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HEAVY-MINERAL STUDIES — VIRGINIA INNER CONTINENTAL SHELF

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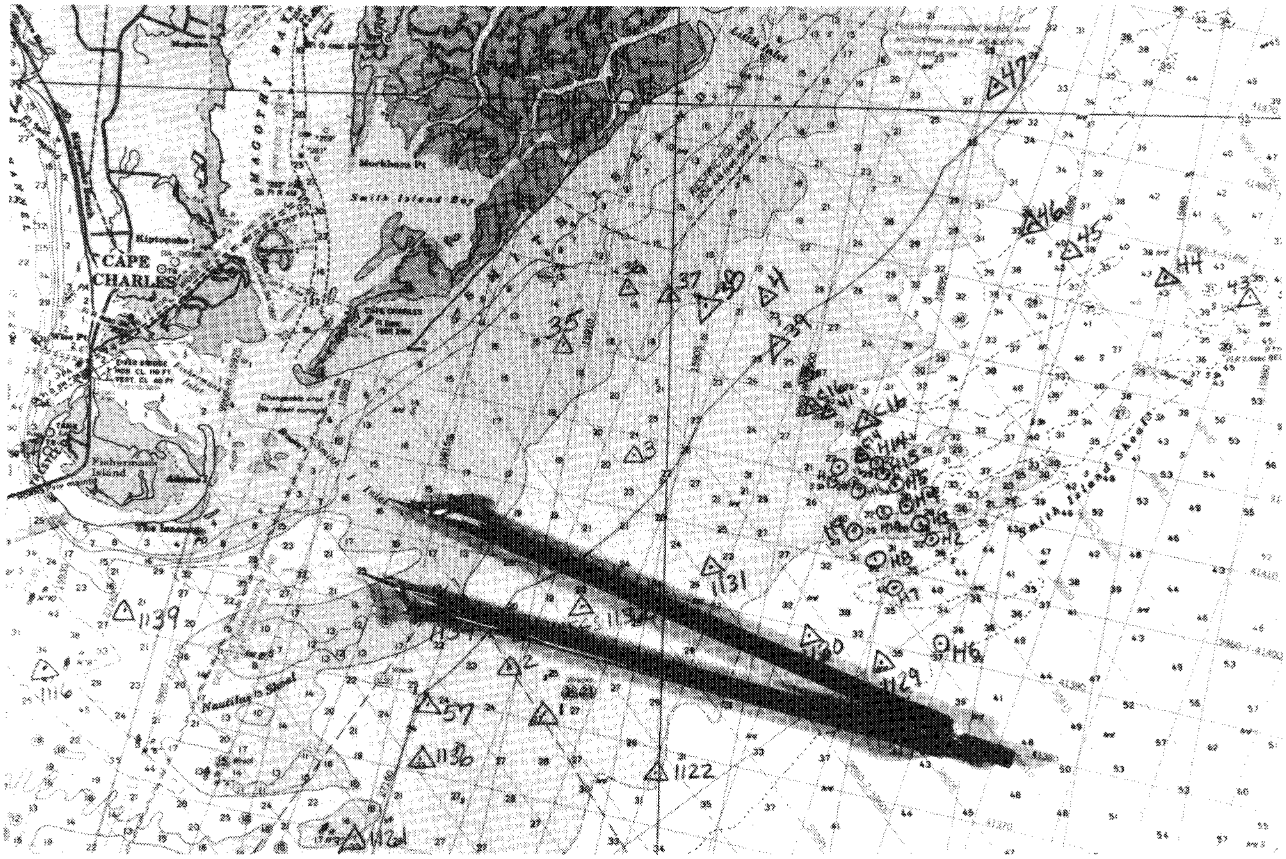

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ACOUSTIC GEOLOGY OF A PORTION OF VIRGINIA'S INNERMOST CONTINENTAL SHELF

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ILLUSTRATIONS

ABSTRACT

Side-scan sonography of the innermost continental shelf between Cape Henry and the Virginia-North Carolina border depicts a relatively typical inner shelf bottom generally characterized by medium density, meso-scale roughness. Sub-bottom acoustic profiles depict the stratigraphy as a Tertiary-age basement separated from Quaternary-age deposits by a regional, angular(?) unconformity. Holocene-age sediments form a discontinuous layer above another unconformity. The area's topography appears to be a function of the presence of the modern sediments.

INTRODUCTION

We collected approximately 534 km (276 n mi) of acoustic-survey line over the innermost continental shelf between the mouth of Chesapeake Bay and the Virginia-North Carolina boundary during July and August 1987 (Figure 1). This paper presents a discussion of a portion of the sub-bottom profiles as well as a qualitative report on the side-scan sonography obtained during that survey. Additionally, the paper includes a discussion of the occurrence of heavy minerals in relation to seismic stratigraphy.

The field work was a collaborative effort of two projects: one a joint Virginia Institute of Marine Science (VIMS) and Virginia Division of Mineral Resources (VDMR) study of the distribution of heavy minerals (Berquist and Hobbs, 1986, 1988a, 1988b), the other, a study by VIMS for the City of Virginia Beach of offshore reserves of sand potentially available for nourishment of the city's public beaches (Kimball and Dame, 1989). As part of the overall combined study, we also collected approximately two dozen vibracores across the survey area (Figure 1).

The area of geophysical investigation generally is inshore of that discussed by Shideler and others (1972) and Swift and others (1977) but does include the shoreface ridge system at False Cape (Swift and others, 1972). The shallow, sub-bottom profiles presented in this study add shallow detail

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to, and confirm, the earlier interpretations. Additionally, the present work provides a shoreward extension of the existing data.

As well as the work of Swift and others (1972, 1977), Shideler and others (1972), and Kimball and Dame (1989), there have been several other studies of the submarine geology of the area. Meisburger (1972) reported on the sediments and geomorphology in the immediate vicinity of the entrance of Chesapeake Bay. Hobbs and others (1984) and Kimball and others (1989) discussed resources of sand within the southernmost portion of Chesapeake Bay. Berquist (1986), Hobbs and others (1986), Colman and Hobbs (1987), and Colman and others (1988) refined the understanding of the geology of the bay mouth. Williams (1987) presented seismic and core data for the area adjacent to, and northeast of, the area of this present study. Bowen and Swean (1985) presented data on the subsurface of a portion of the area associated with the Cape Henry navigation channel.

Terrestrial studies beginning with Oaks and Coch (1973), proceeding through the various works of Johnson and others (1982, 1985), and summarized by Peebles (1984) provide further background data that can be extended offshore to enhance the interpretations.

GEOPHYSICAL SURVEYS

The surveys were performed from the VIMS's R/V Bay Eagle using a Datasonics SBP-5000 sub-bottom profiling system and an EG&G SMS-960 side-scan sonar system. (The use of trade names is for descriptive purposes only and does not imply endorsement of the products by either agency.) The primary navigation system was the ship's loran-c supplemented, at times, by a locally configured Del Norte system. Location fixes were recorded at five minute intervals except in some areas off Sandbridge and Rudee Inlet where the interval was two minutes. The sub-bottom survey was designed in two phases, one before and the other after coring. This was done in order to provide guidance for placement of the cores and then to derive the maximum information in those areas suggested by preliminary interpretation of the combined core and early seismic data.

The sub-bottom profiling system consisted of a Datasonics SBT-220 transceiver, a TTV-120 transducer vehicle, and either or both an EPC-3200 or EPC-4800 graphics recorder. The transceiver-transducer system is a dual frequency arrangement with one frequency selectable at 3.5, 5, or 7 kHz, the other preset at 200 kHz. Most of the profiling was done using a recorder sweep rate of one-eighth of a second (125 ms) yielding a potential full-scale record of approximately 90 m, assuming an acoustic velocity of 1500 ms^{-1}; the actual record seldom exceeded 30 m. Most of the profiles were recorded simultaneously on the two graphics recorders.

The near planimetrically correct sonographs were recorded in real time on electrostatic paper. The data were not recorded on magnetic media. The sea-floor mapping system uses a 105 kHz EG&G Model 272 tow fish. Sea-floor mapping was done at a 100 m half width (200 m full swath).

Side-scan sonography provides a suite of information concerning the character of the bottom surface. By graphically depicting the return strength of a "fan-shaped", acoustic signal transmitted perpendicular to the ship's track, the sonographs provide a general indication of the condition of the bottom (Williams, 1982; Duane, 1987; Duane and Stubblefield, 1988). The system relies more upon energy reflected by grain faces (backscattered) than directly reflected from the broad surface of the sea floor. A strong (return) signal suggests a relatively hard, coarse-grained bottom and a weak signal suggests a softer, finer-grained, muddy bottom (Hobbs, 1986; Wright and others, 1987). The sonographs also depict large-scale elements of bottom roughness: bedforms, as a function of variations in backscattered and reflected energy; and the occurrence of acoustic shadow zones caused by topographic highs. Side-scan sonographs also depict man-made bottom features and artifacts. The side-scan survey was a reconnaissance survey, a secondary objective to be run coincidentally with the sub-bottom profiling and not as a site specific, detailed study; thus the track lines were not spaced to allow overlapping (really side-lapping) images. Thus it usually is not possible to trace specific features from track line to track line; it is possible, however, to correlate or trace trends or groups of features.

Analysis of the sonographs is qualitative and subjective. The analyst sketches observations and interpretations of the images recorded on the sonographs onto a basemap containing the track lines and navigation fixes. The analyst looks for correlation of features and observations on adjacent and crossing lines as well as for broader patterns or trends. The end products are an interpretative map of the bottom and a discussion of general and, where possible, specific elements depicted by the imagery. Although quantitative analysis of some aspects, for example, height of some features above a level sea floor, is possible, it neither was seen as necessary nor undertaken for this project. No attempt was made to estimate the sediment type as suggested by the sonographs on a broad areal basis.

The cores were taken with a 9 cm (3.5 in) inside diameter Vibracorer operated from the R/V Atlantic Twin. The maximum length of the cores is 6.1 m (20 ft); although in some instances it was possible to approach that maximum only by jetting and obtaining multiple sections. In the laboratory, the split cores were analyzed only as to gross lithology (Berquist and Hobbs, 1988b).

RESULTS AND DISCUSSION

Side-scan sonography: Side-scan sonography is of interest in two aspects of the study of offshore heavy-minerals. Knowledge of the bottom grain-size characteristics and presence or absence of bedforms can provide information concerning the occurrence of heavy minerals. The minerals might be concentrated in sediments of a particular texture or the processes that created and maintain the bedforms might be responsible for concentrating particular suites of minerals. Knowledge of bedforms as indicators of a potentially active bottom would be important to those parties concerned with dredging or otherwise working the bottom should heavy minerals of economic interest be present. Additionally, should there be evidence of use of the bottom by man, it would

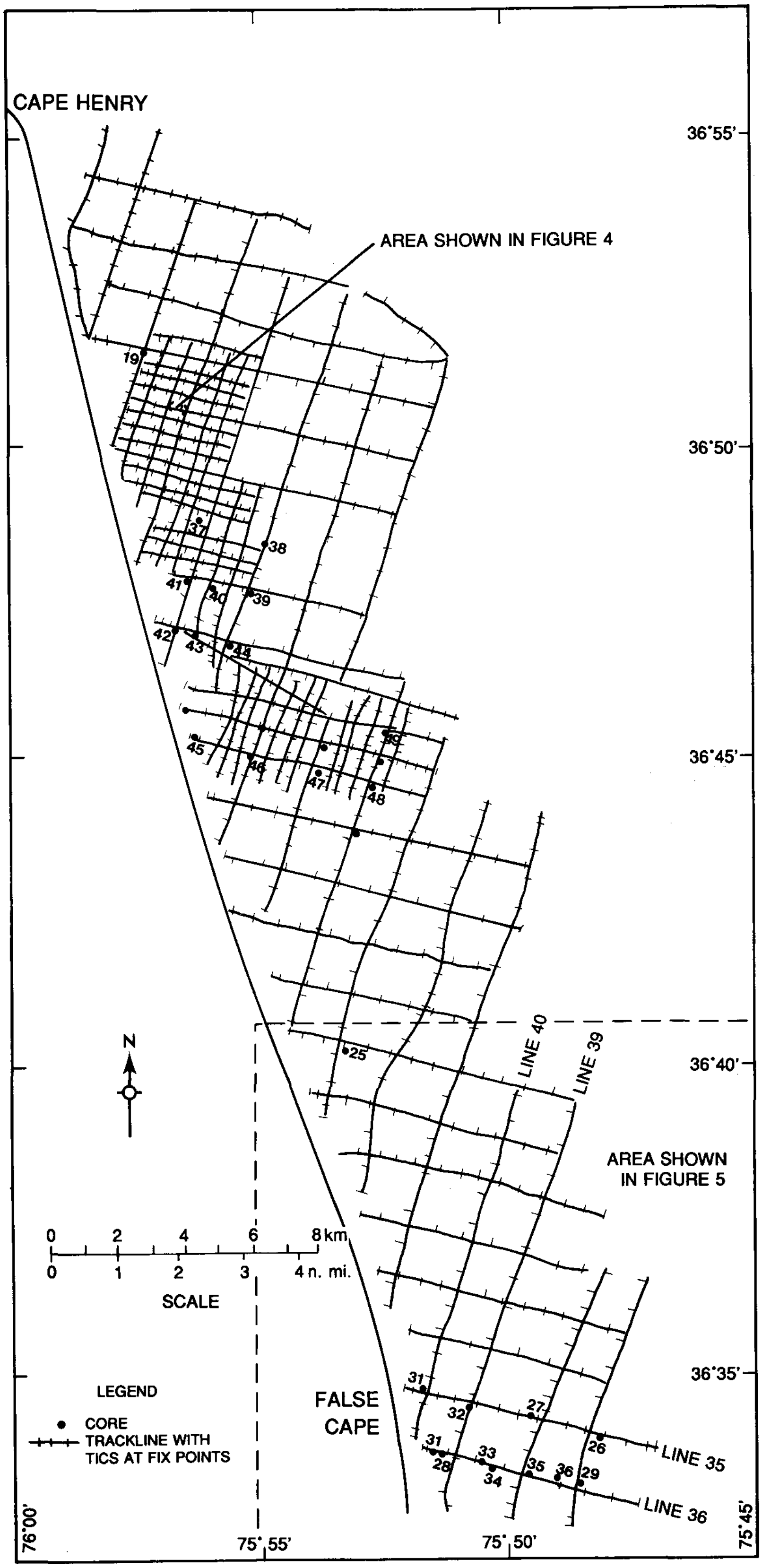


Figure 1. Location map indicating the general location of the study area and specific location of the geophysical track lines and core holes. Highlighted lines are depicted in other figures. The geological interpretation primarily is concerned with the area south of 36°55'.

have to be considered in any plans for dredging or mining.

Figures 2 and 3 are interpretive sketch maps depicting the features on the sonographs of the study area. Because of the greater line-density in the northern portion of the area (Figure 2) and the generally subjective nature of the analysis, it is difficult to assess the differences between the two regions. It appears that there may be a greater density of bottom features in the northern portion of the area, and definitely a greater number of anthropogenic features. Paramount among these is an elongate area of drag marks (Figure 4). If these are drags caused by commercial fishing gear, this would be a strong indication of a relatively intense use of the bottom, which in turn might necessitate an assessment of both the area's benthic resources and the potential impacts of dredging on other uses of the area. Alternatively the drag marks could result from anchor drags indicating another use of the bottom.

Throughout the study area there are rhythmic, light to dark changes in the base tone of the sonographs. These alternations are related to the bottom topography and might indicate changes in grain size or packing across the ridges. Generally the darker areas are associated with the sides of the troughs or between-ridge swales. The tonal variations probably are actual evidence of changes in the sediment and are not artifacts of the sea-floor mapping system as it operates over a nonplanar bottom (S. Kimball, oral communication, 1989; D. Swift, oral communication, 1989).

Whether or not the apparent decrease in bottom features toward the south is real, a function of the less closely spaced track lines, or variation in the analyst's interpretations, or a combination of the three is difficult to assess. If this is a real phenomenon, it probably is the result of increasing distance from the mouth of Chesapeake Bay and its more dynamic current regime (Ludwick, 1978).

The study area fits into Wright and other's (1987) classification as Inner Shelf Shoreface (Type Ia) or Inner Shelf Ridge Field (Type Ib) bottom types. The type section for the Inner Shelf Shoreface environment is adjacent to Dam Neck, Virginia and is within the present study area. Both the shoreface and ridge field environments are characterized by: low biogenic roughness at any scale, the presence of small-scale (heights 1 to 10 cm, wavelengths 1 to 50 cm) wave- and current-induced roughness, and usually, the presence of meso-scale (heights of 0.1 to 2.0 m, wavelengths of 0.5 to 50 m), current-induced roughness.

Sub-bottom profiles: This paper is concerned primarily with the sub-bottom profiles in the southern third of the study area (Figure 1). The remaining portions being the subjects of other studies (Williams, 1987; Kimball and Dame, 1989). Part of this area was discussed by Swift and others (1972, 1977), Shideler and others (1972), and others, whose data and interpretations are significant to the understanding of the historical geology of the area.

Consistent with the interpretation of Shideler and others (1972) and ensuing papers, there are three or four major (acoustic) units separated by two or three unconformities. The lowest unit (unit A) was considered to be of Miocene age in the 1972 work and is most probably the same as the Pliocene-age nearshore, marine deposits discussed by Colman and others (1988). Some of the later Tertiary-age deposits have been reassigned from Miocene to Pliocene on the basis of new data obtained since the publication of the earlier work. This widespread unit, the Yorktown and/or the Chowan River Formations, constitutes local "basement". Cores 32 and 34 (Berquist and Hobbs, 1988b) appear to penetrate unit A, which is discernable by a substantially higher proportion of silt, 53 percent in core 32, 26 percent in core 34, than the overlying units wherein the silt usually accounts for less than 20 percent and frequently less than 10 percent of the sediment.

Unit A is separated from the next younger unit by reflector 1, an easily traceable, wide-spread, regional reflector (Figure 5). Although Shideler and others (1972) and Colman and Hobbs (1987) agree that reflector 1 represents an erosional surface, they differ as to the age of that surface. Colman and Hobbs (1987) suggest a late Wisconsin age but agree that it could be as old as late Pliocene. Within the present study area, reflector 1 ranges from 12 to 20 m below sea level and generally dips gently to the southeast (Figure 5).

Local relief within the study area on reflector 1 is low. One of the few anomalies in reflector 1 is in the southwestern-most corner of the study area (the ends of lines 39 and 40, Figures 1 and 6) where a portion of a filled channel is visible. Although there is insufficient evidence to demonstrate whether this channel is a Pleistocene-age feature or the filled remnant of the Holocene-age Currituck Inlet channel, the magnitude of the channel and the apparent absence of unit D (see discussion below) suggests the older.

Unit B occurs immediately above reflector 1 and, according to Shideler and others (1972), is separated from unit C by reflector 2. In the present work, reflector 2 is not widely identifiable thus separation of units B and C is not always possible. The differentiation is more easily seen in the area just north of the present study (J.K. Dame, personal communication). Reflector 2 and unit C are suggested in at least some of the present study's profiles. Shideler and others (1972) refer to the discontinuous character of unit C, in which circumstance reflector 3 is the upper boundary of unit B.

According to Shideler and others (1972), reflector 2 is the basal boundary of unit C. In the western portion of their study area, which would embrace the study area of the present report, reflector 2 "appears to be truncated by overlying reflector 3." They also describe unit C as pinching out in the western portion of the study area. Thus differentiation of units B and C in the areas closer to shore is problematical. Shideler and others (1972) tentatively correlated unit B with Oak's (1964) Great Bridge Formation - Sandbridge Formation sequence. More recent work (Johnson and others, 1982, 1985) indicates that these two formations now would be mapped as the Pleistocene-age Shirley and Tabb formations. This would indicate that unit B is a pre-Wisconsin-to early Wisconsin-age series of deposits. Johnson and others (1982, 1985) describe these formations as ranging from fluvial to shallow marine, strand complexes.

Shideler and other's (1972) unit D is represented in the present study area. Unit D overlies reflector 2, or where present, reflector 3, is discontinuous, and consists of recent sea-floor sediments. Shideler and others (1972) document a ^{14}C date of approximately 4220 years BP (Figure 5) for unit D. This unit apparently has formed or is forming, during the ongoing transgression. Much of the present variation in sea-

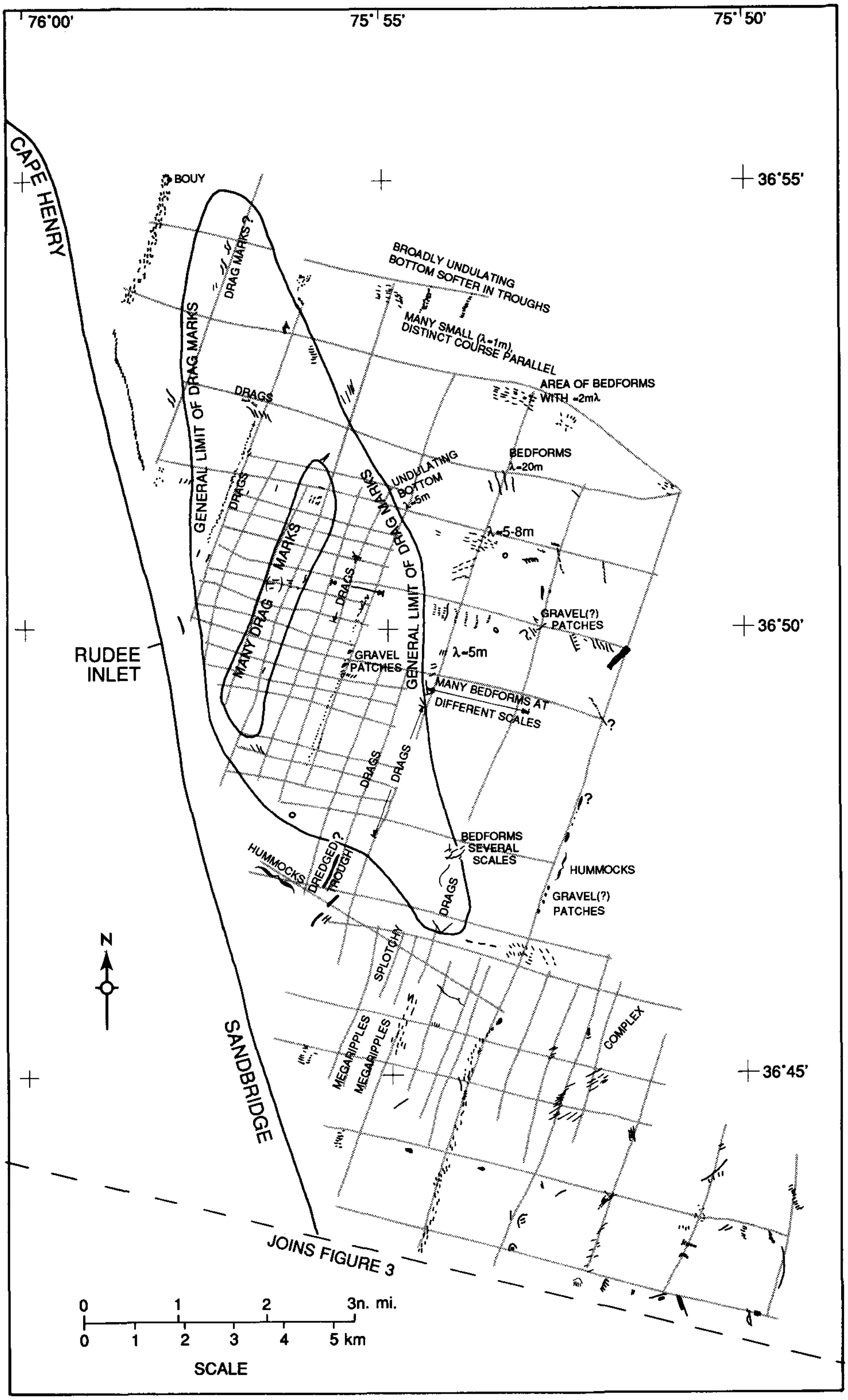


Figure 2. Interpretive map of information from side-scan sonography in the northern portion of the study area.

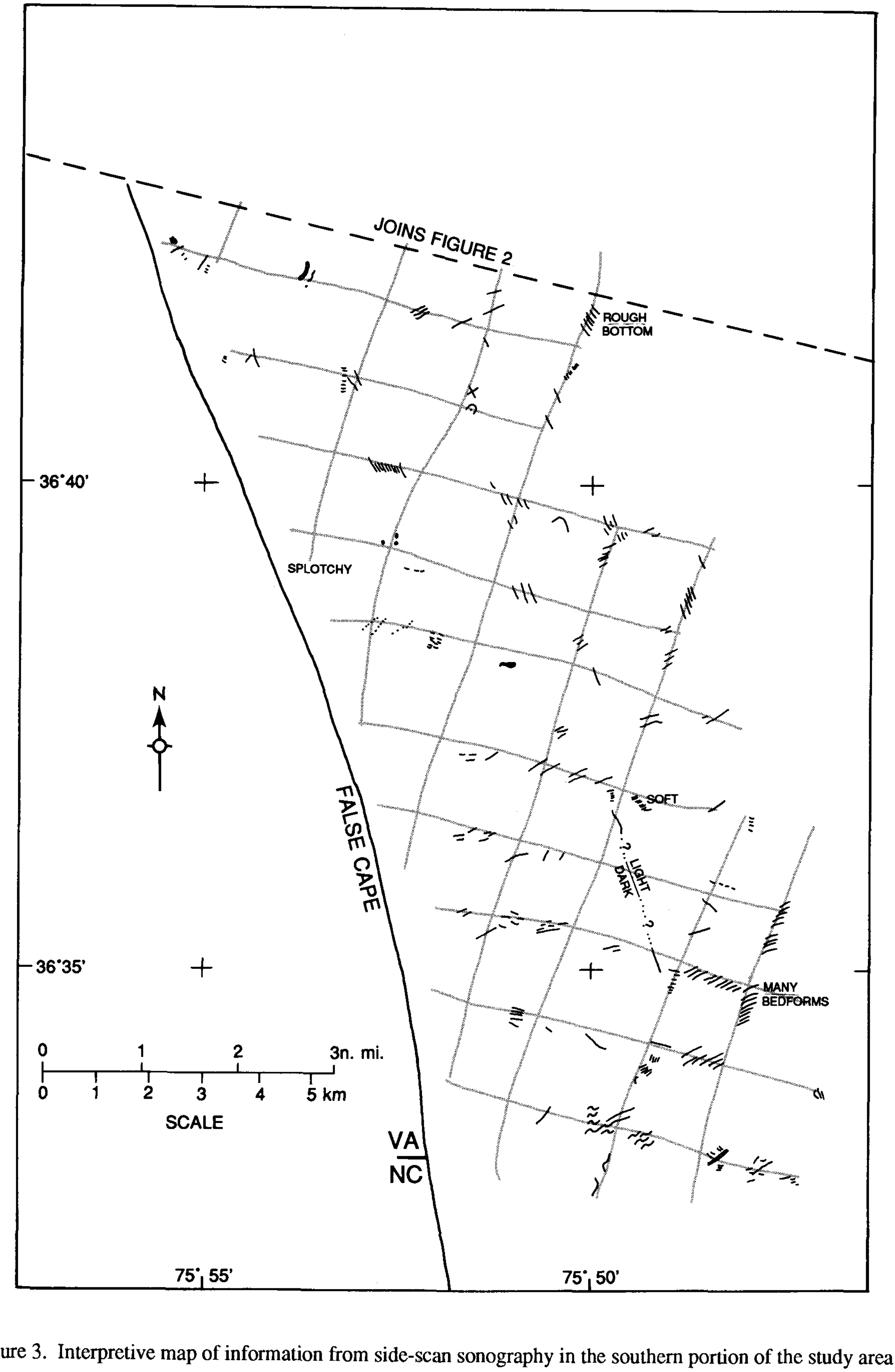


Figure 3. Interpretive map of information from side-scan sonography in the southern portion of the study area.

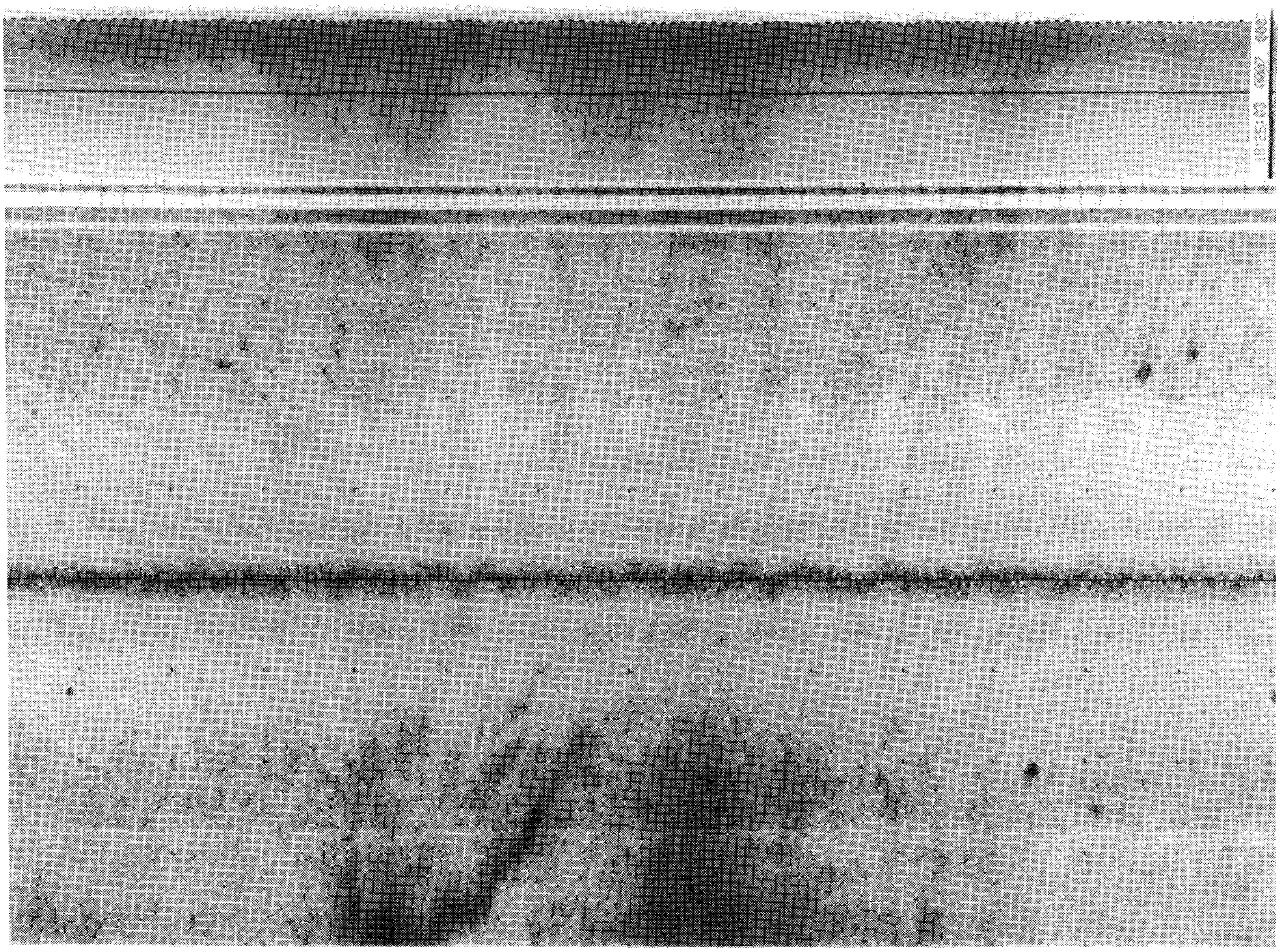


Figure 4. A portion of a side-scan sonograph depicting "drag marks."

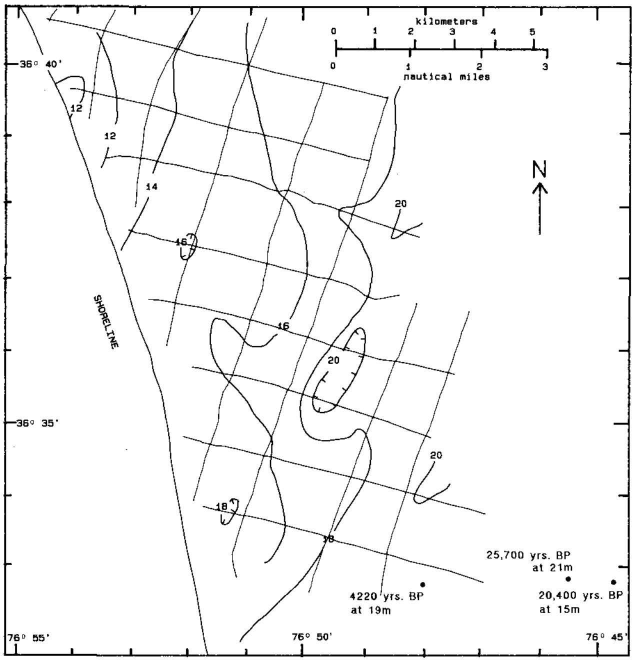
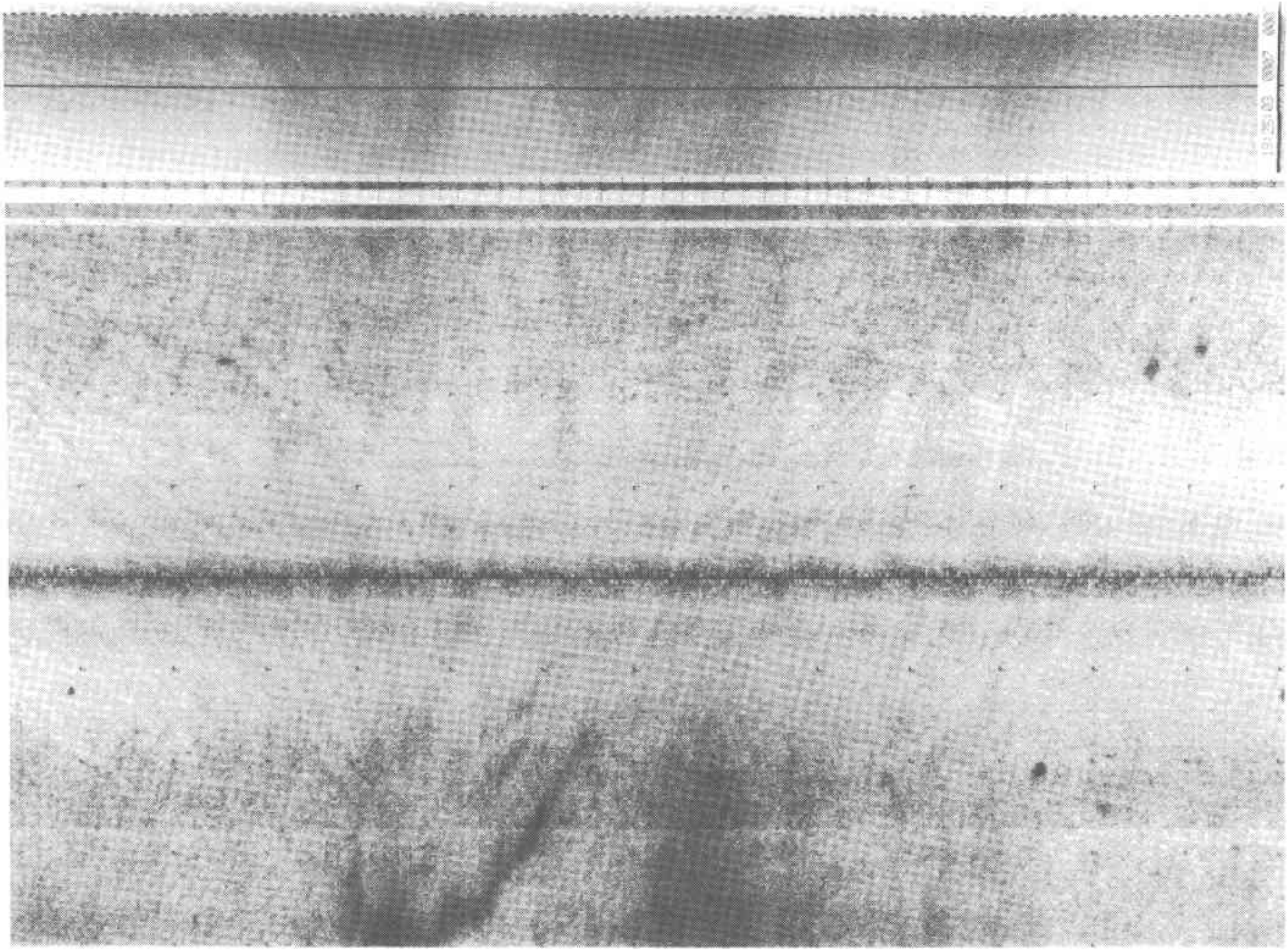


Figure 5. A contour map on reflector 1, the upper surface of unit A. This represents the top of Tertiary deposits. ^{14}C dates are from Shideler and others (1972).

floor topography, such as the False Cape Ridge System (Swift and others, 1972), reflects the distribution of this unit. The intermittent character of unit C is evident in the sub-bottom profiles (Figures 6 and 7).

Heavy minerals: The sediments in the nearshore area of southern Virginia Beach are not as abundant in total heavy minerals or in the titanium-bearing minerals as the sediments in the area north of the mouth of Chesapeake Bay (Berquist and Hobbs, 1988b). This mineralogical difference indicates that the area south of the bay's mouth may have a different source area than the northern area and that the present and past deep baymouth channels (Colman and Hobbs, 1987; Colman and others, 1988) may be an effective barrier for nearshore transportation. For a further discussion of regional mineralogical differences see Ozalpasan (1989) and Calliari and others (1990). The False Cape suite of heavy minerals appears to be more abundant in zircon and monazite (Berquist and Hobbs, 1988b, cores 26, 29, and 32) than other areas although the total concentrations are relatively low. The highest concentration of zircon and monazite occur in the cores taken at sites where unit D is thin or absent, indicating that the minerals occur either as a lag in the troughs between ridges or in older deposits, such as units B or C.



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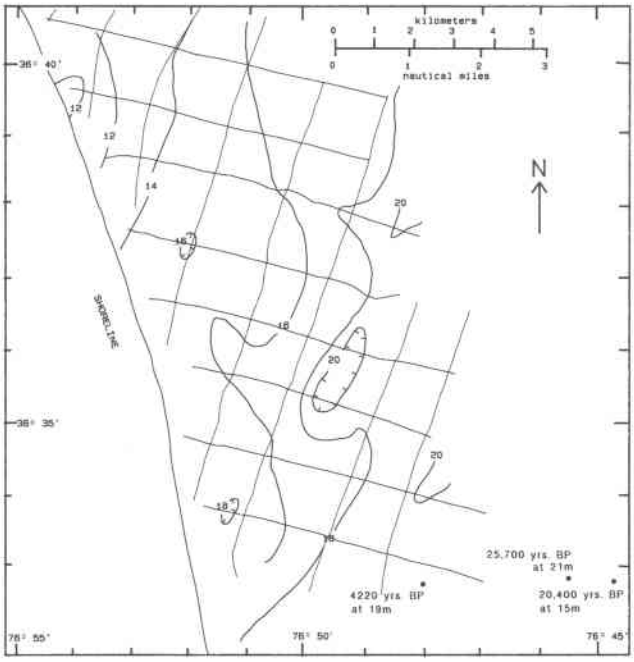

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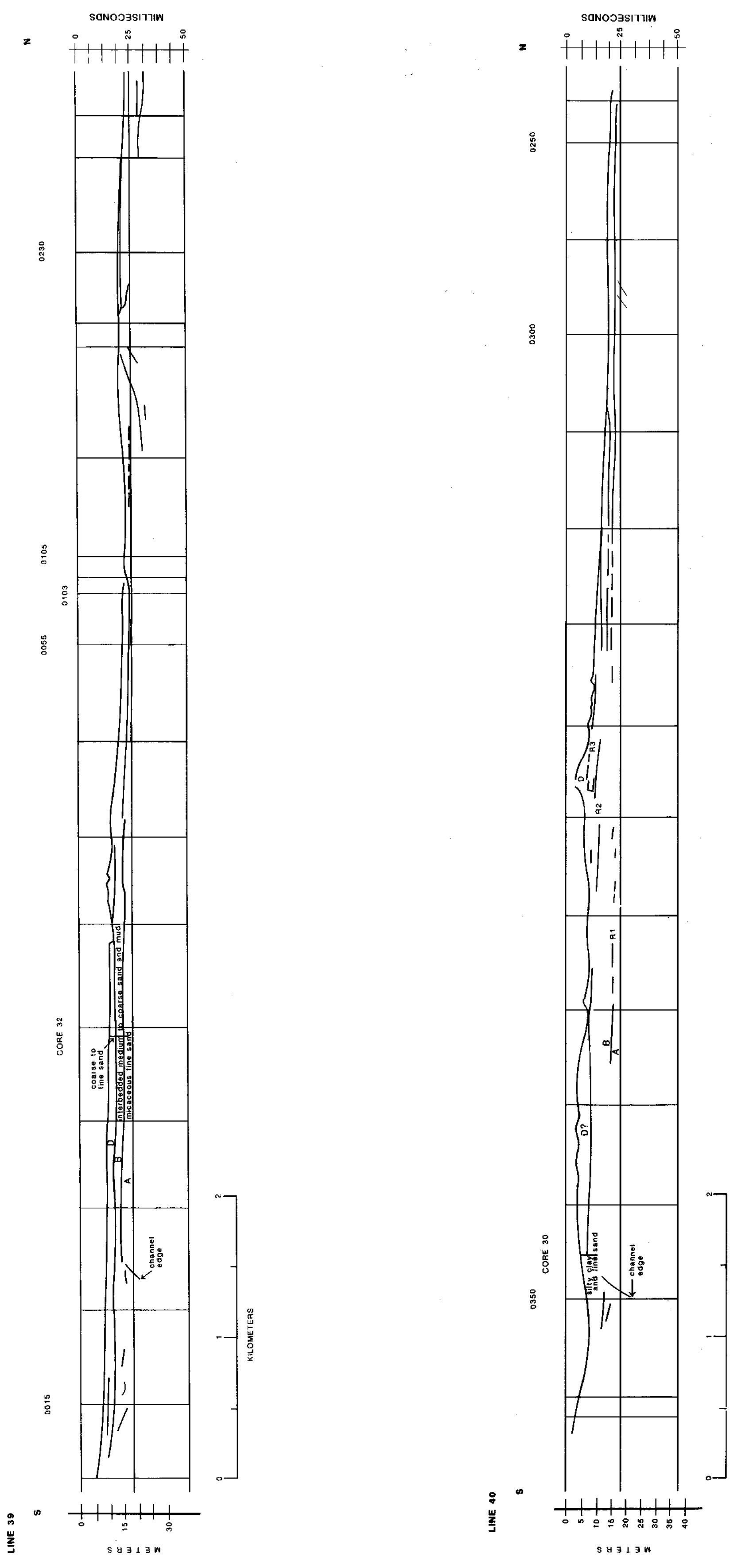

Figure 6. Interpretation of sub-bottom profiles 39 and 40, see Figure 1 for location. The upper portion of a Pleistocene-age channel is evident in the southern portion of profiles 39 and 40. The channel appears to have been eroded in both reflectors 1 and 2 suggesting that the channel fill is at least as young as unit C. The discontinuous nature of unit D, Holocene material, is best displayed in the center portion of Line 40.

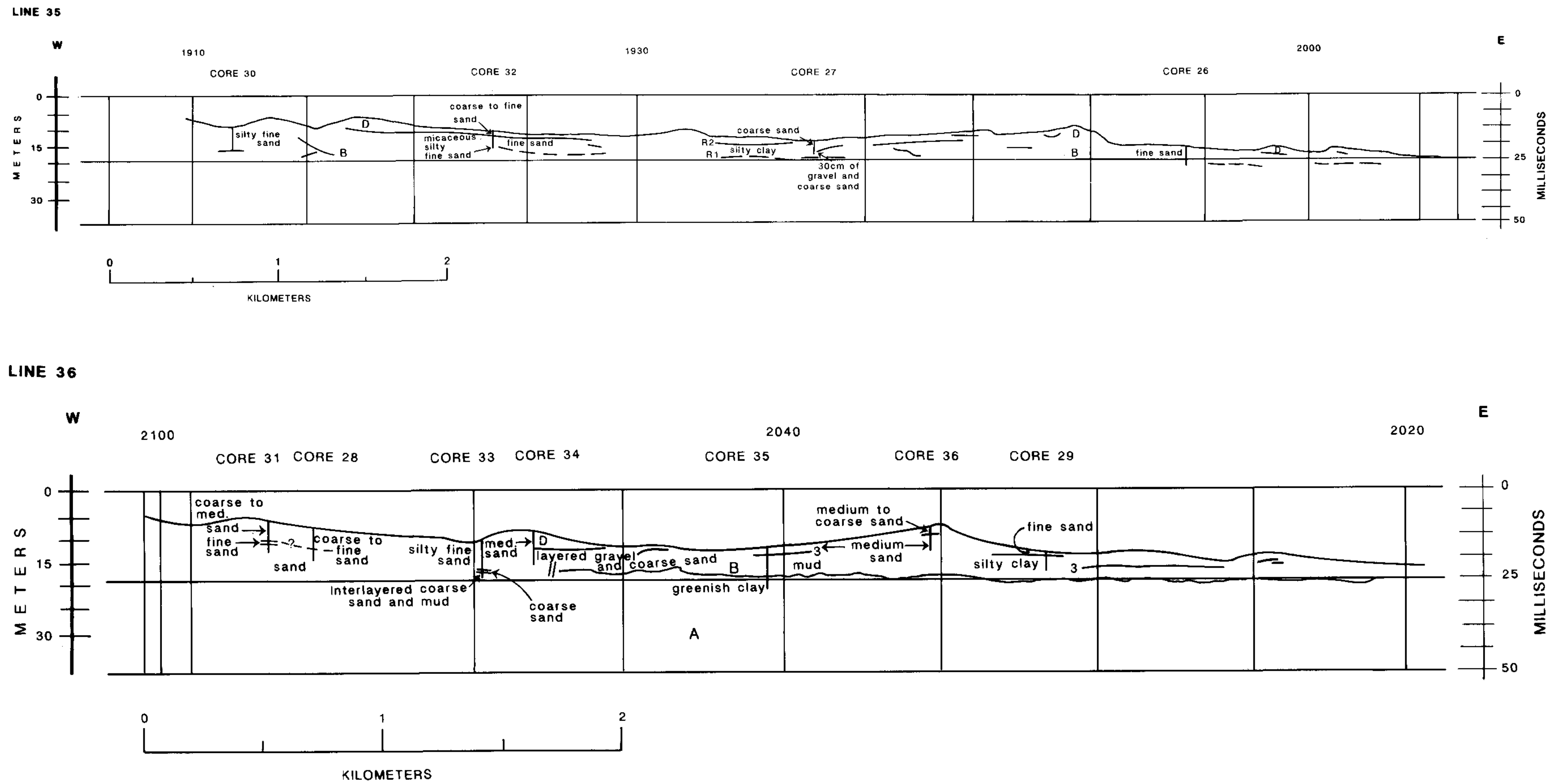

Figure 7. Interpretation of sub-bottom profiles 35 and 36, see Figure 1 for location. These profiles cross the False Cape ridge system at the southern limit of the study area. Reflectors 1 and 3 and units A, B, and D are clearly evident.

Swift and others (1972), in discussing the shoreface ridge system at False Cape, described a complex relationship between grain size and bottom topography. They described the crests as generally covered with fine- to medium-grained sand, the flanks and the margins of some troughs as floored by fine- to very-fine-grained sand, and the axes of the troughs as floored with pebbly, medium- to coarse-grains sands. They surmised that the coarser sediments formed a thin, discontinuous layer over an older substrate. This is consistent with the interpretation of later studies (Shideler and others, 1972; Swift and others, 1977) that the topography is a function of the presence of an active, recent, discontinuous deposit, unit D. This spatial variation in sediment type is reflected in the tonal variations on the side-scan sonographs as discussed above.

Samples of sediment from the most recent set of cores (Berquist and Hobbs, 1988b; Kimball and Dame, 1989) indicate that the sediments of the ridge system, and by analogy with unit D, are somewhat coarser than the sediments of units B or C. The uppermost sediment samples in cores 31, 34, and 36, which were taken at or near the crests of the ridges, have mean grain sizes of 1.56, 1.7, and 1.1 phi, respectively. By contrast, sediments from units B or C generally have mean grain sizes between 2 and 3 phi, although there are some, usually thin, lenses of coarser material. As noted above, sediments of unit A have a greatly increased proportion of silt.

CONCLUSIONS

Side-scan sonography of the inner continental shelf adjacent to Virginia Beach, Virginia, between the mouth of Chesapeake Bay and the Virginia-North Carolina border indicates that the bottom meets the criteria of an inner shelf - shoreface or an inner shelf - ridge field when classified by roughness characteristics (Wright and others, 1987). The present study area includes the type area for the inner shelf - shoreface classification. The sonographs also depict a region containing what are interpreted as "drag marks", that, if correctly interpreted, would be indicative of at least a moderate scale, bottom-fishing industry.

Sub-bottom profiles of the southern third of the area demonstrate a shoreward extension of the acoustic geology described by Shideler and others (1972) and Swift and others (1972, 1977) who worked in the immediate seaward and adjacent areas. Their interpretations proposed a Tertiary-age (Pliocene) "basement", unit A, separated from the overlying Quaternary-age deposits by a strong, regional (angular?) unconformity, reflector 1.

The next younger stratum, unit B, is a Pleistocene-age deposit, separated from still younger deposits by another unconformity. In the northern and eastern portion of the study area, there is another Pleistocene-age deposit, unit C, that is absent to the west and south. The uppermost stratigraphic layer, unit D, is separated from the older units by an unconformity, reflector 3, and is discontinuous. Three of the units appear to have a characteristic sediment type: A having a high silt content, B usually consisting of fine sands with some silt, and D generally being the coarsest unit. There are insufficient data to characterize unit C.

The heavy-mineral suite of the area is dissimilar to that north of Chesapeake Bay. The assemblage here is richer in zircon whereas the northern area has more ilmenite.

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