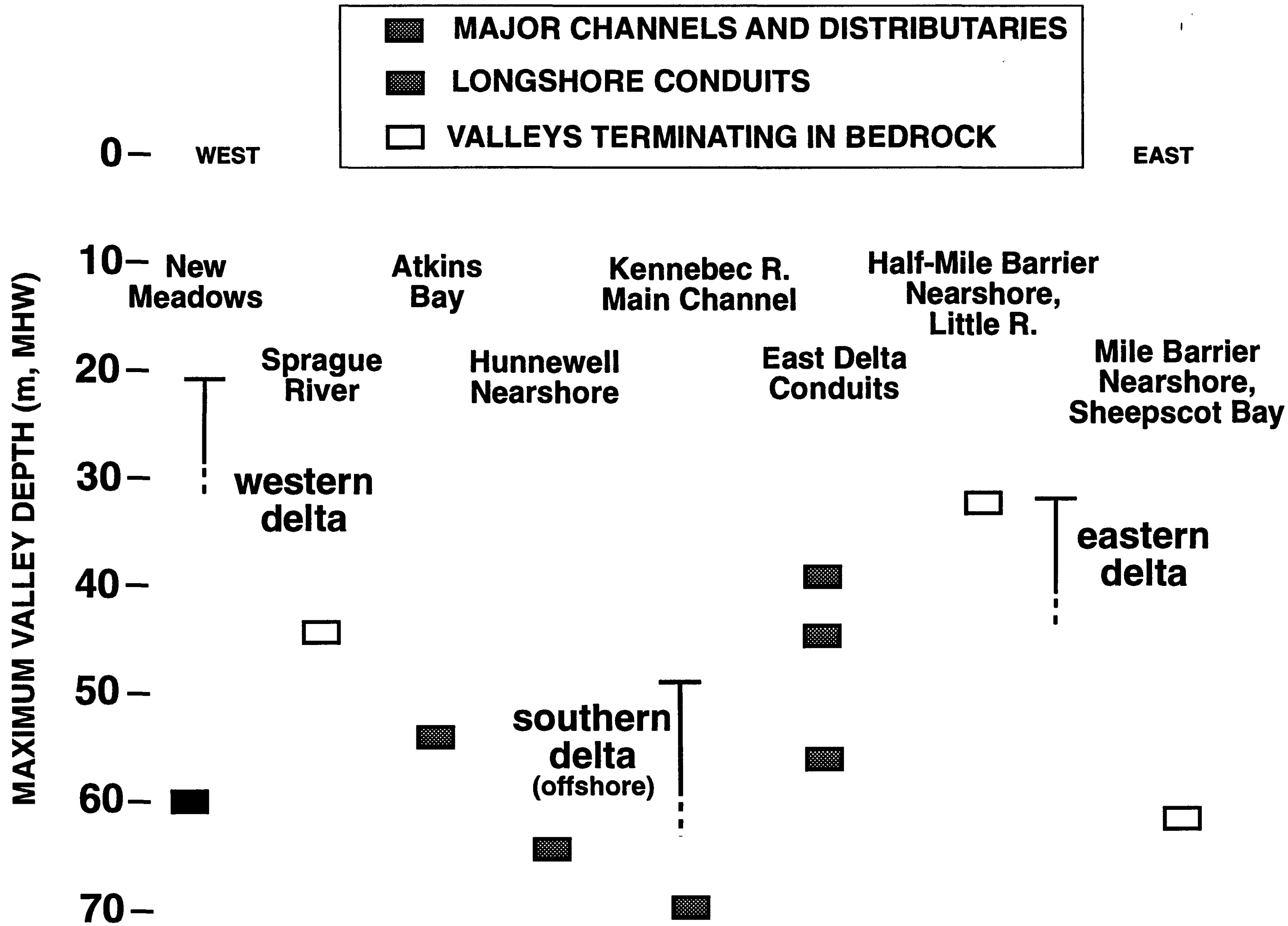


Fig. 16. Maximum depths of bedrock valleys in the nearshore region and depths of shorelines of the three paleodelta lobes (from Barnhradt *et al.*, 1997; inset of Fig. 2B). See Figure 10 for locations.

At present, Kennebec-Androscoggin River system remains an active sediment contributor to the shelf as indicated by: 1) the textural and compositional trends at their confluence in the Merrymeeting Bay (Malone, 1997; Kniskern et al., 1998); 2) the largest bedforms along the lower estuary indicative of the net downstream sediment transport (Fenster and FitzGerald, 1996; Hannum, 1996), and morphological and sedimentological trends at the mouth of the estuary (Buynevich and FitzGerald, 1998; Buynevich and FitzGerald, in prep.).

Former barrier positions can be inferred from the presence of buried inlet cut-and-fill deposits and distribution of backbarrier sediments in the nearshore (Riggs *et al.*, 1992). As shown by Barnhardt *et al.* (1997), a series of submerged shoreline deposits mark the periods of relatively slow sea-level rise or stillstand, when sediment supply was comparable to or exceeded the accommodation space. The shoreline deposits are often modified during transgression and are difficult to resolve from seismic evidence. The transgressive/stillstand barrier deposits must be distinguished from terraces representing delta front positions and formed primarily during regressive and lowstand phases of delta deposition (Shipp *et al.* , 1991). Channel cut-and-fill at the entrance of Small Point Harbor and gas-charged deposits in the central part of the harbor suggest the presence of muddy lagoonal deposits (Fig. 6) and suggest previous, more seaward positions of the barriers.

The seismic signature of natural gas (NG) facies was described by Belknap *et al.* (1989) and Belknap and Shipp (1991). Gas-escape features (i.e., pockmarks, gas-expansion cracks) are commonly associated with muddy sediments and are interpreted to be a result of natural gas (e.g., methane) escape from the breakdown of organic-rich sediments (Kelley *et al.*, 1994; Barnhardt *et al.*, 1997). Some of the areas along the Kennebec River Paleodelta characterized by gas-attenuation signatures were interpreted as backbarrier deposits by Barnhardt (1994) and Barnhardt *et al.* (1997). Large areas of natural gas occur in the south-eastern Casco Bay and along the lower Sheepscot River valley (Barnhardt *et al.*, 1996). Evidence of localized gas concentrations beneath the shoreface and bay sediments seaward of the modern barriers aid in mapping of drowned backbarrier deposits and inferring former barrier positions. In front of Popham and Seawall barriers, 5-15 m thick estuarine deposits (facies E) commonly underlie the transgressive sand and gravel (SG) and marine mud (M) facies and were mapped in a 12-30 m depth range (Barnhardt, 1994). Onshore studies show that fine-grained tidal flat sediments underlie the barrier lithosome at many locations (Buynevich *et al.*, 1996). Evidence is still lacking for preserved backbarrier units beneath the modern shoreface. The present study suggests that in areas such as Small Point Harbor and Sagadahoc Bay, fine-grained backbarrier deposits have been preserved in relatively shallow depths (<10 m; Fig. 8). In addition, the presence of nearshore bedrock highs can result in early barrier stabilization and development of backbarrier deposits (e.g., Half Mile Beach). During later stages of transgression these anchor points, bypassed by the barrier sands, enhance preservation of backbarrier deposits by sheltering the coastline from wave energy.

## CONCLUSIONS

This study extends the shallow seismic database from the inner shelf to the nearshore regions with a number of paleotopographic features traced to previously identified geomorphic zones of the inner continental shelf.

1. Thick sediment fill in the New Meadows paleovalley (5 to 25 m) consists of stratified material and may contain Late Quaternary fluvio-deltaic deposits. Together with textural and compositional data, and the existence of the incised valley fill onshore, the western lobe of the Kennebec River Paleodelta may actually be one of the initial regressive deposits derived from the Androscoggin River. This delta possibly formed prior to 11.0 ka B.P.

2. The deep paleovalley offshore of Seawall Beach is unlikely to have been an active fluvial channel. This valley appears to have served primarily as a depocenter for the sediment draining westward from the main Kennebec valley through connecting valleys underlying the Atkins Bay and Pond Island Shoal. Similarly, the landward portions of the New Meadows and Morse River valleys terminate in bedrock ridges and were not occupied by fluvial channels.

3. Three bedrock valleys east of Salters Island contain 15-30 m-thick stratified channel fill deposits and are part of the regressive fluvial distributary system which fed the eastern lobe of the Kennebec River Paleodelta prior to emergence of the -35 m bedrock pass described by Barnhardt *et al.* (1997).

4. The influence of the nearshore bedrock topography on barrier stratigraphy is well illustrated along the Reid State Park beaches. Along the western portion (Half Mile Beach), a shallow bedrock basement with multiple ledges and islands resulted in

early barrier stabilization of thin barrier (2-5 m) and subsequent accumulation and preservation of backbarrier units. In contrast, Mile Beach to the east has thicker barrier lithosome (5->10 m) and only scattered organics due to an absence of shallow bedrock and consequently higher degree of exposure.

5. The distribution of natural gas in the nearshore areas, particularly within embayments, suggests the presence of organic-rich sediments, and can be used to map the Holocene backbarrier deposits. This, in turn, will help to establish the former barrier positions.

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