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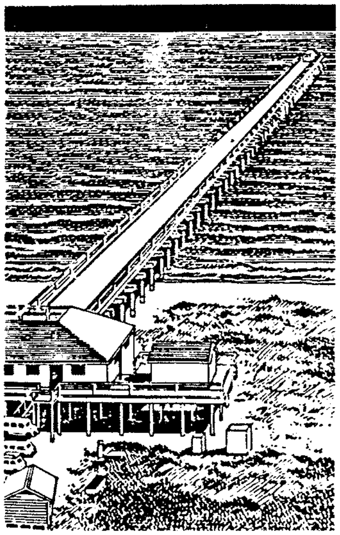

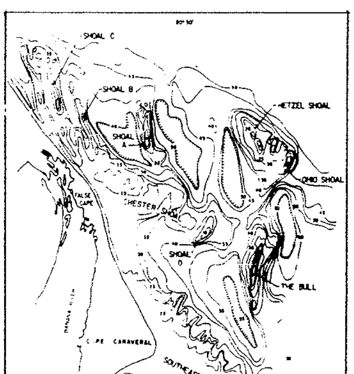

TECHNICAL REPORT CERC-90-18

EXPLORATION AND SAMPLING METHODS FOR BORROW AREAS

by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
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Beach restoration as a means for mitigating severe storm damage is a major coastal engineering activity in the US Army Corps of Engineers. The single most important element in beach restoration is the availability of sand on a beachfront that is both suitable from an engineering standpoint and stable. Since local financial participation is now legally required on beach restoration projects, improving the efficiency of preconstruction exploration and design techniques has become exceedingly important in overall project management. This study is the first of a series that will examine the state of the art of the various geotechnical and geological technologies used to foster effective and environmentally sound coastal project designs.

The current state of knowledge regarding geological indicators of subaqueous, sand-bearing formations is discussed. Existing technology in terms of geophysical equipment and

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application techniques for exploration programs to locate suitable borrow sources for beach fill are reviewed. Techniques for planning, design, and conduct of field exploration programs are recommended based on experiences covering 30 or more years. The main elements of program planning and design are trackline survey layout, core site selection, scheduling of events, selection of equipment and personnel, and preparation of a realistic cost estimate.

Although presently available exploratory equipment is adequate, and there is considerable geological experience in correlating subaqueous geomorphic features to occurrences of sand, there is considerable room for improvement in both areas through future research that could materially lower unit costs for beach sand exploratory programs. Since there is a long-term need for beach restoration, continued improvement in geophysical hardware (in particular, computer enhancement techniques) should be pursued.

PREFACE

The study reported herein results from research performed by the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES) under the Survey of Technologies in Coastal Geology, Work Unit 32538, Coastal Geology and Geotechnical Program, authorized by Headquarters, US Army Corps of Engineers (HQUSACE). Mr. Ben Kelly was HQUSACE Technical Monitor. Dr. C. Linwood Vincent is CERC Program Manager.

This report was prepared by Mr. Edward P. Meisburger, Coastal Geology Unit, Coastal Structures and Evaluation Branch (CSEB), Engineering Development Division (EDD) under the general supervision of Mr. Thomas W. Richardson, Chief, EDD, and Ms. Joan Pope, Chief, CSEB. Chief of CERC during the investigation was Dr. James R. Houston, and Assistant Chief was Mr. Charles C. Calhoun, Jr.

Commander and Director of WES during publication of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet per mile	0.1893935	metres per kilometre
inches	2.54	centimetres
knots	0.5144444	metres per second
miles (US nautical)	1.852	kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

EXPLORATION AND SAMPLING TECHNIQUES
FOR BORROW AREAS

PART I: WORK UNIT SCOPE AND OBJECTIVES

1. This report is the first in a series that will summarize research results, current data collection technologies, and methods for investigation of coastal geology in support of US Army Corps of Engineer projects. Presently, information on these subjects is scattered in numerous reports and journal articles, books, and individuals with practical experience and has not been incorporated into comprehensive sources suitable for use by Corps field agencies.

2. Report subjects were selected by considering the types of geological support required in typical coastal projects and deficiencies in existing sources of guidance. The report titles and expected completion dates are listed below.

- a. Exploration/Sampling of Borrow Sources, 1990.
- b. Technology for Assessing Geological History, 1990.
- c. Impact of Geomorphic Variability in Coastal Features, 1990.
- d. Geology of Cohesive Shores, 1991.
- e. Techniques of Sediment Budget Analysis, 1991.
- f. Stone as a Construction Material in Coastal Projects, 1991.
- g. State of the Art in Coastal Geology Workshop, 1992.

Each of these reports will consider: (a) what is presently known about the subject; (b) procedures for obtaining field data of project areas; (c) how information and field data can be interpreted and applied to the study, planning, and design of coastal projects; and (d) additional research needed to improve the state of the art.

3. Existing information sources on the general subject matter of these reports are numerous; a comprehensive computer search of major archives using the key words coastal geology, coastal geography, coastal geomorphology, and coastal classification listed 1,435 pertinent items. Significant items relating to the report subjects will be reviewed to determine the present state of knowledge on these subjects.

4. Information on field data collection technology and methods will include a review of the types and capabilities of equipment available for specific data collection tasks. Information on the planning and techniques of field investigations is contained in many textbooks, in the scientific and technical literature, and in Corps Manuals and Regulations. In addition, the experience gained by Corps personnel in past coastal projects is a valuable source of information. These diverse sources will be used to summarize procedures and guidelines pertinent to the subject of the report.

5. Project planning and design require the use of information from many diverse sources. Geological information is sparse for many coastal regions, especially for offshore areas where field data collection efforts are usually required to obtain adequate information. Planned reports will contain details on interpretation of field data and the application of results, along with information from other sources, to specific elements of the planning and design functions of coastal projects.

6. The reports will contain suggestions for further research efforts desirable to improve existing equipment and techniques for field data collection and to improve knowledge of geological processes and principles that can be applied to interpretation of field data.

PART II: REPORT INTRODUCTION

Background

7. This report discusses the equipment and techniques that are used in coastal marine and lacustrine environments to locate and characterize potential borrow sources of beach fill material for use in beach nourishment projects. Beach nourishment is a process in which suitable sand from an outside source is placed on beach and dune areas to mitigate erosion, maintain desired width, or increase beach and dune dimensions to protect inland areas against storm flooding and wave attack.

8. Beach fill operations have been conducted since the early part of this century but many early projects failed because the fill material used was unstable in the beach environment and rapidly washed away. More recently, methods for specifying fill material based on the grain size distribution of the native beach material have improved project performance, and fill operations have become a preferred method of shore protection because they are usually a more economical and environmentally acceptable method than construction of hard structures. With the emphasis on using carefully selected fill, finding suitable borrow sources has become a more difficult and expensive undertaking, albeit well justified by improved project performance.

9. Between 1964 and 1981, the Corps of Engineers carried out a general exploration program to assess the resources of potential beach fill material on the inner continental shelf areas off the coasts of the United States. This program was known as the Inner Continental Shelf Sediments Study (ICONS) and was conducted by the Coastal Engineering Research Center (CERC). ICONS studies were completed for the following areas:

Area	CERC Report No.
Maine	No formal report
New Hampshire	No formal report
Massachusetts Bay	TP 76-3
Long Island, NY	TP 76-2
Long Island Sound	TP 81-3
New York Bight	TM-45
Cape May Region, NJ	MR 80-4

(Continued)

Area	CERC Report No.
Central New Jersey	M8-82-10
Delaware and Maryland	TP 79-2
Chesapeake Bay Entrance	TM 38
North Carolina S. of Cape Lookout	MR 77-11 TP 79-3
Florida Atlantic Coast	TM 29 TM 34 TM 42 TM 54
Galveston Area, Texas	MR 79-4
Southern California	No formal report
Eastern Lake Michigan	MR 79-3
Southern Lake Erie	MR 80-10 MR 82-9 MR 82-15

The findings of this program showed that most of the areas surveyed contained large reserves of sand-size sediment having size characteristics that were suitable for fill on nearby beaches. The ICONS program also provided valuable experience in the planning and conduct of borrow source exploration studies and the interpretation of field data.

Scope

10. Borrow source exploration programs are usually divided into seven phases, listed below in normal sequential order:

- a. Preliminary study.
- b. Program design.
- c. General field survey.
- d. Preliminary data analysis.
- e. Specific site surveys.
- f. Final data analysis and interpretation.
- g. Report of findings and recommendations.

11. This report is primarily concerned with the first four of these phases which cover procedures through preliminary analysis of data collected during the general field survey operation. Evaluation and selection of promising borrow sites, their investigation, final data analysis and

interpretation, and preparation of final reports and recommendations are not within the scope of this report.

12. Although terrestrial sources of potentially usable beach fill exist, this report is limited to consideration of subaqueous sources because these deposits are usually more desirable as borrow sources for economic and environmental reasons. However, subaqueous borrow source investigations are much more difficult and expensive, and improvements in technology and techniques can result in a significant reduction in costs.

13. The focus of this report is on the state of the art of borrow source exploration in terms of the basic items of equipment presently available for the conduct of a borrow source exploration program and how they can be used to gather necessary information for locating and characterizing potential borrow sources.

PART III: RELEVANT GEOLOGICAL FACTORS

14. Borrow source exploration programs are designed to obtain information on several geological aspects of the study area that define the presence, character, and surroundings of potential borrow sources. The most important of these are historical geology, geomorphology, stratigraphy, and lithology. While some information on these factors can usually be obtained from maps, charts, and literature sources, sufficient data for project design will require a field exploration effort. In the following discussion, each of the relevant geological factors will be considered in turn.

Historical Geology

15. Historical geology is the study of the origin and development of geologic features through time. An understanding of the role of historical processes and events in the formation and modification of sediment deposits in the exploration area is a valuable asset in program planning and interpretation. Although earth history encompasses a vast range of time, most of the unconsolidated surficial and shallow subsurface of the shore, shoreface, and continental shelves (which are of major interest in developing borrow sources) were formed and developed during the geologically recent Pleistocene and Holocene epochs of the geological time scale.

16. The Pleistocene Epoch, popularly known as the ice age, covers a period of time in which major climatic fluctuations caused repeated episodes of glaciation and deglaciation on a worldwide scale. The subsequent Holocene Epoch covers the time between the last major glaciation, known as the Wisconsin glaciation, and the present.

17. Because of the immense amount of water trapped in the great continental and numerous alpine glaciers during glaciations, sea level was reduced to well below the present stand. Sea level recovered during the succeeding deglaciation, at times rising to well above the present level. During the late Wisconsin glaciation, sea level fell more than 100 m below the present level and large portions of the continental shelves were exposed to subaerial conditions for an extended period of time. With the waning of the late Wisconsin glaciation, water unlocked from the glaciers returned to the sea and sea level rose progressively to resubmerge the shelf areas to their present

depths. This event, known as the Holocene transgression, had an important effect on existing shelf and marginal marine sediment deposits. Although these effects may have been modified by ongoing geological processes, the imprint of the transgression is clearly evident in many places.

18. An important application of historical analysis of potential borrow sites is to determine if they are essentially relict (formed by processes no longer prevalent), or recent (the result of ongoing processes). Relict status is usually evidenced by the fact that the sediment size distribution, composition, organic constituents, or sedimentary structures reflect an environment of deposition that is not consistent with the existing environmental conditions.

Geomorphology

19. Geomorphology is the study of landforms (whether terrestrial or subaqueous), their origin, development, and the processes that create and modify them. Because of established or probable relationships between geomorphic features and other geological factors such as lithology, geological history, and sedimentary processes, a study of geomorphic features in an exploration area can be a valuable element in planning an exploration program and analysis of results.

20. The geomorphic features occurring in marginal marine, continental shelf, and lacustrine areas are in some cases entirely the result of existing geological processes (recent) and in other cases, the product of past environmental conditions (relict). In most cases, relict features have, to some extent, been modified by existing processes. In marine areas, many relict geomorphic features were formed under subaerial conditions during the low sea level stand of the last major glaciation, or under marginal marine conditions during the Holocene transgression. Recent geomorphic features are largely found in the marginal marine zone, but some features, found farther offshore, may be recent or drastically modified relict forms.

21. Studies of marginal marine and continental shelf geomorphic features have shown that some types of constructional features are usually composed of sand or sand and gravel mixtures, and are potentially usable for beach fill borrow sources. Most of these features are of recent age or were formed during the Holocene transgression. Because of their geomorphic

characteristics, such features can often be identified on bathymetric charts and given special emphasis in planning geophysical and core coverage of an exploration area.

22. Existing geomorphic features of the Pleistocene age mostly were formed during the Wisconsin glaciation. Many are erosional features produced by ice scour in glaciated areas or subaerial weathering and erosion of more distant shelf areas that were exposed by the lower sea level associated with the glaciation. Depositional forms occurring in and near glaciated areas consist of features deposited directly from glacial ice and outwash deposits produced by streams of sediment-charged meltwater issuing from the ice front. Sediments deposited directly from glacial ice are mainly heterogeneous mixtures of silt and clay-size particles to boulders (glacial till) that, in general, are not suitable for beach fill. Outwash deposits consist of glacial debris that to some extent has been sorted by fluvial processes and later reworked by shallow marine processes during the Holocene transgression. As a result, these deposits often contain potentially suitable beach fill material. In some places (for example, off Long Island) extensive outwash deposits occur in the nearshore and shelf areas.

23. Pleistocene depositional features found outside the primary areas of glaciation consist mainly of fluvial sediments deposited in stream channels, floodplains, terraces, and deltas. While erosional features such as extension of stream valleys that have not been completely filled (shelf valleys) are fairly common, there is little geomorphic evidence of Pleistocene deposition because of extensive marine erosion, reworking, and burial of many features during the Holocene transgression.

Lithology

24. Lithology is the study of the general character of a discrete rock or sediment body. Commonly described lithologic features are degree of consolidation, mineralogy, shell content, texture, color, fossils, and such other features that may distinguish the rock or sediment body from adjacent rock or sediment units. Obtaining reliable lithologic information is of paramount importance in borrow source exploration programs because lithologic factors, particularly consolidation, texture, and composition are critical in determining fill suitability.

25. Most existing data on lithology of subaqueous areas consists of the description of surficial samples obtained with a primed lead (adhesive-coated sounding weight) or by grab and dredge samplers. While helpful, surficial sediment characteristics cannot be reliably projected downward. For example, in a study of 1,240 ICONS cores obtained from the Atlantic shelf, Meisburger and Williams (1980) found that major changes in lithologic character occurred within 2 m of the surface in 48 percent of the cores and within 1 m in 31 percent of the cores. In-depth sampling, using coring devices or soil boring techniques, is expensive and an often difficult operation. Consequently, existing core and boring data are relatively sparse and widely scattered. Probably the largest single collection of such data is the 1,240 cores obtained by the Corps of Engineers under the ICONS program and now archived by the Office of Energy and Marine Geology.* These cores are available for Corps use upon request.

26. Inferences concerning the lithology of surficial and sub-bottom sediments and rocks can be made by analysis of the side scan and seismic reflection records. However, these inferences are in broad general terms such as distinctions between sand and clay and are tenuous at best. Direct means such as in situ testing procedures are more useful, but in general do not provide definitive information on the size distribution characteristics of material, a crucial factor in evaluating fill suitability. In addition, core data are more useful in correlating between data points and developing sub-bottom stratigraphy and geological history than remote sensing methods.

Stratigraphy

27. Stratigraphy deals with the nature and sequence of stratified rock and sediment bodies. The main function of performing stratigraphic analysis is to identify, delineate, and describe various rock and sediment bodies (stratigraphic units) into a coherent system that shows the relationship of each unit to surrounding units. Stratigraphic units are usually defined by lithological characteristics; however, units can also be defined on the basis

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* Office of Energy and Marine Geology, US Geological Survey, National Center, Reston, Virginia 22092.

of fossil content (biostratigraphic units), absolute age dating (time stratigraphic units), and soil properties (soil stratigraphic units).

28. One aim of the exploration program is to provide data for the construction of an informal stratigraphic framework for the exploration area that will: (a) facilitate correlation between data points; (b) show the extent, thickness, lateral discontinuities, and outcrop areas of units containing potential fill material; and (c) show the relationship of these units to other units in the exploration area. A generalized stratigraphic diagram for the inner continental shelf off northern Florida is shown in Figure 1. Larger scale and more detailed diagrams are usually developed for subareas.

29. Unlike many terrestrial parts of the United States, little is known about the stratigraphy of marine and large lacustrine areas because of the expense and difficulty of obtaining stratigraphic data in subaqueous environments. Consequently, in most places the required stratigraphic data must be obtained in the field.

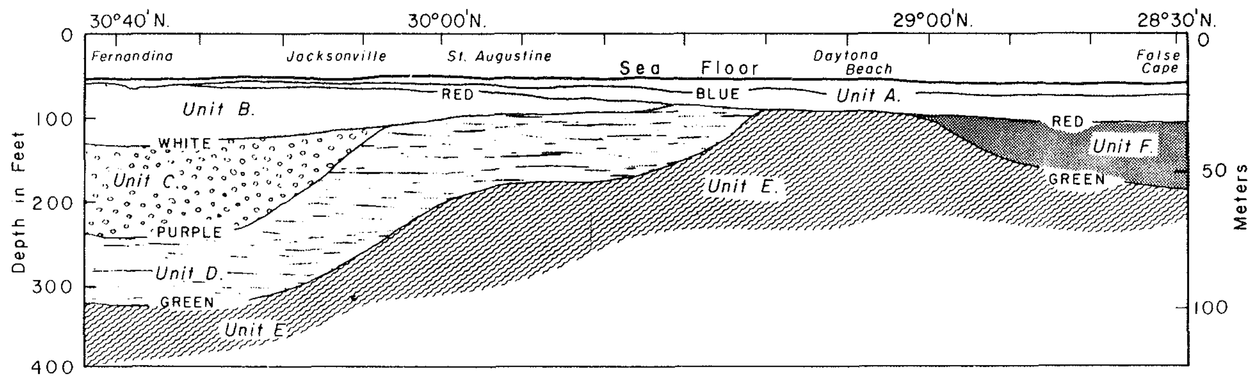

Figure 1. Generalized stratigraphic diagram for the northern Florida inner continental shelf showing informal stratigraphic units and stratigraphic breaks identified by a color name. From Meisburger and Field (1975)

PART IV: TYPICAL BORROW SOURCES

30. Geological research, the ICONS studies, and Corps project borrow source investigations have shown that certain types of relict and modern deposits, occurring in marginal marine and continental shelf environments, are predominantly composed of sand-size sediment, potentially usable as beach fill material, while others contain predominantly fine-grained silt and clay-size material or glacial till unsuitable for beach fill. Many of these deposits are associated with geomorphic features that can be identified on large-scale bathymetric charts. Those associated with sandy sediments can be given emphasis in planning exploration programs. The geomorphic and lithologic character of the more common types of deposits formed in marginal marine and shelf areas are discussed below.

31. Deposits predominantly consisting of silt and clay-size material, usually with some sand, are widespread in marginal marine and continental shelf environments. In marginal marine environments, they are usually modern, active deposits, and are most commonly found in (a) back-barrier marsh, tidal flat, and open lagoon areas; (b) protected bays and estuaries where wave energy is low; and (c) some shore-face areas. On the continental shelves, silt and clay deposits usually have little if any relief. Modern shelf deposits of silt and clay are mostly found in the deeper mid and outer shelf areas, and where wave shadow effects are created by headlands and shoal fields. Relict deposits of silt and clay may occur on any part of the shelf. Commonly, these deposits are remnants of back-barrier and estuarine sediments that were formed during the Holocene transgression. Predominantly silt-clay back-barrier and shelf deposits often contain substantial amounts of sand-size material. Usually, this material is in the very fine to fine size range (Wentworth scale). This size range, together with the silt and clay components, renders such material generally unsuitable for beach fill.

Tidal Inlet Shoals

32. Inlets are considered to be any narrow opening connecting two bodies of water. Tidal inlets are breaches in barrier islands that connect the open body of water to the lagoon, marsh, and tidal creek complex in the lee of the barrier. Inlets of this type are comparatively small and often

unstable features that can migrate along the coast or open and close in a short period of time. Tidal flow into and out of the inlets usually forms shoal deposits from material transported by strong tidal currents (Figure 2). Such shoals formed seaward of the inlet are called ebb tidal shoals and may or may not be present because in many cases the material transported seaward may be dispersed by waves and currents. Shoals formed landward of the inlet are called flood tidal shoals and are usually present in the more protected back-barrier environment.

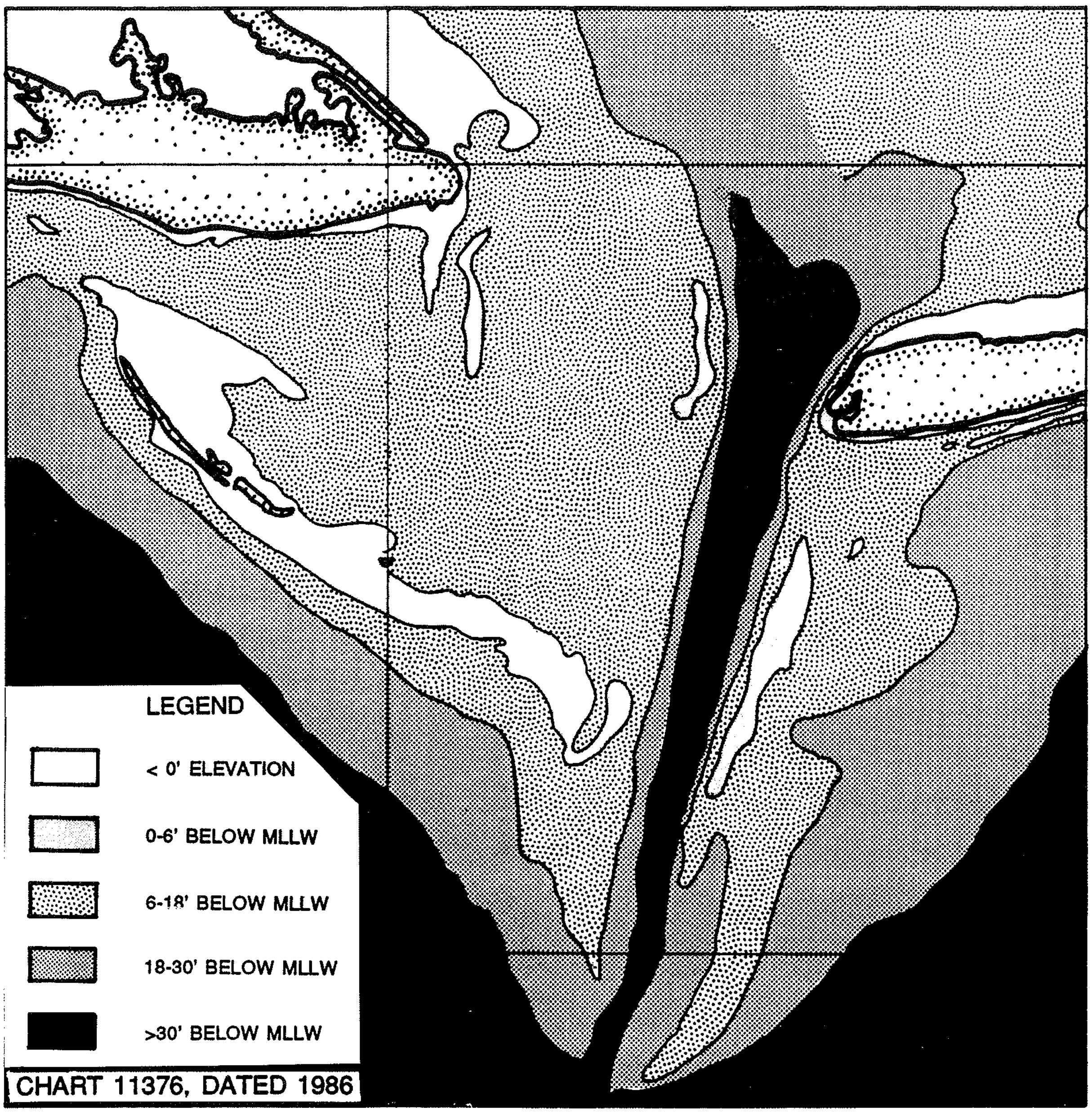

Figure 2. Plan view of an ebb tidal shoal off an inlet

33. Much of the material transported by inlet-associated tidal currents is derived from erosion of updrift coastal areas and is carried to the inlet by littoral drift processes. Inlet shoals are thus a sediment sink and inlets often contribute to sand starvation and consequent erosion of downdrift beaches. Where sand starvation of a downdrift project beach is the major problem, the remedial action may be a sand bypass operation that transfers sand across the inlet rather than a conventional beach fill operation.

34. Because sand accumulated in inlet shoals usually comes from updrift beaches it is often of a character suitable for beach fill. However, dredging of inlet shoals may affect the hydrodynamic conditions of the inlet complex and altered bathymetry of ebb tidal shoals may cause changes in waves and wave-generated currents that adversely affect nearby shore areas. Dredging of shoals at active inlets requires detailed study of the possible indirect effects on nearby areas.

35. Relict tidal shoals that are no longer active because of inlet closure or migration may be more practical as borrow sources than active shoals; however, ebb tidal shoals may be eroded and removed when the tidal currents that maintained them no longer exist. Relict flood tidal shoals create fewer problems, and their situation near the shore and in the lee of the barrier make them economically and operationally attractive borrow sources. However, back-barrier areas including the flood tidal complexes are important elements in the ecology of many coastal and migratory organisms and are sensitive to disturbance of natural conditions. As a result, use of relict tidal shoals creates undesirable environmental effects.

Linear Shoals

36. Linear shoals are elongated, ridgelike features occurring on the continental shelf (Figure 3). They are prominent and abundant in the mid-Atlantic region of the United States (Swift, Duane, and McKinney 1973) and occur in lesser numbers on the south Atlantic coast and parts of the Gulf coast. Similar features have been observed in South American and European waters (Swift et al. 1978). Linear shoals may be tens of kilometers long, more than a kilometer wide, and have a relief of up to 10 m. On the Atlantic shelf, most linear shoals are oriented with the long axis in a N-S to NE-SW direction (Duane et al. 1972).

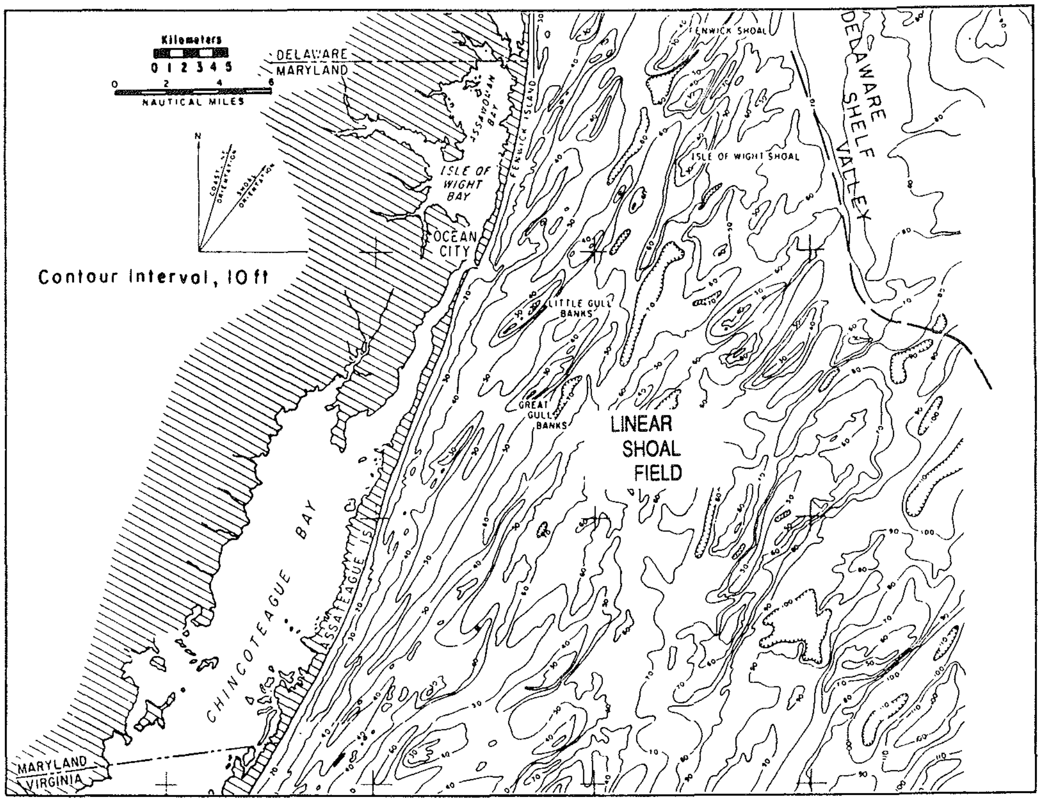

Figure 3. Linear shoal field off the Delmarva Peninsula (Field 1979)

37. Some early investigators believed that linear shoals were remnants of drowned barriers overstepped during the Holocene marine transgression which occurred as a result of a general rise in sea level following the late Wisconsin glaciation. Later research has strongly suggested that they probably formed during the Holocene transgression in the shore-face zone of beaches, retreating across the shelf in response to rising sea level, and were subsequently detached by continued retreat of the shoreline (Duane et al. 1972). Shore-face connected shoals, apparently in the formative stage, presently exist in many places and support the suggestion that isolated shoals farther seaward initially formed as shore-face connected shoals.

38. Cores from many linear shoals on the Atlantic shelf have been obtained by CERC and others during the past two decades. In nearly all cases, the shoals were found to consist of unconsolidated sand-size material which in places contains various amounts of gravel. Seismic reflection profiles across linear shoals often reveal a strong reflector passing beneath the shoal at the approximate elevation of the intershoal sea floor. Cores between shoals that

penetrate this reflector contain a wide variety of materials, often of distinctly different character than the shoal material.

39. Where they occur, linear shoals provide the most favorable prospects for fill material because of their dominantly sand-size composition, large volume, general uniformity, and accessibility. An added advantage is their distinctive morphology that can usually be recognized on large to medium scale contoured bathymetric charts; thus, they can be targeted efficiently for more intensive geophysical and coring operations than areas of lesser potential.

40. Linear shoals, especially when located on the shoreface or inner continental shelf where their crests are at a relatively shallow depth, may significantly alter waves passing over them. Any borrow source operation that results in changing the shoal bathymetry can produce undesirable effects on nearby shore areas by increasing or focusing wave energy impinging on the shore. This disadvantage can be avoided or minimized by study of the possible modification in wave characteristics, if any, that may occur by comparing wave transformation for previous post-dredging shoal morphology.

41. The main ecological effects of dredging on linear shoals are direct mortality of sessile benthonic organisms, and creation of silt plumes in the water column that may affect the biological conditions in peripheral areas.

Arcuate Shoals

42. Swift et al. (1972) defined two general classes of arcuate shoals: cape-associated (Figure 4) and estuary-associated (Figure 5). Cape-associated shoals occur off cuspate forelands where there is a convergence of littoral drift. Estuary-associated shoals occur near the mouths of large estuaries and sounds where littoral drift is intercepted by tidal currents flowing into and out of the entrance. Remnants of arcuate shoals have been recognized extending from the existing capes and estuaries to well out on the continental shelf. These shoal fields, termed shoal retreat massifs (Swift 1975), were formed and abandoned as the parent capes and estuaries retreated across the shelf during the Holocene transgression.

43. In many parts of active shoal areas, especially arcuate shoals, direct data collection is restricted by shallow crest depths and shoal mobility, which create hazardous navigation conditions. Detached linear shoals and

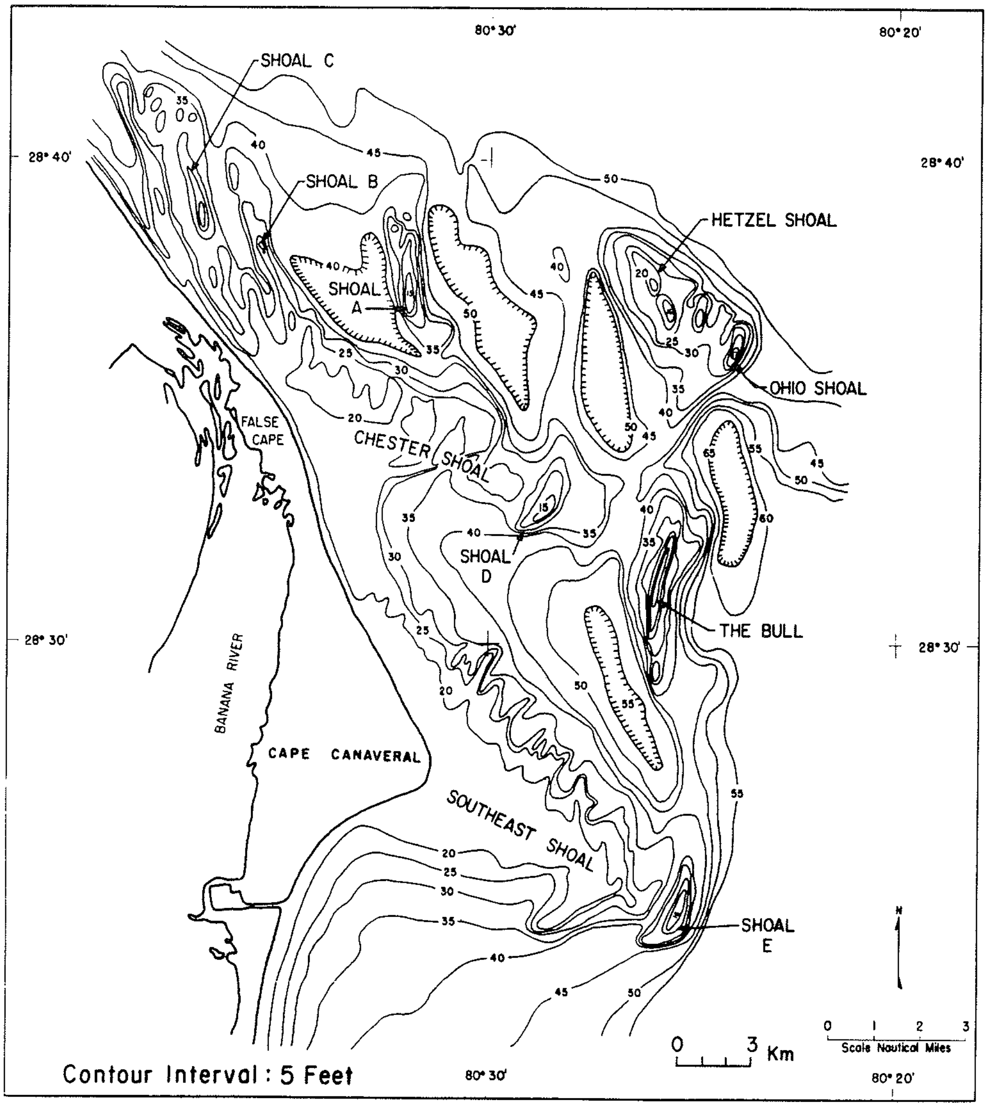

Figure 4. Cape-associated shoals off Cape Canaveral, Florida (Field and Duane 1974)

abandoned arcuate shoals of the shoal retreat massifs are more accessible for field data collection. From studies of these off-lying shoals and those parts of active shoal areas that are accessible, it appears that clean fine to coarse quartz sand, potentially usable for beach fill, makes up the bulk of the shoal material.

44. A typical cape-associated shoal field is located off Canaveral Peninsula on the Florida Atlantic coast. A detailed investigation of this area using bathymetric, seismic reflection and core data was carried out by CERC under the ICONS program and reported in CERC TM 42 (Field and Duane 1974). Two large active arcuate shoal fields occur in the area: Southeast Shoal off

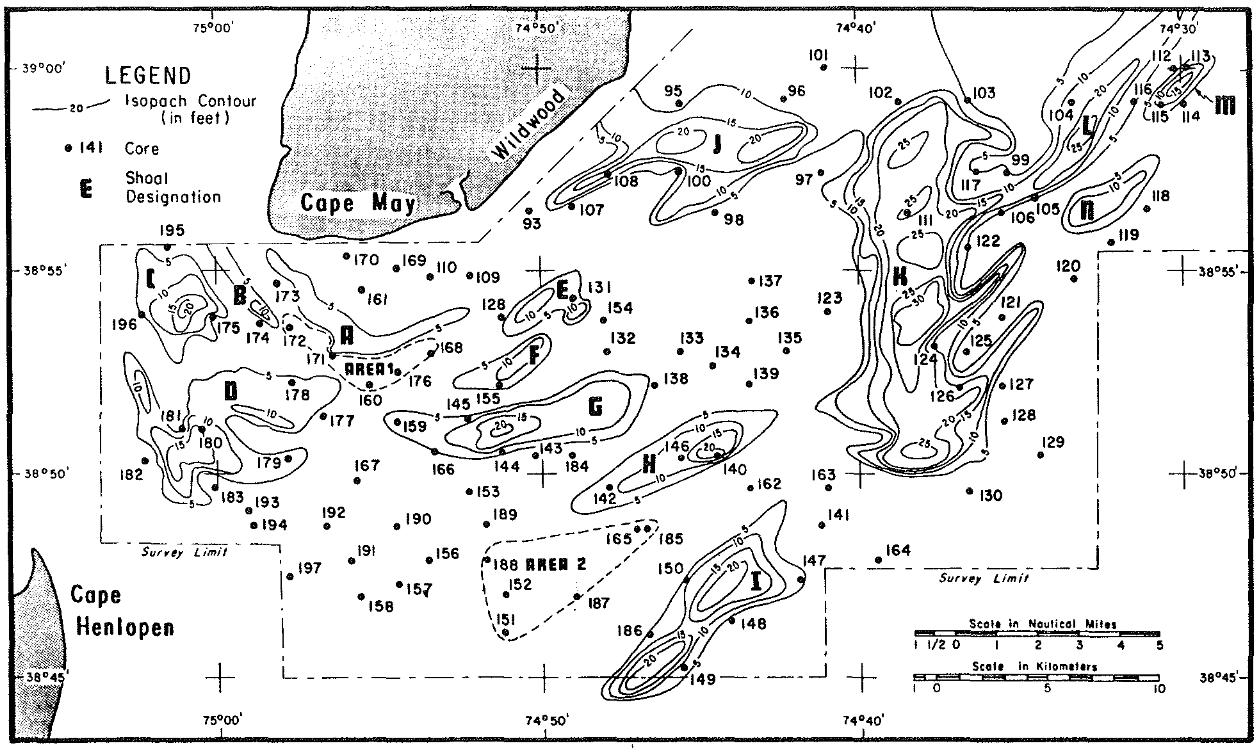

Figure 5. Estuary shoals south of Cape May, New Jersey, shown by isopach map of sediment thickness above the shoal base (Meisburger and Williams 1980)

Cape Canaveral and Chester Shoal off False Cape about 15.8 km to the north. Several large shoals, which Field and Duane (1974) considered abandoned and somewhat modified cape-associated shoals, occur seaward of the modern shoal fields.

45. Cores in accessible parts of the modern shoals and in the abandoned shoals offshore were found to be composed of well-sorted medium to coarse quartz sand with a substantial amount of biogenic calcium carbonate derived primarily from mollusks and barnacles. The shoal sediments were relatively free of silt and clay, and there was evidence that the shoal material, as deep as 3 m below the surface, may be periodically reworked. In terms of the beach sand characteristics of the Canaveral Peninsula area, most of the shoal material was found to be suitable for beach fill.

46. A good example of estuary mouth shoals and a related shoal retreat massif can be found near the mouth of Delaware Bay (Figure 6). A modern shoal complex extends across the mouth of the bay, except for tidal channels and the Delaware Shelf Valley, which form a breach in the southern part. The Delaware

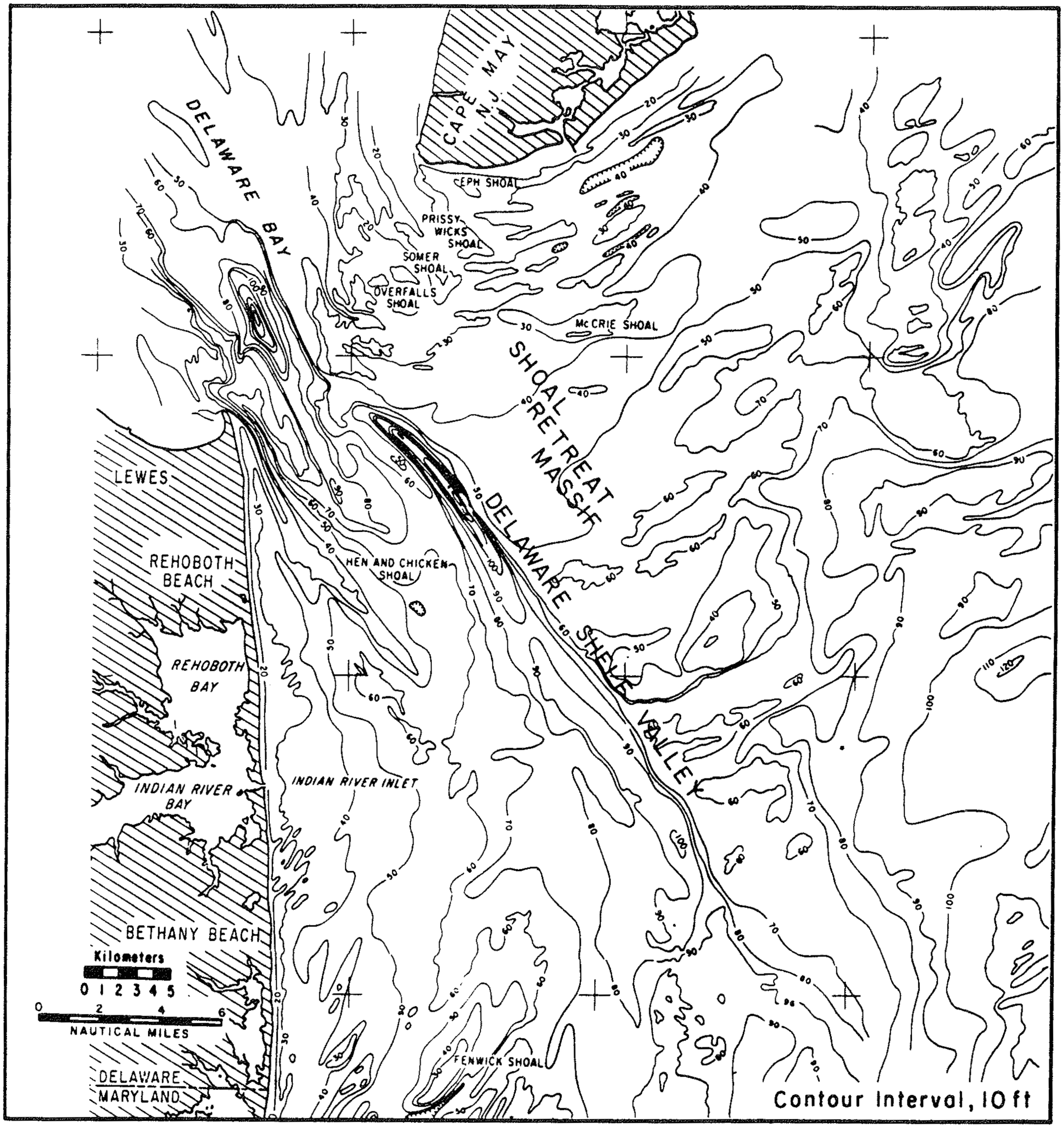

Figure 6. Delaware shelf valley off Delaware Bay entrance (Field 1979)

Shelf Valley and shoals along its northern flank extend to the midshelf where a large irregular shoal complex occurs past the terminus of the Valley.

47. These features were described by Swift (1973) who also offered an explanation of their origin and development, which is summarized below. The Delaware Shelf Valley marks the retreat path of a large tidal channel created as the Delaware Valley was progressively flooded during the Holocene

transgression, and is only approximately superimposed on the ancestral fluvial channel of the Delaware River. Modern shoals in the Delaware Bay entrance have been derived from littoral drift moving along the New Jersey shore and distributed by tidal currents in the estuary mouth. These shoals can be traced seaward along the north flank of the Delaware Shelf Valley where they presumably formed as estuary shoals during the Holocene transgression, and thus can be considered an estuary-associated shoal retreat massif. These shoals are oriented in a shore-parallel direction while the modern estuary mouth shoals are oriented in a shore-normal direction. This can be attributed to the effects of southwest trending, storm-generated currents that have drastically modified the shoals after their formation. The large midshelf shoal is interpreted as a delta that formed during a stillstand of sea level at about -40 m below present level. On this delta are superimposed shoals that are believed to be a cape retreat shoal massif that was created by littoral drift convergence at a cuspate foreland that was developed on the delta.

48. Although Swift (1973) did not have data on sediments, core data from the modern shoals south of Cape May are contained in CERC MR 80-4 (Meisburger and Williams 1980). These data indicated that modern shoals contain large amounts of medium to coarse sand which is considered potentially usable as beach fill material. Little data is available on the composition of the off-lying shoal retreat massif; however, it seems likely that these shoals were also created from littoral drift material and would be similar to the modern shoals in the Delaware Bay entrance area.

Fluvial Channels

49. During the low sea level stand that accompanied the Wisconsin glaciation, streams extended their channels across the present continental shelf areas leaving behind fluvial deposits that in many cases have survived the Holocene transgression. This is particularly true of the channel deposits that are incised in the shelf surface with only the upper part exposed to erosion. Floodplain and alluvial terrace deposits probably occur but seem to be rare. Many of the larger streams have cut valleys that are not completely filled, resulting in linear depressions on the shelf called shelf valleys (Figure 6). Since the valleys must have been embayed for long periods of time

during the Holocene transgression, it is likely that fine-grained, marine deposits cover coarser channel and valley flat fluvial deposits.

50. Smaller streams that cut into the shelf surface may have no geomorphic expression. In many cases, the stream channel deposits are exposed or are near enough to the surface to be economically dredged. Such channels can often be detected on seismic reflection records by their shape, elongation, and the often complex bedding of the channel deposits.

51. An example of channel fill deposits was discussed in CERC MR-79-4 (Williams, Prins, and Meisburger 1979). In this study of the Galveston, TX area, two sand-filled channels were located off Bolivar Beach north of Galveston Inlet. These channels cut through the now submerged area during a lower sea level stand and eventually filled with sandy fluvial sediments having size characteristics similar to nearby beaches. In this case, however, an overburden of 1 m of soft mud reduced the potential value as fill.

Deltas

52. Deltas form where sediment-laden streams enter a standing body of water such as an ocean, lake, estuary, or lagoon. Delta formation occurs when the amount of sediment discharge is greater than the competence of waves and currents to effectively disperse the material. Thus, favorable conditions occur where there is a high sediment discharge and/or comparatively low nearshore wave and current energy in the standing water body. Low-energy conditions usually occur in protected water bodies such as lagoons and semi-enclosed bays, and in open coast areas where a low-energy wave climate prevails or shallow offshore slopes attenuate deep water waves.

53. Deltas are usually divided into three large components, the delta plain, delta front, and prodelta. The delta plain is relatively flat and consists of abandoned subaerial deposits closest to shore, an intertidal zone, and a subaqueous outer zone that terminates in a comparatively steeper delta front that connects the plain to the prodelta deposits on the basin floor.

54. Deltaic sediments are characteristically muddy in most places, although coarser sand and gravel occur in areas where streams have the competence to transport such material. Enrichment of sand-size components usually occurs nearest the stream mouths and near the shoreline where waves and

currents rewash the sediment and carry off the finer fraction. In general, sediment tends to become increasingly finer in an offshore direction.

55. Because of the muddy character of many deltas, clean sand suitable for beach fill is not of widespread occurrence and tends to be concentrated near the shore where waves and currents winnow out fines. These sandy deposits are usually in the form of barrier islands and spits and associated shoreface and offshore shoal deposits. Subsidence due to compaction of buried sediments is a common occurrence in deltas and results in shoreline transgression, which may drown former shore and nearshore features. For this reason, the shallower subtidal areas of the outer delta plain are the most likely to contain suitable fill material for nearby beaches.

56. In addition to existing deltas, it is probable that most streams deposited deltaic sediments on the present continental shelf areas at times of lower sea level stands and those of the late Wisconsin and Holocene transgression times may be preserved. Deltaic sediments have not been widely recognized in shelf deposits; however, this may be due to the general lack of detailed information on shelf sediments or to extensive reworking during the Holocene transgression and by modern shelf processes. For example, Swift (1973) identified a large mid-shelf shoal off Delaware Bay as a probable ancient delta of the Delaware River built during a stillstand in the transgression at -40 m that has a superimposed, cape-associated shoal retreat massif.

Relict Glacial Features

57. During Pleistocene glaciations, the ice sheets advanced beyond the present shorelines, leaving erosional and depositional features on the present continental shelves. Subsequently, during interglacial periods, these features were drowned by the sea level rise associated with deglaciation. Most of the existing glacial features on the shelves probably originated during the last major glaciation (late Wisconsin) and were inundated during the Holocene transgression. Some types of glacial deposits contain material that is potentially suitable for beach fill. The geomorphic features associated with glacial deposits are helpful in locating suitable material, but because of the great complexity of geomorphic forms associated with glacial deposits, are less reliable indicators than for other types of deposits considered in this

report. Seismic reflection profiling, discussed in Part V, can be of value in differentiating various types of glacial deposits.

58. The material in glacial deposits is known by the general term of glacial drift. Drift is usually divided into two large categories, nonstratified and stratified. Nonstratified drift, called till, is material that has been transported and deposited directly by ice and is usually a heterogeneous mixture of very poorly sorted material lacking apparent stratification. Till deposits occur in many different forms that originated near the ice margins and within the interior of the glacier. Marginal forms may extend for great distances and have a relief of up to 50 m. Terminal moraines form at the maximum point of advance. In valley glaciers, lateral moraines form at the junction of the glacier and confining valley walls. Nonstratified drift accumulates beneath the interior of the glacier in ground moraines that cover much of the glaciated regions. They are characteristically undulating plains with general relief of less than 10 m. Some superimposed features, however, may be considerably higher.

59. Stratified drift is deposited mostly at the margins of the ice and beyond the ice front. All stratified drift has, to some degree, been transported by flowing water in contrast to the unstratified drift that was deposited directly from the ice. Because of this transport by flowing water, stratified glacial deposits are better sorted than till, and in many cases, can make suitable beach fill. The principal geomorphic features associated with stratified deposits are kames, eskers, and proglacial outwash material.

60. Kames are moundlike features that may have a relief of up to 50 m and diameter of up to 400 m. They are often associated with large circular depressions up to 10 m deep known as kettles. Kames and kettles form a characteristic irregular topography, but in many cases, are difficult to differentiate from some till deposits without obtaining core samples or geophysical data.

61. Eskers are sinuous ridgelike features that form in channels, tunnels, and crevasses in the ice by meltwater transport and deposition of glacial material. Eskers are variable in dimensions but, at their largest, can be up to 100 m high, 2 or 3 km wide, and many kilometers long, although the longer eskers may occur in the form of loosely connected segments. In subaqueous environments, eskers may be difficult to differentiate from some moraines or non-glacial linear shoals on geomorphic evidence alone.

62. Proglacial deposits are formed beyond the glacial front by sediment-laden meltwater streams issuing from the glacier. These streams are usually braided in an intricate pattern and the channels frequently migrate laterally so that the interfluve areas are not stable, and erosion and deposition occur throughout the area. Proglacial deposits are intricately bedded, usually coarse-grained, and form topographically subdued outwash plains that may be very extensive. Many outwash plains contain material that is suitable for beach fill but, because of their complex bedding, the sediment characteristics are usually not uniform and thus may require more detailed sampling to determine their suitability for a given beach fill project.

63. An example of glacial drift material that is potentially usable as fill is found in the area north of Erie, PA, described in CERC MR 82-9 (Williams and Meisburger 1982). Here, a large submerged ridge of glacial till and stratified drift (believed to be a moraine formed near the end of the last glaciation) was drowned by the filling of Lake Erie. As the lake filled, the moraine was subject to waves and littoral processes that washed and sorted the till material forming beach and dune deposits of relatively clean sand and gravel. Many other examples of erosion and selective sorting of till sediments which formed paleo-coastal features can also be found in marine areas.

Inter-Reef Deposits

64. A type of sediment deposit that occurs in the continental United States south of Boca Raton, FL was discussed in CERC TM-29 (Duane and Meisburger 1969). Low, reef-like, shore-parallel ridges have formed inter-reef troughs in this area that have partially filled with predominantly biogenic sand and gravel-size sediment. Although not ideally suited for beach fill, this material was the only unconsolidated sediment available in the area within feasible dredging depths and large quantities were used for beach fill on adjacent beaches.

PART V: GEOPHYSICAL TECHNOLOGY

65. Geophysical survey techniques are widely used methods for gathering subsurface geological and geotechnical data in terrestrial and subaqueous environments. Three types of geophysical survey systems are typically used for borrow source exploration programs: Fathometers, seismic reflection sub-bottom profilers, and side-scan sonar. These systems are used to obtain information on sea floor geomorphology, small-scale bottom features such as ripple marks and rock outcrops, and the underlying rock and sediment units (Williams 1982). All three systems are electrically powered acoustic devices that function by propagating sound pulses in the water, and displaying the data graphically on a chart recorder. The description of the Fathometer in a subsequent section will illustrate the basic principles of operation for all three systems.

Position Control

66. Accurate navigation and position control is essential for borrow source exploration programs. CERC Coastal Engineering Technical Aid 80-4 (Prins 1980) recommends an accuracy of 3 m; however, in most cases, satisfactory control can be obtained with a system with an accuracy of 15 m. Positioning and navigation controls presently in general use are low-frequency radio-wave, microwave, and laser-type devices. In addition, a satellite-based system is in the process of development and is expected to be available for general use in horizontal positioning in 1991.

67. Loran C, a pulsed low-frequency radio wave navigation system, is presently widely used on private and commercial vessels. It has long range, uses an inexpensive receiver, and does not require the portable onshore transponder stations required for microwave systems. However, the accuracy of Loran C is not sufficient for use in borrow source exploration programs except in preliminary field reconnaissance operations.

68. Microwave navigation and positioning systems have been in general use for many years and have proven to be suitable for high accuracy surveys. Many microwave systems are on the market and they have frequently been employed by Corps of Engineer agencies for borrow exploration and other coastal studies. Microwave systems are relatively expensive. Their typical

range is 25 to 40 km and they can achieve an accuracy of 1 to 3 m. The major components are a master station aboard the survey vessel and two onshore transponder stations set up at known locations. Basically, the system determines horizontal position by measuring the round-trip time for signals to travel between the transponders and the master station, and then converting this data to linear distance. Position is calculated using the range distances and the length of the baseline between the two transponders.

69. Microwave systems have a few limitations. They are restricted to line-of-site situations. The transponders must be located near the shore or at a sufficiently high elevation to eliminate any obstruction to the signals. Onshore personnel are required to periodically move the transducers from place to place as the survey progresses and to protect them from vandalism. The cost of these systems is considerably more than required for Loran C receivers.

70. Laser-type positioning systems provide distance and angle measurements from a shore station that can be converted to x-y coordinate data. They are highly accurate systems that can locate a vessel within an error of 0.1 ft/mile.* Because their range is limited to about 4 km, laser systems are not suitable for a general borrow site exploration program although they could be used for detailed site surveys of specific deposits that were within their range.

71. Satellite navigation and positioning systems are a new, space-age technology that may replace both the Loran C and microwave systems in the future. The Navstar satellite system under development by the Department of Defense is expected to provide continuous horizontal two-dimensional coverage positioning by 1991. The satellite systems should provide satisfactory accuracy and they cost no more than microwave systems.

Fathometers

72. Fathometers are instruments that use acoustic pulses to measure water depths in streams, lakes, and oceanic areas. There are a variety of Fathometers on the market ranging from the small, direct-readout models,

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

widely used by fishermen and small boat owners, to much more sophisticated, highly accurate instruments that permanently record depth data and have numerous features to enhance flexibility and data quality. Fathometers are used in borrow source exploration to provide accurate data on water depths along the survey tracklines covered during the exploration program. For this purpose, they should be recording-type, high-quality models with sufficient flexibility to meet the anticipated requirements for bathymetric data of the exploration area.

Principles of operation

73. The basic principle of Fathometer operation is suggested by its popular name of "echo sounder." It is common knowledge that if one shouts or makes any loud noise in a hilly area, the sound will be repeated as an echo at the point of origin after the elapse of a short period of time. The delay is due to the fact that the sound must travel at a finite velocity from the source to the object that reflects it and back again. The farther the reflector is from the source, the longer the time lapse. Because the velocity of sound in various mediums such as rocks, sediments, or water is known or can be accurately determined, it is possible to calculate the distance between the sound source and reflector by the following formula:

$$D = \frac{Vt}{2} \qquad (1)$$

where

D = distance to reflector

V = velocity of sound in the medium

t = two-way travel time

Fathometers make use of this principle by generating repetitive acoustic pulses at the water surface and measuring the time necessary for each signal to travel to the bottom and reflect to the surface. This measurement is converted to an equivalent depth and recorded on a chart.

Available equipment

74. The basic components of a Fathometer are a transducer that both emits the acoustic pulses and receives the reflected signal, and a transceiver unit that provides power and control to the transducer, processes the return

signals, and makes a permanent strip chart or digital record. In vessels with a continuing need for a Fathometer, the transducer is usually permanently mounted in the hull. For temporary use, the transducer is usually mounted outboard and secured to a rail or bracket.

75. Modern Fathometers have a range of capabilities and features that allows manual or automatic selection of various parameters such as chart speed and scale. For borrow source exploration programs, features considered necessary are event markers and a means of selecting the chart scale, chart speed, and correction for transducer depth. Automatic event marking and annotation are valuable options that can save on personnel costs. Many available Fathometers contain other features that improve quality and operational capabilities but are not essential. These features provide automatic corrections for tidal stage, variations in sound velocity, and vessel motions. Other features allow selective adjustment for acoustic pulse frequency, energy, pulse length and repetition rate, and automatic adjustment for sensitivity.

76. A recent development that would be valuable in borrow source exploration is a signal processing unit that can be interfaced with a Fathometer and used to indicate the sea floor sediments in terms of Wentworth or other general classification systems. This is accomplished by measurements of two independent variables, roughness and hardness, from the acoustic signal and interpreting these data in terms of sediment type.

Seismic Reflection Systems

77. Seismic reflection systems are similar to Fathometers in their basic principles of operation; however, they normally use acoustic signals of lower frequency and higher energy. These pulses are not totally reflected or attenuated at the bottom-water interface, but part of the sound energy penetrates the sub-bottom zone where it reflects from interfaces separating rock or sediment units having different acoustic impedance properties (Figure 7). The greater the difference, the greater the reflection of acoustic energy. The impedance of a medium is the product of its bulk density and the velocity of a compressional wave traveling through it. The compressional wave velocity is in turn a function of the bulk density, compressibility, and rigidity of the material. These factors are usually related to lithology. Consequently, seismic reflection profiles can be roughly analogous to a geological cross

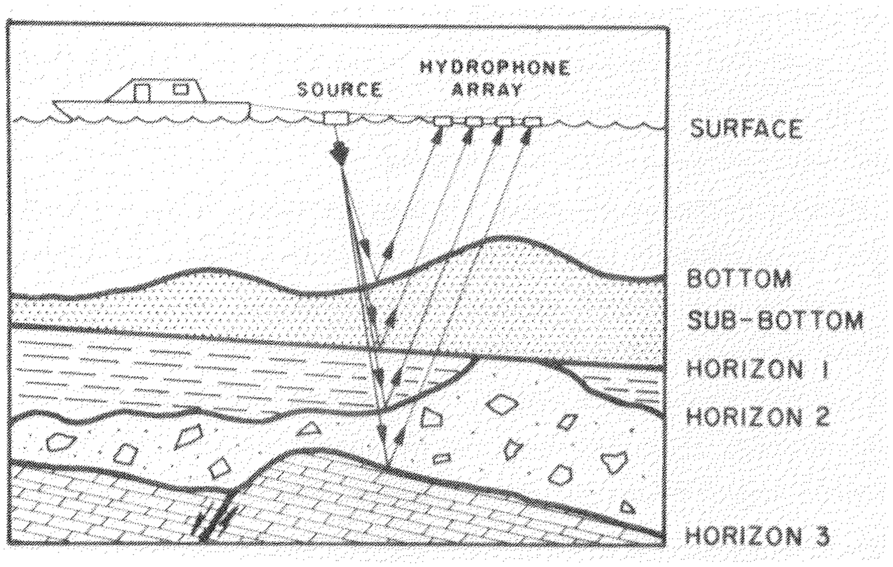

Figure 7. Schematic showing signal paths of a seismic reflection profiler

section of the subbottom material. However, reflections can appear on the record where there is little significant difference in the lithology of underlying and overlying material, and significant lithologic differences may go unrecorded due to close similarity of acoustic impedance between bounding units. Because of this, seismic developed stratigraphy should always be considered tentative until supported by direct evidence of lithology from cores.

Basic components

78. Seismic reflection systems are usually composed of four major components: a source that produces acoustic signals, a power supply to provide energy to the source, a signal processor to amplify and filter return signals, and a recorder to control the initiation and repetition rate of the pulses and display the data in graphic form as it is received. In addition, ancillary components, described later, can be used to increase the quality of the data.

79. The overall characteristics and capabilities of seismic reflection systems are largely determined by the type of device used to generate the acoustic pulses (acoustic source) and their energy output. Since the introduction of seismic reflection techniques, a variety of sources have been developed. Most of these sources use gas, compressed air, electric arcs, or electromechanical and piezoelectric devices to generate the repetitious acoustic pulses that are used to probe the bottom and sub-bottom materials. These basic types can be obtained in a number of variations having different energy

levels and pulse characteristics; thus, there are a considerable number of options available from which to choose a sound source to best meet the needs of a specific field survey. For borrow source exploration, the principal types of sound sources used are low to moderate energy, electrically driven piezoelectric (pinger), electromechanical (boomer), and electric arc (sparker) types with high resolution capability. Seismic reflection profilers using these three sources are reviewed below in detail.

Vertical resolution and penetration

80. The two most important capabilities of a seismic reflection system are its vertical resolution and degree of penetration. Vertical resolution is the ability to differentiate closely spaced reflectors. This ability is primarily a function of the compressional wave velocity of the medium and the frequency of the acoustic signal and can be approximated as follows:

$$T = \frac{0.5v}{2f} \qquad (2)$$

where

T = thickness of a unit between two reflectors that can be resolved

v = compressional wave velocity of the material

f = dominant frequency of the acoustic pulse

From this expression, it can be seen that the higher the dominant frequency, the finer the resolution. Unfortunately, raising the frequency of the acoustic pulses increases attenuation of the signal and consequently decreases the effective penetration. For borrow source exploration, it is necessary to obtain good resolution because of the importance of relatively thin layers in calculating sediment volumes and overburden thickness. However, to achieve good reflector continuity and obtain a coherent pattern of the subbottom stratigraphy, it is necessary in many places to use equipment that has greater penetration capability than the high resolution profilers in general use. To obtain the needed resolution and penetration, it is a common practice to use two seismic reflection systems simultaneously during the survey; one having high resolution capabilities and the other being capable of greater penetration. Generally, the data from both systems can be displayed, one over the other, on a single strip chart record. Since the major expense of geophysical surveys is incurred for boat rental, and operation and navigation control, the modest cost of operating an additional seismic reflection system is well justified by the increased detail and comprehension obtained.

Pingers

81. Tuned transducers are primarily used in moderate to low energy, high-resolution seismic reflection profilers often called pingers. They consist of a suitably housed element of piezoelectric material that is capable of both emitting and receiving acoustic signals. It is generally used with a transceiver unit that provides the electric power at the proper operating frequency to drive the transducer, and amplifies the return signals for display on the recorder. Tuned transducers can be permanently mounted in a water-filled compartment in the hull of the survey vessel, clamped to a rail or frame outside the hull, or towed behind the vessel on a suitable floating vehicle. Many tuned transducer systems are composed of relatively small components that make them highly portable and capable of being installed on relatively small boats.

82. Most tuned transducer sources have a narrow frequency spectrum and usually operate at a frequency of 3.5 to 7.0 kHz. Units are available where the frequency can be switched so that an operator monitoring the record can select the most useful frequency for a given situation. Tuned transducers, especially when operated at the higher frequency modes, are capable of higher resolution than other types of sources. However, their penetration is correspondingly limited and, in some instances, they provide no sub-bottom data. For this reason they are often employed as a high-resolution component of a dual system survey paired with another source capable of deeper penetration.

Boomers

83. Electromechanical acoustic sources, often called boomers, produce acoustic pulses in water by means of a magnetically induced, rapid displacement of a metal plate which produces a pulse of short duration containing a relatively broad spectrum of frequencies. Boomer sources are usually mounted on a catamaran or other suitable vehicle and towed behind or alongside the survey vessel with a hydrophone to receive the signals. Because of wave motions on the towed vehicle, the bottom and sub-bottom lines on the record are increasingly distorted as wave height increases with a consequent deterioration in the record quality that impairs analysis and accurate determination of the actual line elevations. This causes unproductive downtime when sea

conditions preclude obtaining adequate records, and some reduction of record quality under any but calm conditions. To alleviate this problem, some boomer sources have been installed in vehicles that are towed under water so that wave motions are significantly reduced. Boomer systems are not as portable or easily set up as other tuned transducer systems; however, they can usually be installed and prepared for operation in a single day.

84. Because of their broad frequency spectrum, boomer sources can achieve relatively good resolution coupled with substantial penetration. Boomers of the type most suitable for borrow source exploration can, under reasonably favorable conditions, produce records with a resolution of less than 30 cm with a penetration of 50 m. Boomers are often used in conjunction with tuned transducer systems because of their relatively greater penetration and capacity to obtain data in areas where sub-bottom materials are opaque to tuned transducer systems.

Sparkers

85. Electric arc acoustic systems, or sparkers, can only be used in seawater. They are versatile units that range from relatively low-energy, portable systems with characteristics suitable for use in borrow source exploration to the high-powered units capable of achieving penetration of thousands of meters used for petroleum exploration and deep stratigraphic studies. Sparkers produce acoustic pulses with a broad range of frequencies by creating repetitious electric arcs in the water between an electrode or array of electrodes and a ground return. The arc causes an almost instantaneous vaporization of water in its path creating a vapor- and ion-filled bubble that generates an acoustic pulse. This is followed rapidly by a second pulse, called the bubble pulse, that is created by the collapse of the bubble; thus, each reflector on the record is shown as two closely spaced lines.

86. In use, electric spark sources are towed behind or alongside a survey vessel, and paired with a hydrophone array for receiving the direct and reflected signals generated by the source. Electric energy is supplied by a power supply and capacitor unit that is modular and can be combined in different ways and numbers to vary the energy transmitted to the electrodes. Variations of pulse characteristics can be obtained by altering the size, number, and spacing of the electrodes. Sparker systems can provide a range of characteristics from which to select a source configuration and energy level most suited to a specific program.

87. In general, electric arc sources do not achieve the degree of resolution that can be obtained by tuned transducer and electromechanical sources. However, their flexibility is a useful trait, especially in areas where it is difficult to obtain adequate subbottom penetration. Paired with another source capable of obtaining high resolution of the uppermost sub-bottom reflectors, electric arc sources are suitable for borrow source investigations in saltwater environments.

Hydrophone receivers

88. Unlike tuned transducer systems that both transmit and receive acoustic signals, electromechanical and electric arc profilers require a separate receiver component. These components consist of one or more hydrophones, usually composed of piezoelectric material, that can convert acoustic signals to an electric voltage of the same frequency and proportional strength. Voltage is processed by a signal processor component and displayed on a graphic recorder.

89. Hydrophone receivers may consist of a single element or an array of electrically connected multiple elements contained in an oil-filled, plastic tube that is towed behind the survey vessel. Since hydrophones must be sensitive to weak signals in order to obtain data from deeper reflectors and low acoustic impedance interfaces, they also respond to acoustic energy from other sources such as other geophysical instruments, ship noise, turbulence created by towing the hydrophone array, and noise created by waves. These extraneous signals are picked up by the receivers, and generate marks on the graphic record that obscure or complicate the patterns generated by actual reflectors. Some reduction in extraneous noise can be made by varying the length of the hydrophone array, and the number and spacing of elements, in such a way as to enhance the reception of valid signals. Other measures such as using frequency filters, and physical methods such as increasing the distance between the vessel and towed array and using reduced boat speeds, are also effective ways to suppress unwanted noise.

Energy sources

90. Energy is supplied to electrically driven acoustic sources by a power supply component consisting of transformers and capacitor banks that convert input from a standard generator or battery supply to high energy electric pulses that are used to drive the acoustic sources. The transformers are used to boost the line voltage and supply electrical energy to the capacitor

banks which build up and intermittently discharge high energy electrical pulses in response to triggering commands from the recorder. In small, portable units, the power is usually supplied by batteries, and the unit may have several functions (e.g., power supply and recorder) combined in a single housing. In larger systems, the power supply is separate and electrical input is provided by a portable, deck-mounted generator. Some power supply units have the transformers and capacitor banks in separate modules that can be combined in different numbers to produce different power levels.

91. Because of the high energy of the power supply output, it must be protected from rain or spray, and from contact with personnel. It should be attended by a qualified electronic technician familiar with safe installation, operation, and maintenance of seismic reflection systems.

Signal processors

92. Seismic signal processors are used to amplify the signal received by the hydrophones and to selectively filter out signals in preselected frequency ranges. These functions may be performed by separate components or combined in a single unit. The simplest amplifiers increase the strength of all acoustic signals equally. In this mode, setting the amplifier gain high enough to increase the strength of the weaker reflections may cause excessive burning of the chart at the usually strong bottom reflector. To allow the weaker signals to be increased without excessive burning, many amplifiers have automatic or time variable gain controls. Automatic gain controls selectively increase amplification of the weaker signals on all parts of the record. Time variable gain controls increase amplification progressively as the stylus crosses the chart paper, thus increasingly reinforcing the deeper reflectors that are most likely to be weak because of signal spreading and attenuation.

93. Band pass filters are used to reduce extraneous acoustic noise unrelated to the sound source. Extraneous noise is usually produced by the survey vessel, turbulence created by towing the hydrophone streamer, and ambient noise generated by waves or other natural sources in the water. Band pass filters function by filtering out acoustic signals with frequencies outside preset high and low cutoff frequencies. The cutoff frequencies are selected on the basis of the frequency range of the acoustic source and the characteristic frequencies of the extraneous signals. Band pass filters are especially useful in playing back raw acoustic data taped during the survey when different band pass frequencies are tried to obtain maximum record quality.

Recorder

94. The main functions of the recorder are to trigger the acoustic source, and display the data being generated on a strip chart record showing bottom and sub-bottom reflection horizons. The recording element consists of a stylus on a continuous belt that crosses the chart paper at a selected rate of speed called the sweep speed. When the stylus is at the upper margin of the chart, the sound source is triggered and emits an acoustic signal, and as the stylus continues across the chart, electric potentials created by return signals are routed to the stylus, which makes a mark on the wet or dry type electrosensitive chart paper. In this way, the time lapse between pulse initiation and return signals for each reflector is graphically displayed, and as the chart paper advances with each sweep, a coherent profile line is created. The recorded time differences between the zero line and reflector traces can be converted to distances by use of appropriate conversion scales. The scales are based on the following expression:

$$D = \frac{V}{2} \times t \qquad (3)$$

where

D = depth to reflector

V = velocity of sound in the media traversed

t = two-way travel time

This is the same formula used for conversion of Fathometer data. However, instead of one medium, water, the signal also travels through one or more sub-bottom layers having different sound velocity characteristics. For the relatively shallow water and limited subbottom penetration of the systems used for borrow source exploration, a velocity of approximately 1,500 m/sec in the water column and 1,600 m/sec in unconsolidated sub-bottom material is reasonably accurate in most cases.

95. The intensity of marks made on the graphic recorder showing the reflectors can be varied by means of a gain control to bring out the weaker reflectors; however, a too high gain will cause excess burning of the traces of strong reflectors such as the bottom-water interface. To alleviate this

problem, recorders or signal processors are available that incorporate the automatic or time variable gain control features described above.

96. Recorders contain a selection of stylus sweep speeds that control vertical scale, and chart transport speeds that control horizontal scale. Newer recorders have reversible sweep direction, a very useful feature that allows parallel lines, run on opposite headings, to be directly compared as if both were run on the same heading. Since adjacent seismic profiles are usually run in opposite directions, out on one line and in on the next, reversible sweep features are of great value in later comparative analysis and interpretation.

Ancillary equipment

97. In addition to the basic components of seismic reflection systems, a number of ancillary components have been developed to increase the capabilities and improve the quality of the system as a whole. These components are valuable additions that are well worth the relatively small cost of their rental compared to overall equipment and personnel costs. In many cases, components such as motion compensators and automatic record annotators can actually decrease costs by limiting downtime due to weather and reducing personnel requirements.

98. Tape recorders. Tape recorders, having two or more channels, can be used to advantage with seismic reflection systems to record the key pulse and the unprocessed return signals. This provides an additional record from which the graphic record can be reproduced in the event of loss or damage of the original. In addition, the raw acoustic data can be repeatedly processed after the survey using different combinations of band pass filters processing other variables such as scale and chart speed settings, which can improve overall record quality and enhance selected aspects of the data. Such records are particularly useful where the acoustic source creates pulses with a broad band of frequencies produced from boomers and sparkers. Multiple-channel recorders can be used to simultaneously record other survey data such as side scan and navigation information.

99. Motion compensators. Seismic reflection records are adversely affected by wave conditions because of the cyclic vertical motions imparted to the acoustic source and receiver, which give a jagged saw-tooth character to the lines marking reflectors. This irregularity complicates interpretation and introduces a significant element of error in measuring the precise depth

of reflector surfaces. Several devices are available that reduce or eliminate the effects of wave-induced motions. One of these devices uses an accelerometer to sense the motions and to apply an appropriate correction to the timing of the acoustic pulse intervals. These devices can only be used where the acoustic source and receiver are directly mounted on the survey vessel or towed vehicle such that both are moving in tandem. Where these components are towed separately, the motions can be compensated for by use of an electronic device that senses the frequency of the waves and selectively filters out the incident motion effects. This device can be incorporated in the seismic reflection system aboard the survey vessel or used later in recreating the records from taped data. A more direct means of reducing wave effects is available in the form of a vehicle for the acoustic source and receiver that is towed beneath the surface at depths that are less affected by surface waves.

100. Signal stacking. Signal stacking is a technique for improving the signal-to-noise ratio. The process involves storing the data on two or more sequential acoustic pulses and return signals in an electronic buffer that permits displaying of the summed output on the record. The data for true signals adds constructively, increasing the signal strength while extraneous noise, being random, is reduced by the summation process; thus, there is considerable improvement in the signal-to-noise ratio. Signal stacking can be used during the actual survey or applied to later reprocessing of the taped raw acoustic data.

101. Record annotators. Geophysical records require frequent annotation to provide essential information on navigation control and time that is used to make tidal corrections. The annotators are keyed to event marks on the record made at intervals of 2 or 3 min. Record annotators automatically mark the time, navigation fix numbers, and other types of information. This has the advantage of freeing the monitor from a need to make frequent notations and prevents systematic errors caused by entering an erroneous fix number.

Side-Scan Sonar

102. Side-scan sonar is an acoustic technique for visualizing sea floor features (Williams 1982; Clausner and Pope 1988). Acoustic signals, from a

source towed below the water surface, are directed at a low angle to either side, unlike downward-directed Fathometer and seismic reflection signals. Side-scan sonar thus searches a broad swath on one or both sides of a trackline, and detects such features as rock outcrops, boulders, man-made objects, and other features that project above the sea floor. It is capable of resolving very small features such as ripple marks, and can discriminate between broad differences in bottom sediment character. It is a useful adjunct to seismic reflection and Fathometer equipment, especially where rock outcrops or boulders that would limit or preclude dredging occur.

103. Side-scan sonar systems consist of a control and recorder unit and a towfish unit that is towed behind the survey vessel at a desired depth below the water surface. Transducers in the towfish generate acoustic pulses both to port and starboard, and receive reflected signals that are converted to proportional electric energy, which is transmitted to the recorder unit. The acoustic pulses emitted by the transducer are reflected from any object rising above the general level of the sea floor, and recorded on the strip chart as a dark tone. The area immediately beyond in the shadow of the object is recorded as a light tone. Depressions are likewise recorded, but the light tone is nearest the trackline and the dark tone outlines the far wall. The strength of the reflection is indicated by the intensity of the dark tone, which is a function of the acoustic impedance between the water and the reflecting object, and the angle between the object and the incident acoustic signal. Signal strength increases with increasing acoustic impedance and with approach to a 90-deg relationship between the object face and the acoustic beam.

104. Available side-scan sonar equipment is capable of high resolution imaging of the sea floor up to over 200 m to either side of the vessel trackline; thus, a total swath of 400 m or more can be covered at each pass. In common with seismic reflection profilers, the range increases and resolution decreases progressively as the operating frequency is lowered. To alleviate this problem, some systems are capable of dual operation by using both high- and low-frequency signals that are simultaneously recorded on separate channels of a recorder having four or more available channels. Units are also available that can correct slant ranges to objects to true horizontal position and to correct vessel speed so that the records show true position, which makes the data analogous to maps or aerial photographs.

Adequacy of Existing Equipment

105. Available geophysical equipment and techniques are, in general, adequate for borrow source exploration. Research and engineering efforts to improve basic equipment are continually undertaken by manufacturers, and several improvements such as swell filters and automatic gain control have been developed over the years. Given the physical factors involved in geophysical survey methods, it seems unlikely that elemental changes in the existing systems will be made in the foreseeable future; further advances in the technology will probably be in the nature of improvements to the design and engineering of existing basic system components and computer analysis of data leading to improved record quality.

106. Of the possible improvements that would be of benefit, the most desirable are increased economy of operation, flexibility, noise reduction and suppression of false reflectors known as multiples, and an increase in the ability of seismic reflection profilers to penetrate difficult material without excessive loss of resolution. Greater economy of operation could be achieved by an increased ability to function under unfavorable weather conditions and operate at higher survey speeds with consequent reduction of downtime and increased daily trackline mileage. The equipment most sensitive to weather conditions and survey speed is the seismic reflection system. Present capabilities for towing the acoustic source and receivers well below the surface can considerably reduce wave motion effects and extraneous acoustic noise associated with towing these components on the surface. However, given the depth range to which borrow source exploration programs are limited, the water would be too shallow in many areas for effective use of submerged vehicles.

107. Because of the often highly variable geologic conditions found in coastal areas, flexibility is a valuable feature in geophysical systems used for borrow source exploration. Selective control of such features as scale and frequency range are integral parts of existing equipment. Tape-recording of raw acoustic signals greatly increases flexibility by allowing subsequent playbacks using different control settings to obtain optimum record quality. Increased control of output power levels is one area in which increased flexibility could be achieved by enabling record monitors to make rapid variations in output power to adjust to rapidly changing geological conditions.

108. Noise suppression has been a primary objective of attempts to increase the quality of seismic reflection equipment. Available technology includes several measures for noise suppression that have considerably improved record quality. In addition, techniques for interpretation of records have improved with growing experience, and much of the ordinary noise can be recognized and dealt with by the analyst. Multiple traces, however, remain a major problem, especially in the relatively shallow waters where borrow source explorations are normally carried out. Here, closely spaced multiples often conceal upper sub-bottom reflectors, or create a possibility of their being interpreted as valid reflectors.

109. Seismic reflection profilers are in many places limited in penetration by materials in the bottom or sub-bottom deposits that cause severe attenuation of the acoustic pulse, and consequent loss of data on underlying materials. Coarse sand and gravel, glacial till, and highly organic sediments often create such conditions. In some cases, increases of power and using lower frequency acoustic pulses can achieve penetration but at a necessary reduction in resolution that may greatly diminish record quality.

PART VI: BOTTOM AND SUB-BOTTOM SAMPLING

110. Seismic reflection records do not provide direct information on the nature of the sediment and rock units penetrated by the acoustic pulses. However, inferences can often be made from consideration of factors such as acoustic transparency, diffraction patterns, configuration and continuity of reflectors, and apparent bedding patterns. While consideration of these and other factors evident on the records is valuable in working out the sub-bottom stratigraphy, this type of analysis does not provide information on the nature of sub-bottom materials giving the precision, detail, or reliability needed for evaluation and selection of borrow sources. Adequate information can only be obtained by analysis of physical samples of bottom and sub-bottom materials. For this reason, it is essential that cores be obtained to directly determine material characteristics and suitability for fill, and to substantiate correlation of the geological data.

Objectives

111. Cores are collected during the general exploration of the program to provide evidence of the lithologic character of sediment and rock units associated with reflector patterns, and to identify units containing potentially usable fill material. Correlation of core and seismic reflection data permits construction of an informal stratigraphic model in which the approximate lateral extent, thickness, and accessibility of units containing potentially usable fill material can be determined. From this information, promising areas can be selected for detailed site investigation.

Grab Samplers

112. There are a variety of grab-type samplers of different sizes and design that are used for obtaining surficial sediment samples. Most consist of a set of opposing, articulated, scoop-shaped jaws that are lowered to the bottom in an open position and closed by some mechanism. In this process, a sample is retrieved between the closed jaws. Many grab samplers are small enough to be deployed and retrieved by hand; others require some type of lifting gear. A simple and inexpensive dredge-type sampler can be made of a

section of pipe that is closed at one end and dragged a short distance across the bottom to dredge up a sample. Although not representative of a single point as are grab samplers, and subject to losing finer material during recovery, dredge samplers are useful in areas where shells or gravel prevent complete closure of grab samplers.

113. Obtaining surficial samples, while helpful, is of limited value because, as mentioned in PART III, vertical projection of surface data is highly unreliable. The expense of running the tracklines for the sole purpose of sampling surficial sediments is not economically justified by the value of the data obtained. Samples could be taken during the geophysical survey, but use of grab and dredge samplers would require the vessel to stop at each sampling station, thus losing survey time and creating an interruption of data coverage. Samplers are available that can be deployed over the side of the vessel without its stopping, and these may be useful if deployed in such a way as not to foul the towed seismic reflection and side-scan sonar equipment.

Vibratory Corers

114. Direct sampling of sub-bottom materials is essential for borrow source identification and evaluation. This is usually accomplished by means of a continuous coring apparatus that can obtain cores 20 to 40 ft in length in unconsolidated sediments. In the types of sediment usually encountered in borrow site exploration, gravity corers are not suitable for obtaining cores of the requisite length, and some form of powered corers must be used. In most cases, vibrator-driven coring devices have been used for this purpose (Meisburger and Williams 1981).

115. Vibratory corers have been in use for several decades and have been improved through the years as field experience has accumulated. They are relatively simple devices consisting of a frame, coring tube, and drive head consisting of a pneumatic, hydraulic, or electrical vibrator. While the hydraulic and electrical vibrators can be used in deeper water than the pneumatic vibrators, the depth range of the pneumatic device is adequate for borrow site investigations where the maximum depth of usable borrow sources is limited by practical and economic considerations. Because of their relative simplicity and economy, pneumatic coring devices have been used most often for

borrow source exploration programs, and will be the primary focus of the following discussion.

Components

116. Pneumatic vibratory corers consist of three main components: frame, core barrel, and vibrator (Figures 8 and 9). The frame is designed to allow the corer to be freestanding on the sea floor. It usually consists of a quadrapod arrangement with four legs connected to a vertical beam that in turn supports and guides the core barrel and vibrator. Depending on the size of the corer, the vertical beam is 10, 20, or 40 ft high. The core barrel assembly and vibrator can freely slide up and down the beam for coring and retraction. The core barrel assembly consists of a 4-in.-diam steel pipe fitted with a cutter head and core catcher, and a plastic tube inner liner that contains the cored material. The vibrator is usually a piston-type, industrial bin vibrator that uses compressed air to drive the piston in the rapid up and down movements that drive the core barrel into the bottom. The compressed air supply is produced by a compressor on the support vessel, and is transmitted to the vibrator and exhausted to the surface by means of air hoses. Deploying and retrieving the corer requires the use of a crane, A-frame, or similar hoisting equipment with a lifting capacity of about 10-15 tons.

Capabilities

117. Available pneumatic vibratory corers are capable of penetrating up to 40 ft (12.2 m) of unconsolidated sediment. However, actual performance depends on the nature of the sub-bottom material. Under unfavorable conditions as little as 1 m or less may be recovered. Limited recovery occurs for several reasons. Chief among these is lack of penetration. In general, stiff clays, gravel, and hard-packed fine to very fine sand are usually most difficult to penetrate. Another reason is the "freezing" of material in the core liner due to high skin friction before full penetration is reached. When this happens, new material cannot enter the sampler although the core barrel continues to penetrate. Compaction and loss of material during recovery can also cause a discrepancy between penetration and recovery, but occurs less frequently.

118. The coring operation, including setup, deploying the corer, coring and recovery, is quite rapid in comparison with standard soil boring operations. Usually, a core 20 ft (6.1 m) long or less can be obtained in a manner

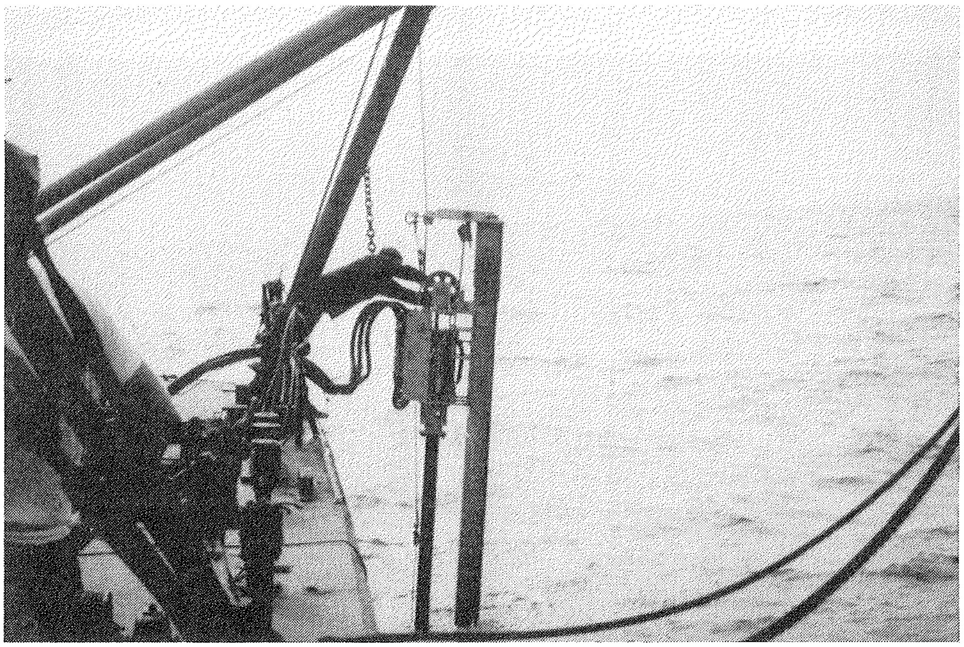

Figure 8. Closeup view of vibratory coring device showing the vibrator section

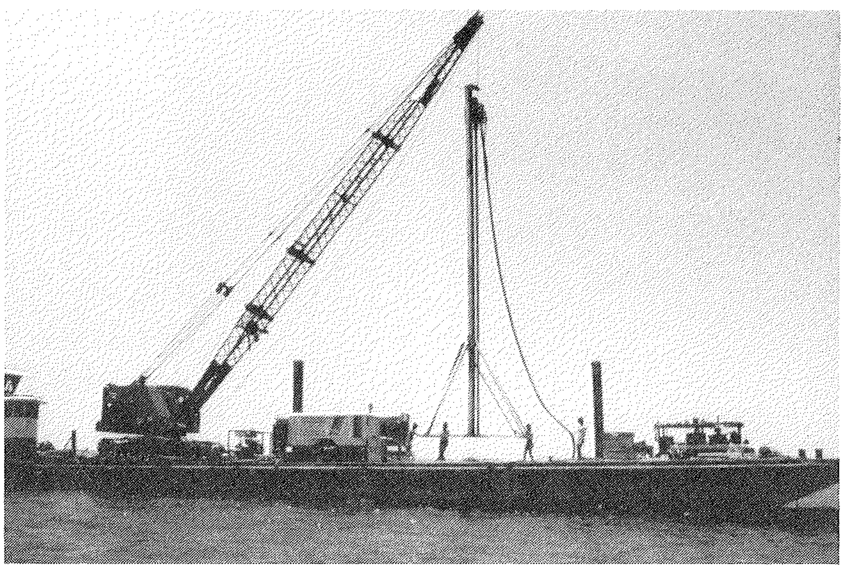

Figure 9. A 40-foot vibratory coring device being deployed from a barge

of minutes. Cores over 20 ft in length require a two-step operation (described in the following section) that consumes more time but is still comparatively rapid.

PART VII: DESIGN AND SEQUENCE OF EXPLORATION PROGRAMS

119. The design of a borrow source exploration program involves a determination of the scope of the program in terms of the extent of the area to be surveyed and the location and amount of geophysical and core data needed to adequately cover the exploration area. In addition, the planning process includes establishing the requirements for various phases of the operation including time, equipment, and personnel requirements that can be used to estimate costs. Flexibility is a key element of program design. Need for changes and adjustments of the basic plan should be expected as incoming field data provides more accurate and detailed information on the exploration area.

Defining Boundaries

120. Delineating the boundaries of the area to be explored is an important aspect of the planning process. Two types of boundaries may be delineated: (a) the overall outer boundaries of the general exploration area; and (b) boundaries of subareas within general limits where various factors preclude either the occurrence of suitable borrow material or recovering any material that may exist. The maximum limits of the general exploration area, if not otherwise restricted, are set by the economically feasible transport distance between the project beach and potential borrow sources. Other important factors that may limit the outer boundaries or create restricted subareas are bathymetry, navigation hazards, special-use areas, adverse geological conditions, and environmental considerations.

121. Restrictions due to bathymetry occur where water depths are too shallow or too deep to allow operation of suitable equipment for dredging and transporting fill material. The landward limit of the general exploration area is usually based on bathymetry and, in places, the seaward limit as well. Shallow shoal areas and hazardous obstructions occurring within general limits may create inaccessible subareas that must be excluded from the exploration plan. Special-use areas in which recovery and transport of fill material are restricted or precluded include areas of heavy maritime traffic, waste disposal sites, cable and pipeline routes, fish havens, offshore structures, and localities reserved for military use. Unfavorable geological conditions usually occur in the form of areas of consolidated rock or glacial till and areas

where surficial layers of unsuitable fine-grained sediments are thick enough to preclude economic access to underlying materials. Environmental factors that may rule out the use of certain areas are usually related to the direct mortality of desirable or rare organisms or alteration of the habitat to which they are adapted.

122. The main sources of information on these factors are the navigation charts and coastal pilots of the US coasts published by the National Ocean Survey (NOS). The charts provide a base for plotting the boundaries and information on most of the factors noted above. The 1:80,000-scale coastal charts published by NOS provide comprehensive coverage of the US coasts at a common scale and are the most useful for boundary determination and plotting. Larger scale charts of some areas are also available and should be on hand as a supplement to the 1:80,000 series. Coastal pilots are useful for discussions and explanations on navigation hazards and restrictions.

Survey Layout

123. Part of the planning process is to develop a plot of the exploration area showing the position, alignment, and extent of tracklines to be run by the geophysical survey boat, and sites where cores are to be taken. The initial plots are based on such knowledge of the area which is available at the time. Because of the usual dearth of information on most offshore areas, the initial plots are tentative; advantageous alterations, additions, or deletions to the trackline and core site coverage should be made in the field as survey and coring operations develop a more reliable and comprehensive overview of the exploration area geology.

124. Normally, the layouts of the tracklines and core sites are made on the 1:80,000-scale NOS charts, keeping the coverage within the boundaries previously established. Bathymetric charts are usually the chief, and often only, source of information available for guidance in preparing trackline plots and selecting core sites. The most important item of information that can be gleaned from the charts is the sea or lake floor geomorphology. They also contain surface sediment notations that are helpful in planning coverage. While the published navigation charts reveal the major geomorphic features, a much more detailed representation can be obtained from unpublished, larger scale charts that were prepared as a step in compiling the published version

which contains only a selected part of the full survey data. Copies of these preliminary charts can be obtained from NOS on request and are a desirable addition to the source material, not only for planning purposes, but for interpretation of data and report preparation.

125. Geomorphic features in the exploration area can best be displayed by contouring the charts at the closest vertical scale practical with the density of soundings. In most cases, geomorphic data from the charts will be sufficient to locate and identify any existing inlet; estuarine, cape-associated, or linear shoals; shoal retreat massifs, or other positive features in the exploration area. Shoals are the primary prospects, and exploration should be emphasized in these areas in terms of data coverage and density. At the same time, the investigator should not neglect to obtain sufficient coverage of intervening areas to identify large potential sources such as relict stream channels that may lack geomorphic expression, and to maintain continuity of data coverage throughout the exploration area.

126. Geophysical tracklines are usually laid out either in a grid pattern or in a continuous zig-zag onshore/offshore alignment (Figure 10). Grid lines (Figure 11) are used in areas where there seems to be a good possibility of finding potentially usable material such as a shoal area. The zig-zag alignment (reconnaissance lines) is used to connect grid areas to maintain continuity and detect indications of possible sources that warrant further investigation. The spacing of tracklines is based on an estimate of the probable variability of bottom and subbottom features. Grid line spacing of 0.8 km (0.5 mile) or less may be necessary in complex areas while spacing of 1.6 km (1.0 mile) may be adequate where conditions are more uniform. Configuration and spacing of reconnaissance lines is also based on a judgment of the complexity of the area. The configuration and spacing of tracklines need not follow the grid and zig-zag patterns but can be varied in any fashion that would be more appropriate for a particular area. The main objective is to acquire comprehensive coverage that best reflects the surficial and sub-bottom geology of the exploration area at an economically feasible cost.

Schedule of Events

127. Part of the planning procedure for borrow source exploration programs is scheduling of the individual phases of the operation. The schedules

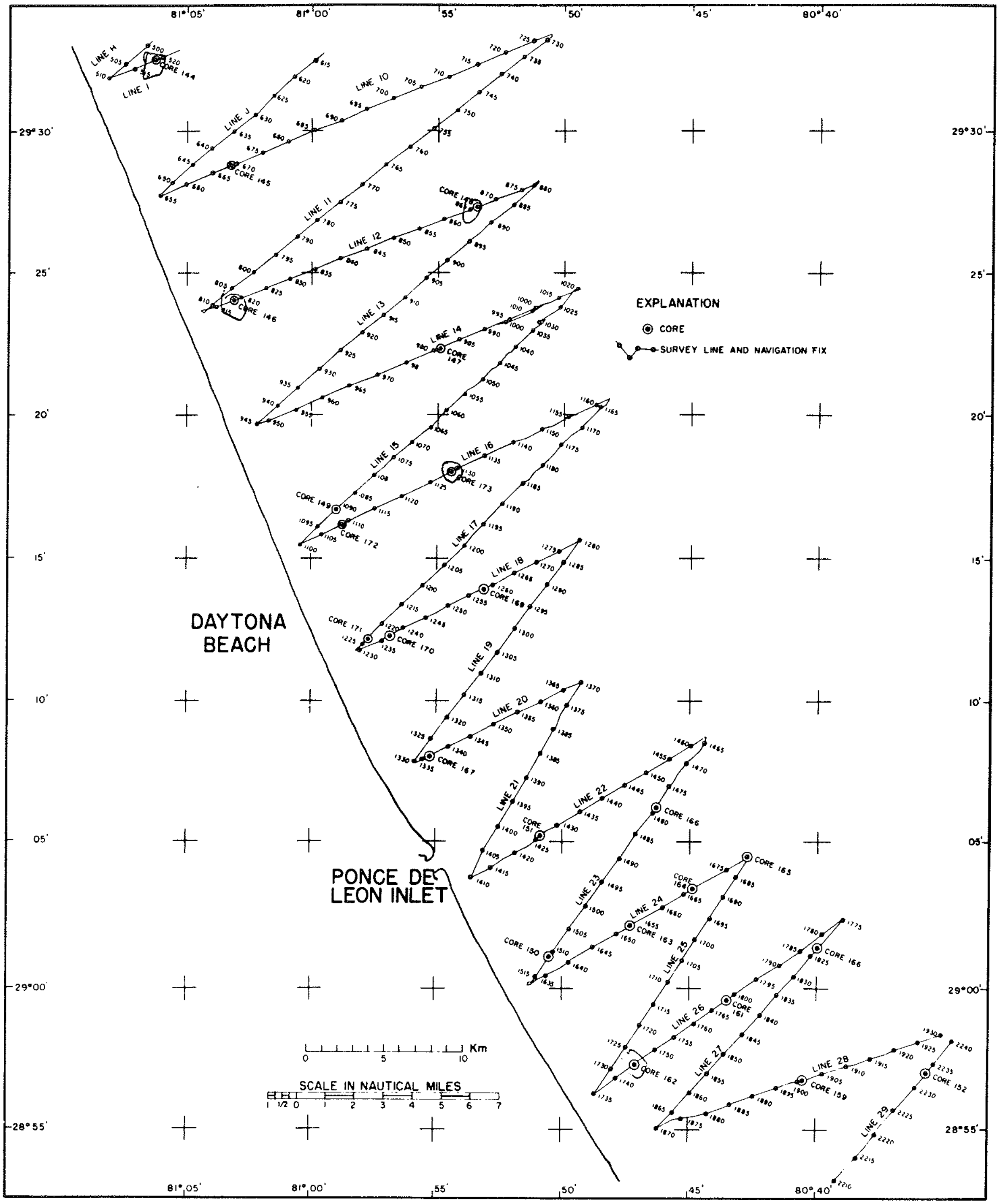

Figure 10. Reconnaissance line plot from the north Florida coast. From Meisburger and Field (1975)

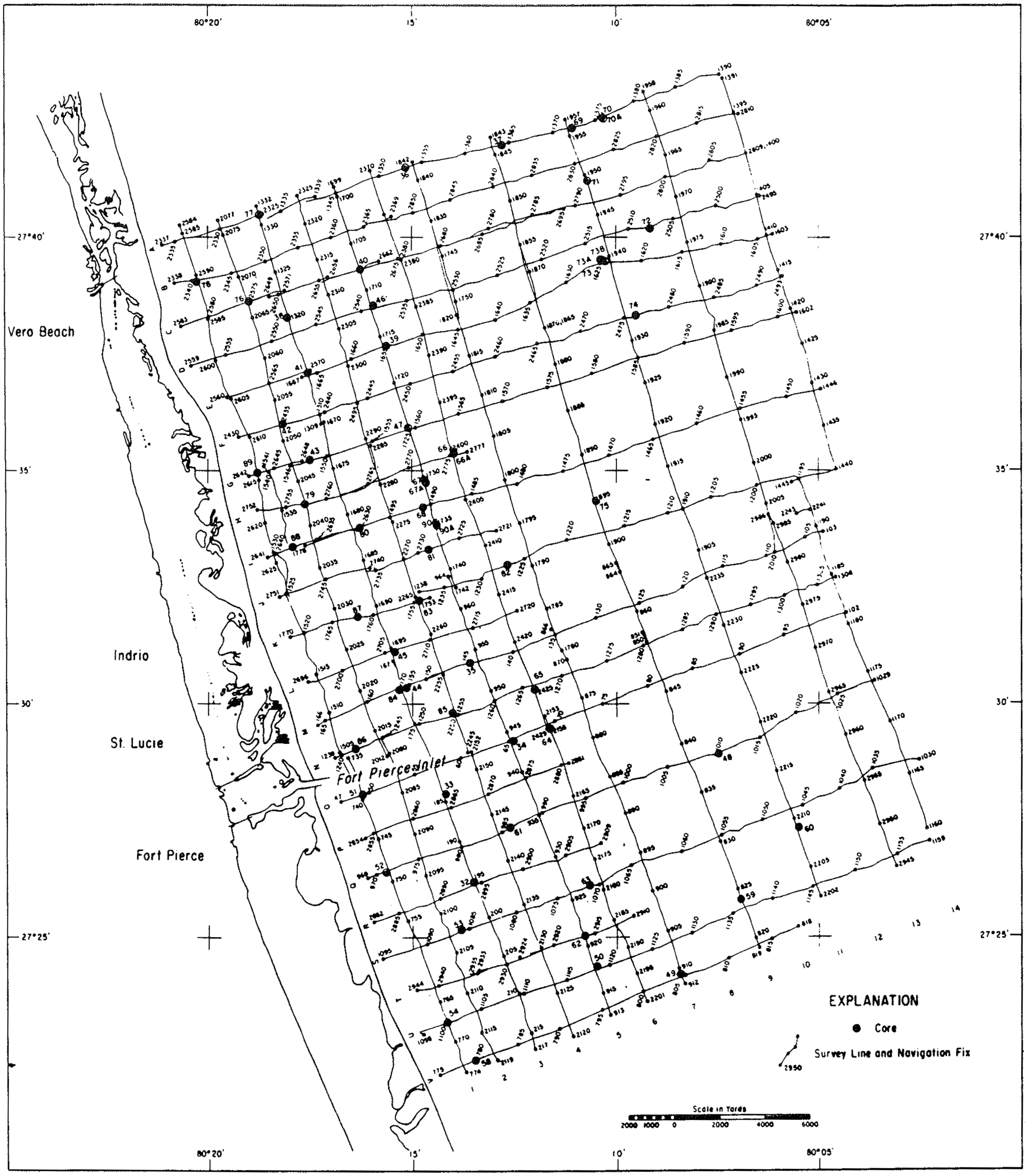

Figure 11. Grid lines covering a detailed survey area off Fort Pierce, FL (Meisburger and Duane 1971)

are developed in terms of the sequential order of various events, time needed to complete each event, the optimum season for field work in the exploration area, and availability of necessary personnel and equipment.

128. In past exploration programs, geophysical and coring operations were usually carried out in sequence with the geophysical survey, followed by coring operations either later in the same season or during the following year. Although this sequence of events provides more time to analyze the geophysical data before selecting core locations, there are advantages in carrying out both operations at approximately the same time. In this procedure, the coring operation lags a few days behind the geophysical survey so that enough data are collected on each area to permit effective core site selection. This permits preliminary field analysis of cores and geophysical data for the purpose of making advantageous or needed changes in the survey and coring coverage as work proceeds. When concurrent operations are used, one member of the field party should be skilled in interpretation of geophysical and core data, and have the primary duty of processing the records and cores on a day-to-day basis as they become available, and recommending alterations or additions to the basic preplanned coverage.

129. Basic time elements considered in preparing a schedule are mobilization and demobilization, field operations, and contingency time due to weather or equipment malfunction. Mobilization and demobilization of needed equipment can usually be performed in two or three days; however, mobilization may be extended if the vessels used must travel some distance to reach the mobilization site.

130. Operational schedules are basically derived from a consideration of (a) the number of miles to be traversed to obtain the desired geophysical coverage and the boat speed when running survey tracklines; and (b) the approximate distance between core sites, speed of the coring vessel, and on-site time needed for mooring and taking the core. Time must also be allowed for daily travel to and from the part of the exploration areas currently being covered. Distance values for calculating operational time can be obtained from the trackline and core site plots. Boat speeds for running seismic reflection lines with surface-towed source and receiver combinations must be kept at about 4 knots or less to obtain good quality records. However, seismic reflection equipment in which the acoustic source and the receivers are towed beneath the surface are said to more than double the

practical survey speed and could substantially reduce overall survey time. The types of vessels used for coring operations are usually slow, and unless the vessel to be used is already known, a speed of about 5 knots is reasonable for estimating time schedules.

131. Downtime due to weather is often a significant factor in exploration costs. With surface-towed acoustic sources and receivers, the quality of seismic reflection records progressively deteriorates when waves exceed 1 m in height. Similarly, the efficiency and safety of coring operations deteriorates as wave heights increase. While some improvement in seismic reflection data can be achieved by using submerged source and receiver combinations that are less affected by wave motions, much time may also be lost when wave heights become hazardous to the vessel, and all operations must be suspended. It is, therefore, advantageous to schedule field operations to coincide with the season of most favorable weather and/or sea conditions. This can be determined best by analysis of historical sea and swell data for the exploration area.

132. Downtime can also occur because of malfunction of essential equipment. This can be avoided or minimized by having a trained technician in the field party who can maintain and repair equipment, and by having backup equipment either on hand or available on short notice from the manufacturer or equipment rental source.

Equipment

133. A list of equipment needed for the exploration program should be compiled during the planning stage for the purpose of cost analysis and procurement of necessary items. A sample equipment list, modified from Prins (1980), is contained in Appendix A. The most costly and important items are the vessels used for support of the geophysical and coring operations. It is essential that vessels contain enough space to accommodate the equipment, and are capable of operating under the expected predominant sea and swell conditions. Although some vessels are designed for marine research activities and have special features to facilitate use of the types of equipment required for an exploration program, installation of these items in an otherwise suitable vessel can usually be accomplished in one or two days.

134. Vessels used for geophysical surveys require sufficient covered space to accommodate the power supply recorders, signal processors, and navigation control equipment that could be damaged by spray or rain. Although geophysical surveys are carried out at relatively low rates of speed, the survey vessel should be capable of a higher rate of speed for moving between the dock and current survey area, thus maximizing time for active operations.

135. Vessels commonly used for coring, such as barge and tug combinations, usually have relatively slow cruising speeds. Since most of the time spent in coring operations is consumed by traveling between core sites, core production is proportional to the speed of the coring vessel; thus, relatively high speeds are desirable. Although not a necessity, a reconnaissance boat equipped with the offshore navigation station can be used to locate and mark selected core sites, which eliminates need for the slower and less maneuverable coring platform boat to locate the site.

Cost Estimate

136. An example of a cost estimate for a borrow source exploration program from Prins (1980) is contained in Appendix B. In order to draw up such an estimate, the following factors must be determined:

a. Plant rental costs for equipment and vessels per day.

b. Personnel costs per day.

c. Overall costs for travel, expendable supplies, and equipment preparation.

d. Expected average miles of geophysical survey per day.

e. Expected average number of cores collected per day.

f. Expected downtime due to weather or equipment malfunction.

The example does not program time for collecting additional trackline miles that may be added as a result of the day-to-day data review. Experience in the ICONS program suggests that this figure should be 15 to 20 percent of the preplanned geophysical trackline miles and cores.

137. Factors a, b, and c in the above list can usually be determined precisely from readily available sources such as pay scales and travel fee schedules. Factor d is usually limited by the practical towing speed of the seismic reflection system source and receiver elements. With surface-towed units this is about 4 knots. Using a 10-hr working day, about 40 nautical

miles of geophysical trackline can be run per day. Factor e is more difficult to estimate because it depends on three main factors: (a) the vessel speed; (b) mooring time; and (c) the distance between coring sites. On-site time for mooring and taking the cores is usually less than the time spent in moving from site to site. Distances between sites can be obtained from the pre-planned trackline and core site plots. Accurate information on vessel speed and mooring time can be obtained if the vessel to be used has been selected. If no selection has been made, an assumed speed of 5 knots and an assumed time of 30 min for mooring, taking the core, and getting underway to the next site are reasonable planning factors.

138. Contingency days for weather can be estimated by referring to historical sea and swell data summaries such as the CERC Wave Information Studies. Survey equipment is usually reliable; however, a sufficient contingency time of 10 percent of the estimated total survey time should be added to cover the probable delay in replacing system components by air freight.

139. Costs shown in the sample estimate (Appendix B) are average costs in 1980, and current rates are substantially higher in most cases.

PART VIII: PRELIMINARY DATA ANALYSIS

140. As mentioned previously, preliminary analysis of the geophysical and core data is desirable in order to obtain information that can be used for making necessary or advantageous changes in the survey and coring plan as field work progresses. The objective of this part is to discuss techniques of analyzing geophysical and core data for the purpose stated above. A more complete and comprehensive formal analysis must wait until a later date when the complete set of geophysical records and cores of the exploration area are available.

141. The limited time available for field analysis of geophysical data is best devoted to analyses of the seismic reflection records. Fathometer traces need no special interpretation techniques, and side-scan sonar records do not normally contain information crucial to decisions on modifications and additions to the survey and coring plan; therefore, the following discussion is limited to seismic reflection and core data.

Seismic Reflection Records

142. Analysis of seismic reflection records is a fairly straightforward process. Reflectors are shown by line traces on the record that are similar to a geologic cross section of the area beneath the tracklines. However, some of these reflector traces are not related to actual reflecting surfaces in the sub-bottom, but are spurious by-products of the seismic reflection method. Much of the analysis involves sorting out the true from the false reflectors and correlating true reflectors from line to line.

143. Analysis of seismic reflection records involves the handling of strip chart sections of individual tracklines that are as much as 10 m or more in length. A primary requisite for analysis is to obtain sufficient space to lay out enough record at any one time to obtain an overall view of a substantial part of the line. This allows the interpreter to better develop the reflector patterns and to sort out spurious reflectors and project trends. In general more space is required than can be found on a desk top or drafting table. A reasonable minimum should be about 5 m. A portable table of sufficient length made from plywood paneling supported on wooden trestles can

conveniently be set up in a motel room or other covered space for record analysis.

Record annotations

144. Marking reflectors on seismic reflection records can be done directly on the original record, on copies of the record, or on transparent overlays. Permanent markers should not be used on the records or overlays since the initial delineation of reflectors is tentative and may change as the overall pattern is developed and spurious reflectors are identified. Although soft markers such as chalk can be used to mark the original record, the paper can be easily damaged and it is preferable to leave the originals unmarked and delineate the reflectors on a suitable copy or overlays. It is important that all analysis, interpretation, and correlation be accomplished by examination of the original record. Copies and overlays are used only as a base for recording the results of the analysis.

145. Reflectors are delineated by drawing a line with a suitable marker along the top of the reflector traces. Dashed lines can be used to indicate projections across gaps, and through sections obscured by multiples or other sections where continuity is not certain. Persistent reflectors can be given a letter, number, or code word designation to identify them along each profile and on other records where correlation is established.

Spurious reflectors

146. While seismic reflection records show the position and configuration of sub-bottom contacts between sediment and rock bodies with contrasting acoustic properties, they also show apparent reflector traces that are spurious and not related to geological factors directly beneath the path of the survey vessel. These false reflectors create two problems: (a) they can be mistaken for true reflectors; and (b) they can obscure valid reflectors on the graphic record. Discrimination between actual and false reflectors is of primary importance in record analysis. False reflectors can usually be identified by certain inherent characteristics that reveal their nature.

147. The most common type of spurious reflector is known as a "multiples." Multiple traces on a record are caused by the signal bouncing between two high-contrast reflectors so that the lower reflector is recorded one or more times in a position below the true reflector elevation. Usually, the most common and prominent multiples are the bottom multiples (Figure 12). The multiple traces are created when part of the acoustic energy reflected from

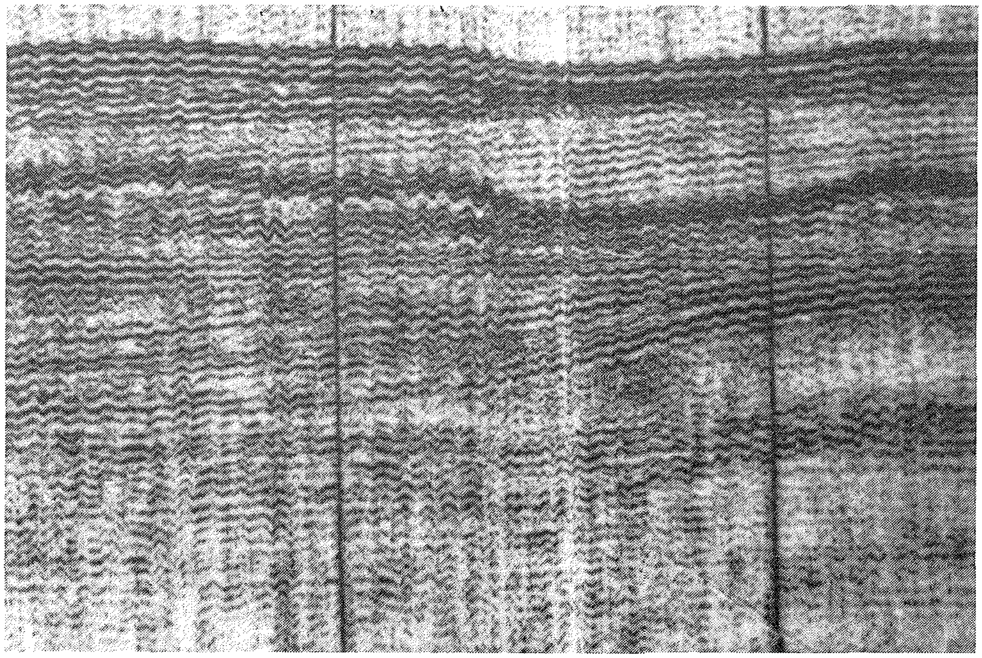

Figure 12. Section of seismic reflection record showing bottom multiple. Note mimicking of bottom topography and series of reflectors dipping to the left. (Meisburger and Field 1975)

the bottom is re-reflected at the high-contrast air-water interface at the surface, returned again to the bottom and back to the surface where it is picked up by the receivers and recorded in a position below the true bottom reflector corresponding to the two-way travel time. Because of the geometry involved, the apparent depth of the reflector is equal to the water depth at that location. The signal can bounce repeatedly and two or more multiples can appear on the record spaced at intervals equivalent to the water depth, becoming progressively weaker as the energy is attenuated. In addition to bottom multiples, there is an almost endless variety of multiples that can be created by signal bouncing between any combination of reflectors. However, random multiples are usually not as prominent and persistent as bottom multiples and, in general, are a lesser problem.

148. Where multiples of any type occur, they can often be identified because they repeat the configuration of the source reflector and cut across other reflectors. Crossing of true reflector surfaces is rare in nature and crossed reflectors usually indicate that one is spurious. The more difficult problems occur where the bottom, or other source reflector, is even and

horizontal or nearly so, and true sub-bottom reflection surfaces are likewise even and near horizontal. In such cases, discrimination of multiples is difficult at best, and in shallow water, the multiples may completely obscure any sub-bottom reflectors.

149. Other common spurious signals that can be recorded are direct arrival, side echoes, and point sources. The direct arrival occurs when the acoustic source and receivers are towed separately, and the arrival of the acoustic signal is recorded directly from source to receiver as distinct from reflected signals. Usually the separation of source and receivers is less than the water depth, and the direct arrival appears in the water column as a strong signal, generally parallel to the zero time line, but may become irregular where the source-receiver spacing changes from time to time (as when boat turns are made). Side echoes occur where reflections are received from irregular features that are not directly beneath the trackline, but are close enough to produce one or more short reflectors that cut across sub-bottom reflectors at an angle. Point source reflections are a type of side echo produced by a distinct object such as a boulder or rock outcrop that appears on the record as a hyperbola with the object being beneath the apex and the sides cutting across the sub-bottom reflectors. In most cases, the direct arrival, side echoes, and point source signals are readily identifiable and do not unduly complicate record analysis.

Record analysis

150. The main purpose of record analysis is to develop a tentative stratigraphic framework of the exploration area that shows the thickness and areal extent of the various sub-bottom rock and sediment bodies. When correlated with core data, the lithologic character of these bodies can be established. Those areas, potentially suitable as a borrow source, are identified, and the thickness, extent, and lithology of overburden material are determined. To do this, the reflectors on each profile line are delineated and correlated with adjacent lines to construct the three-dimensional framework.

151. An initial assumption is made that all valid traces on the profile lines are of some stratigraphic significance. As core data are acquired, a more complete and reliable interpretation can be made and the initial assumption of significance tested. Experience from past operations where cores or borings were also obtained, indicates that, in most cases, reflectors have

stratigraphic significance. This is especially true of persistent reflectors that can be traced over a substantial area.

152. The process of record analysis is largely one of separating valid from spurious reflectors, correlating the more persistent reflectors from line to line, and projecting reflector trends between gaps in the trace or where the reflector trace is obscured by spurious reflections. The first step is to delineate and mark the trace of the true reflectors on copies or overlays of each line in turn, using the original records, as mentioned above, for making the interpretation. Having done this, correlations are made wherever possible between the same reflector surface on adjacent lines so that the areal extent of each rock and sediment body can be determined. If core data are available at this point, they can be of great value in making reliable correlations.

153. Various procedures can be used to organize the seismic reflection data into a coherent system that can depict the stratigraphic framework. The procedure described here was developed during the course of the ICONS program. In this procedure, three elements are used: primary reflectors, secondary reflectors, and reflection units (Figure 13). Primary reflectors (or horizons) are those that persist over a substantial area and can be traced from line to line. Primary reflectors are given an identifying letter, number, or name. Secondary reflectors are much less extensive than primary reflectors and often may be related to internal bedding features. They are delineated and marked but not usually given an identification except in detailed studies of a relatively small area. Areas between primary reflectors are called reflection units and are assumed to be stratigraphically definable elements (Figure 13). These units are usually given an identifying letter, number, or name and correlated throughout the area of their occurrence.

Core Logging and Sample Analysis

154. During the field data collection phase of an exploration program, a preliminary analysis of the cores and samples from the cores is made on a day-to-day basis to obtain information for making advantageous modifications to the survey plan. In addition, when the specific site surveys of high potential borrow sources are undertaken immediately following the general survey, the preliminary analysis must suffice for selection of these sites, and needs to be as complete and accurate as possible.

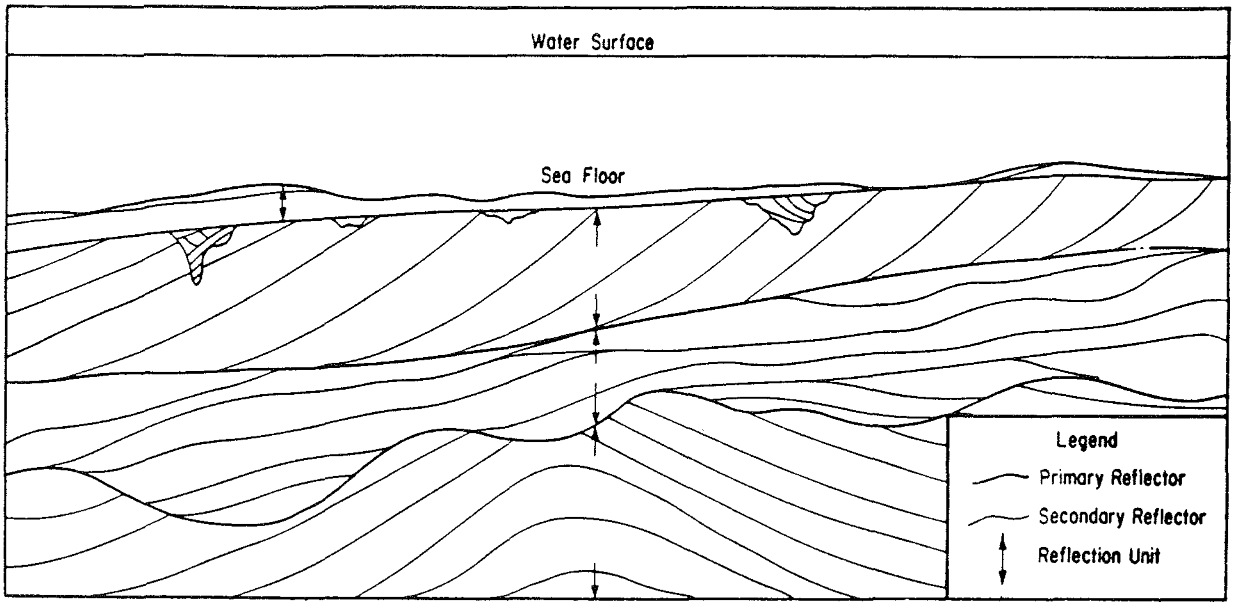

Figure 13. Schematic profile showing primary and secondary reflectors and reflection units (Meisburger 1979)

155. The scope of preliminary core and sample analyses in the field is limited by three factors, as follows: (a) only partial visual and physical access to the cores for preliminary logging and sampling is usually possible; (b) the type and extent of sample analysis possible in the field is in many respects not comparable to laboratory analysis; and (c) in order to keep pace with the progress of the survey, the field analysis for each core must be completed in a limited time frame.

156. Many large vibratory corers such as those commonly used for borrow source investigations have plastic tube liners inserted in the core barrel to contain the sediment. After each core is taken, the liner containing the cored materials is removed and replaced by a fresh liner. Usually the liners consist of clear acrylic plastic that allows observation through the wall. However, in some cases heavy scratching by granular material or silt and clay coatings of the inner wall obscure the contents. Where the cored material is visible, logging and selection of samples representative of the cored section can be made by direct visual inspection. Some vibratory corers use aluminum or opaque plastic tubing as core barrels without liners and use the core barrels themselves as the containers using a fresh core barrel for each core run. This procedure presents a problem in field logging and sample selection since only the material in the top and bottom of the core tube is visible. For this

reason, clear core liners are preferable for making core logs and selecting representative samples.

157. Ideally, visual and physical access to cores is best obtained by splitting the cores lengthwise to expose the cored section. However, in the field this is undesirable because split core tubes have little structural strength, and even when rejoined and taped together, are difficult to handle and ship to the laboratory without breaking, loosing material out the sides, or causing serious disturbance of the contents. Thus, field procedures for viewing potential borrow material are limited by a need to maintain the integrity of the core container.

158. The normal procedure in field sampling of cores is to obtain top and bottom samples from the ends of the tube before they are capped, and to obtain samples between the ends by using a 1- to 2-in.-diam hole saw to bore through the tube wall and provide access for removing a small sample. After this, the hole is sealed by tape. Representative samples should be obtained from each lithologically distinct layer identified in the visual logging process. In cases where the core container is opaque, no precise log can be made. The best way to obtain information about lithologically distinct sediment units in the core is to drill a number of arbitrarily selected holes with a 1/2- or 3/4-in. flat bit to permit visual inspection, be able to approximate the location of boundaries, and select sample positions.

159. The objective of sample analysis in the field is to obtain lithologic information on the material contained in the cores for inclusion in core logs and identification of possible borrow material for the project beach. Primarily, samples are examined visually to determine pertinent characteristics such as size distribution and composition in terms of relatively broad categories. For this purpose, a hand lense and size comparison chart are useful aids. In addition, samples that appear, on visual examination, to be possibly suitable as fill material should be further analyzed to obtain data on their size distribution characteristics by more accurate means than visual inspection. This can be done by using small 3-in.-diam sieves to separate small samples into appropriate size fractions which are then weighed to determine the percent weight of each size fraction. Minimal equipment needed for this procedure is a drying oven of 1-ft^3 capacity or more, but small enough to be portable, 3-in.-diam sieves covering the Wentworth sand size ranges at 1/2-phi intervals, and a small top-loading electronic balance with a precision

of 0.01 g. The simplest procedure for determining size distribution is to hand sieve small samples that have been washed and dried in the oven. Although hand shaking normally does not provide a complete separation, especially in the finer size ranges, it is considerably more accurate than visual estimation. A recently developed device that effectively shakes down the material, yet is small enough to be readily portable, uses sonic vibrations to agitate a stack of graduated sieves and thus promote downward flow. Results of this method are comparable to standard sieving methods using large mechanical shakers. The sonic vibrator, oven, and balance are all small and light enough to be set up on a table and operated in a motel room or similar small space and can be readily transported and set up for operation in new locales as the survey base is changed.

PART IX: SUMMARY AND CONCLUSIONS

160. Borrow source exploration in a subaqueous environment requires consideration of a number of geological factors. The most important of these are historical geology, geomorphology, stratigraphy, and lithology. A substantial part of the data needed to assess these factors must, in most cases, be obtained by a field collection effort.

161. Certain geomorphic features of marginal marine and inner continental shelf environments have been found to contain sand-size sediment potentially usable for beach fill. These features are barrier island inlet shoals, linear shoals, cape- and estuary-associated arcuate shoals, relict fluvial channels, and shoal retreat massifs.

162. Field exploration for borrow sites involves geophysical and sediment-sampling operations. The geophysical operations make use of Fathometers, side-scan sonar, and seismic reflection profilers. Sediment samples are obtained with grab or dredge samplers for surficial sediments and vibratory corers for sub-bottom sampling.

163. Existing geophysical methods and equipment are adequate for borrow source exploration; however, improvements are needed to increase economy, flexibility, noise suppression, and range of available equipment. Methods and equipment for obtaining sub-bottom sediment samples are adequate but highly expensive. Improvements in economy, and greater reliability of penetration achievement, are ongoing research and development goals.

164. Procedures for designing borrow source exploration programs are based on past experience in design and conduct of exploration programs. The main elements of the design are initial layout of trackline patterns, core site selection, selection of personnel and equipment, schedules, and cost estimates. The program should be flexible and amenable to changes made in the field based on review of the data as it becomes available.

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APPENDIX A

LIST OF EQUIPMENT AND SPECIFICATIONS

a. Seismic operations

(1) Research vessel

38-ft (11.6 m) minimum length
40 sq ft (3.7 m^2) minimum table space
40 sq ft minimum deck space
110-volt a.c. power
Compass (gyrocompass desirable)
Marine radio
Cruising range: 100-mile (160.9-km) minimum
Cruising speed: 10-knot minimum

(2) Sub-bottom profiling system

(a) Medium resolution, medium penetration

Penetration capability: 50 to 200 ft (15.2 to 61.0 m)
Power output: 300 to 1,000 J
Frequency range: 400 Hz to 14 kHz

(b) High resolution, low penetration

Penetration capability: 30 ft (9.1 m)
Power output 10 kw
Frequency range 3.5 to 7 kHz

(3) Side-scan sonar system

Frequency range: 95 to 100 kHz
Port and starboard scanning capability
500-ft (152.4-m) range in either direction

(4) Geographic positioning system

Range: 20-mile (32.2-km) minimum
Accuracy: 10 ft

(5) Microprocessor

Interfacing capabilities with positioning system

(6) Radios

(a) Marine-band radio

(b) Two-way radio

Range: 10-mile (16-km) minimum

(7) Vehicles

Three minimum for shore personnel

b. Coring operations

(1) Coring platform

(a) Tug and barge

Tug: capable of 8-knot (14.6-km) minimum with barge in tow

Barge: Sufficient deck space to accommodate coring device, crane, compressor, and core storage; or

(b) Ship

Requirements essentially same as barge

(2) Reconnaissance boat

32-ft (9.8-m) minimum length
10-sq ft (0.9-m^2) minimum table space
110-volt a.c. power
Compass
Cruising range: 100-mile minimum
Cruising speed: 10-knot minimum

(3) Geographic positioning system

Range: 20-mile (32.2-km) minimum
Accuracy: 10 ft

(4) Coring device, vibrating

Capable of 20- to 40-ft cores

(5) Compressor

120 psi (8.4 km/m^2) at 250 ft^3 (7.1 m^3) per min

(6) Crane

11-short-ton (10-metric-ton) minimum
30-ft minimum boom length

(7) Bottom grab sampler

Various types available

(8) Miscellaneous

Floats, cord, and anchor weights
Logbooks
Office supplies
Batteries
Sample bags
Waterproof markers
Tools and hardware
Cable and clamps

APPENDIX B

EXAMPLE COST ESTIMATE*

Location: Lake Erie from the New York-Pennsylvania border west to Toledo, OH

Data Requirements: 700 track-line miles of seismic reflection profiles, side-scan sonar, and 150 cores

Date of Estimate: 1977

	Use	Unit cost	Item cost	Subtotal
1. Presurvey planning		$ 2,400	$ 2,400	($ 2,400)
2. Seismic operations				($ 65,225)
a. Travel and equipment transport				5,150
(1) Research vessel and crew		1,500	1,500	
(2) Seismic system				
(a) Seismic equipment and two operators		1,500	1,500	
(b) Truck rental		800	800	
(c) Electronics technician		500	500	
(3) Positioning system		250	250	
(4) Technical personnel				
(a) Project leader		200	200	
(b) Project geologist		250	250	
(c) Engineering technician		150	150	
b. Equipment and manpower				
(1) Seismic data collection				18,600
(a) Seismic system checkout and preparation (bench)		1,200	1,200	
(b) Seismic system (includes system, operators, and electronics technician)		$600/day		
1 Data collection for 700 trackline miles	20 days	600/day	12,000	
2 Contingency days	5 days	600/day	3,000	
3 Mobilization and demobilization	3 days	600/day	1,800	
4 System checkout (field)	0.5 day	600/day	300	
5 Miscellaneous supplies		300	300	
(2) Side-scan sonar data collection				10,065
(a) Side-scan system checkout and preparation (bench)		500	500	
(b) Side-scan system (includes system and operators)				
1 Data collection	20 days	325/day	6,500	
2 Contingency days	5 days	325/day	1,625	

* Prins, D. A. 1980. "Data Collection Methods for Sand Inventory Type Surveys," Coastal Engineering Technical Aid No. 80-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

3 Mobilization and demobilization	3	days	325/day	975	
4 System checkout (field)	0.5	day	325/day	165	
5 Miscellaneous supplies			300	300	
(3) Geographic positioning data collection					16,860
(a) Positioning system checkout and preparation (bench)			0	0	
(b) Positioning system					
1 Data collection	20	days	400/day	8,000	
2 Contingency days	5	days	400/day	2,000	
3 Mobilization and demobilization	3	days	400/day	1,200	
4 System checkout (field)	0.5	day	400/day	200	
5 Shore station operators (technician and three student aids)	21	days	260/day	5,460	
(4) Research vessel (includes captain, engineer, and deckhand)					14,550
(a) Data collection	20	days	500/day	10,000	
(b) Contingency days	5	days	500/day	2,500	
(c) Mobilization and demobilization	3	days	500/day	1,500	
(d) All systems checkout	0.5	day	500/day	250	
(e) Miscellaneous expenses			300	300	
3. Coring operations					($121,680)
a. Travel and equipment transport					9,800
(1) Coring platform with crew and crane			8,600	8,600	
(2) Coring device, truck, and operator			1,200	1,200	
(3) Positioning system and technical personnel (cost included in seismic operations)			0	0	
b. Equipment and manpower					
(1) Coring platform (includes tug and barge, captain, engineer, and two deckhands)					56,975
(a) Data collection	19	days	2150/day	40,850	
(b) Contingency days	5	days	2150/day	10,750	
(c) Mobilization and demobilization	2	days	2150/day	4,300	
(d) All systems checkout	0.5	day	2150/day	1,075	
(2) Coring device (includes coring device, compressor, crane, and operator)					26,880
(a) Data collection	19	days	520/day	9,880	
(b) Contingency days	5	days	520/day	2,600	
(c) Mobilization and demobilization	2	days	520/day	1,040	
(d) Coring device checkout	0.5	day	520/day	260	
(e) Core liners	160		80 each	12,800	
(f) Miscellaneous supplies			300	300	
(3) Positioning system					15,800
(a) Data collection	19	days	400/day	7,600	
(b) Contingency days	5	days	400/day	2,000	
(c) Mobilization and demobilization	2	days	400/day	800	
(d) System checkout	0.5	day	400/day	200	
(e) Shore station operators (technician and three student aids)	20	days	260/day	5,200	

(4) Positioning boat (includes captain and fuel)					12,225
(a) Data collection	19	days	450/day	8,550	
(b) Contingency days	5	days	450/day	2,250	
(c) Mobilization and demobilization	2	days	450/day	900	
(d) All systems checkout	0.5	day	450/day	225	
(e) Miscellaneous expenses			300	300	

SUMMARY OF COST

Presurvey planning	$ 2,400
Seismic operations	65,225
Coring operations	121,680
Total project cost	$ 189,305

From: Prins, D. A. 1980. "Data Collection Methods for Sand Inventory Type Surveys," Coastal Engineering Technical Aid No. 80-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.