The Volume of Sand and Gravel Resources in the Lower Bay of New York Harbor

H.J. Bokuniewicz

C.T. Fray

marine sciences research center
state university of new york

new york sea grant institute
suny and cornell

SPECIAL REPORT 32

REFERENCE 79-16

MARINE SCIENCES RESEARCH CENTER
STATE UNIVERSITY OF NEW YORK
STONY BROOK, NEW YORK 11794

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December, 1979

This study was funded by the New York Sea Grant Institute through a contract with the New York Office of General Services and by the State University of New York

Special Report 32

Reference 79-16

Approved for Distribution
J.R. Schubel
J. R. Schubel, Director

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ACKNOWLEDGEMENTS

We are grateful for the help of K. A. Kastens in preparing this report and for the cooperation of J. Marotta of the New York Office of General Services, S. J. Williams of the Coastal Engineering Research Center, Army Corps of Engineers, J. Lovegreen of Woodward-Moorehouse Assoc., J. Peterac of the New York State Department of Transportation, and R. Allen from the Bell Laboratories. We would also like to thank Douglas LaTour, who constructed a three-dimensional model of the core and boring data, and Susan Risoli, who typed this report.

This research was supported by the New York Sea Grant Institute through a contract with the New York Office of General Services and by the Marine Sciences Research Center of the State University of New York at Stony Brook.

ABSTRACT

The shallow (< 100 ft) stratigraphy of the Lower Bay floor was investigated in order to estimate the volume of sand and gravel deposits under the Lower Bay. Four types of information were studied. These were: (1) core and boring logs, (2) seismic reflection profiles, (3) the surficial sediment distribution on the floor of the Lower Bay, (4) the stratigraphy in Long Island, Staten Island, northern New Jersey, and the New York Bight. In general, marine sands overlie glacial outwash sands which, in turn, overlie unconsolidated Cretaceous sediments. Along the margins of the Bay, sands are known to rest on fine-grained deposits at depth; the composition of layers underlying the surficial sand deposits in the central and eastern Bay is unknown. Surficial mud deposits are confined primarily to Raritan and Sandy Hook bays. They may be as much as 150 feet thick. Sand deposits were identified that have a total volume of 3,429 million cubic yards.

INTRODUCTION

New York Harbor spans two major geologic boundaries. The first is the boundary between the ancient crystalline rocks of the Piedmont and New England physiographic provinces and the geologically younger, thick sediment layers of the Coastal Plain Province and their extension on the continental shelf. This boundary is the landward limit of the coastal plain separating the young fringe of coastal plain sediments from the old continental rocks of the interior of North America. The boundary cuts northeasterly across Staten Island and Long Island, then under Long Island Sound. To the north and west lie Triassic and Paleozoic rocks that are 190 to 570 million years old, and Precambrian rocks which are greater than 570 million years old. To the south and east are the coastal plain sedimentary layers; these are all younger than 136 million years old.

The second major geologic boundary that runs through the Harbor is the Harbor Hill Moraine. This is a ridge of mixed, poorly sorted, unconsolidated particles of all sizes from boulders to fine clay. This moraine was formed at the edge of the great ice sheet during the last, or Wisconsin, glaciation. This moraine forms the northern backbone of Long Island. It is breeched by The Narrows and continues westward across Staten Island, New Jersey, and beyond. To the north of the moraine the terrain has been sculptured directly by the slowly moving glaciers and then blanketed with sediments from melting ice. These sediments are called glacial till and typically contain not only sand and gravel, but also large rock fragments and boulders as well as silt and clay. South of the moraine, however, thick layers of sands and gravel were deposited by streams that drained the melting ice. These deposits are called outwash sand and the sand grains in the outwash sands are more uniform in size. Boulders that could not be carried by streams were left north of the moraine and very fine-grained silts and clays were, for the most part, washed out to sea. Because so much of the world's water was frozen in the huge, glacial ice caps, sea level at that time was much lower than it is today. The outwash sands were deposited far out on what is now the continental shelf. The area that is today covered by the Harbor was then dry land crossed by twisting streams that predate the Hudson River.

The glaciers began their retreat to the north about 15,000 years ago, and the ancestral Raritan and Hudson rivers wound their way across the outwash plain that would become the floor of the Lower Bay. As the ice melted, sea level rose. The sea invaded the Lower Bay and the slow submergence of the continent is continuing today. When the Bay finally became an arm of the sea, waves and tidal currents set to work reshaping the shoreline and the Bay floor. The growth of Sandy Hook is one of the most impressive alterations.

Sanders (1974) and the authors of the other geological papers referenced in this report give the details of the geological history of the study area.
port.

The glacial outwash sands that are submerged beneath the Lower Bay are a valuable, natural resource. Sand and gravel are needed for construction aggregate, landfill, and beach nourishment and it appears that as sand reserves are depleted on land, our offshore resources will need to be further developed to avert serious shortages (Cruickshank and Hess, 1975). Offshore sands have been mined in New Jersey, Rhode Island, and California as well as in New York. About 90 million cubic yards have been removed from the floor of the Lower Bay already (Kastens, Fray, and Schubel, 1978) and it is estimated that an additional 34 million cubic yards will be needed over the next five years (J. Marotta, New York Office of General Services, personal communication).

This report is part of a larger study of sand mining in the Lower Bay of New York Harbor (Fig. 1). Other reports in this series include Kastens, Fray, and Schubel, 1978; Swartz and Brinkhuis, 1978; Jones, Fray, and Schubel, 1979; Bokuniewicz, 1979; Wong and Wilson, 1979; Kinsman, Schubel, Carroll, and Glackin-Sundell, 1979. The purpose of this report is to describe the general vertical distribution of sediments in the Lower Bay in order to guide future exploration and the management of our submarine sand resources. In this report we will map out the extent and distribution of both mud and sand using surficial sediment maps, seismic reflection profiles, and cores and borings. To the extent possible, we will describe the layers of sediments under the Bay floor and indicate some specific problems that remain to be studied.

METHODS

When describing the geology of a region, the usual convention is to begin with the lowest (i.e., oldest) stratum and work upward. We will not use this geological convention in this report, however, because it is designed to evaluate potential mining areas and, as a result, we are most interested in the surficial layers. We will, therefore, begin with a description of the uppermost, youngest, and most well-known layers, and then discuss the underlying strata. Our investigation of the subsurface is limited to a depth of about 100 feet because (1) this is probably the maximum depth to which dredging is practiced, (2) core and boring samples rarely extend to depths greater than 70 feet, and (3) the most prominent subsurface features that can be detected seismically are usually seen above at 130 feet, and only in a few places can any structures be detected below this depth (Kastens, Fray, and Schubel, 1978).

There are four types of information used in this report. These are:

(1) the surficial sediment distribution on the floor of the Lower Bay,

(2) the records of cores and borings that have been recovered in the Lower Bay floor,

(3) seismic reflection survey lines that have been run in the Lower Bay,

(4) geologic reports of the areas surrounding the Lower Bay, i.e., Staten Island, western Long Island, northern New Jersey, and the New York Bight.

After a brief discussion of the

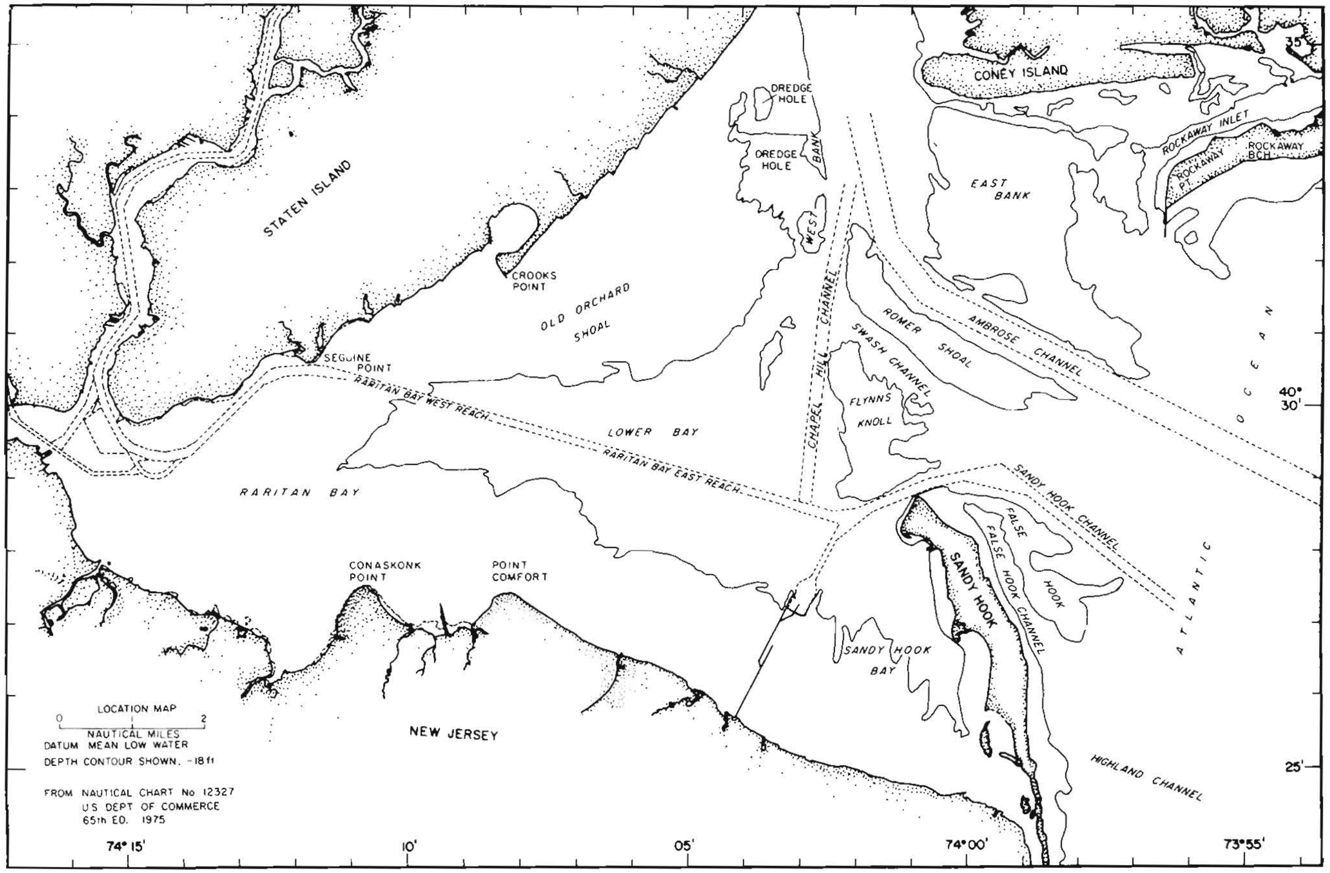


Fig. 1. Index map of the study area in the Lower Bay, New York Harbor.

quantity, quality, and limitations of each of these sources, we will describe the vertical distribution of sediments under the Bay floor using generalized cross-sections and then estimate the volumes of material present in each of the sand bodies identified in the Bay.

Sources of Information

Surficial Sediment Distribution

Kastens, Fray, and Schubel (1978) have described the sediment types over the entire Bay floor; and Jones, Fray, and Schubel (1979) have made a more detailed examination of the eastern Bay. The latter report identified 25 sand and mud bodies (Fig. 2). In Raritan Bay, four major sedimentary regions were first defined by Nagle (1967); these sediment bodies are called the Sandy Hook Bay Muds, the West Raritan Bay Muds, the Keansburg Sands, and the Lower Bay Sands. Using the additional data from Kastens, Fray, and Schubel (1978) and unpublished data from Bell Laboratories (R. Allen, Bell Laboratories, New Jersey, personal communication), the boundaries of the sedimentary regions in Raritan Bay have been modified and included on Fig. 2. An additional minor sand body, the Ward Point Sands, has been added at the southern tip of Staten Island. The outlines of these sediment bodies are included on all subsequent figures for reference.

Cores and Borings

Many cores and borings have been taken in the Lower Bay by other investigators. These samples were usually less than 70 feet long. (Depths, or elevations, are given with respect to mean sea level.) The quality of the descriptions varies greatly and the distribution of sites is not uniform. Furthermore, because the Bay floor has been shaped by wandering rivers and tidal flows, the sediment types change over very short distances. Often two cores less than one mile apart show a different sequence of layers and, over large distances, correlations can only be done with coarse, general divisions.

The records used in this study are from five sources. These are:

(1)A series of 21 borings made along the New Jersey coast (U.S. Army Corps of Engineers, 1962). The maximum penetration was to a depth of 40 feet and the sediments were described by grain-size classes.

(2)A series of 12 borings taken along the Staten Island shore (U.S. Army Corps of Engineers, 1964). The maximum penetration of these was 95 feet and the layers were described by grain-size classes.

(3)A collection of 33 cores and borings compiled by K. Kastens (Marine Sciences Research Center, personal communication); the locations, sources, and descriptions of these samples are given in Appendix I. These samples typically reached to a depth of about 50 feet but some were much deeper. The maximum depth was 105 feet.

(4)A transect of test borings that was made for a proposed bridge between Conaskonk, New Jersey and Seguine Point, Staten Island. These were recovered in 1930-1931 and discussed by MacClintock and Richards (1936, p. 315). They are also described in a report by Fray (1969) that gives the grain-size class and the color of the sediments. The deepest boring reached -180 feet through 155 feet of sediment.

(5)A series of borings taken along or near the Naval Weapons Station Earle Piers (as reported by the Northern Division, Naval Facilities Engineering Command, 1979). These were described by grain-size class and color. The silts and clays were also described as "soft," "very soft," "sticky" or "very sticky." The longest boring reached to -50 feet but they were typically 20 feet long.

The location of these cores and borings are shown in Fig. 3.

Seismic Reflection Profiles

Three series of seismic reflection profiles have been made in the Lower Bay. The most extensive survey was conducted by the Marine Sciences Research Center and has been reported by Kastens, Fray, and Schubel (1978). This consisted of 92 n. miles of tracks mostly in the eastern part of the Lower Bay. Additional tracks were done by E G & G Incorporated (Sieck, 1965). These run eastward across Raritan Bay to Rockaway Point and up the Ambrose Channel. The third series was done by CERC (Williams and Duane, 1974). For the present study a cursory examination was made of all these records but only the most suitable were examined in detail.

It must be remembered that subsurface structures seen by the acoustic instruments are reflecting interfaces that mark the boundaries between two layers of different acoustic impedance. Acoustic impedance is the product of the density of the sediment and the velocity of sound in that sediment. Changes in the acoustic impedance often occur between sediment layers of different types. The structures seen with the seismic equipment are called "reflectors," "acoustic horizons," or, simply "horizons." In this report, prominent reflectors will be interpreted to show changes in the sediment type. It must be remembered, however, that all the reflectors seen with the seismic equipment may not correspond to changes in the sediment type as recognized by direct sampling nor may each change in sediment type be detected as an acoustic reflector.

In some areas, deep reflectors are hidden under sediment layers that the sound signal is unable to penetrate. Such acoustically opaque layers may be gaseous muds or very strongly reflective interfaces. This is the case, for example, very near the sediment-water interface. The instrument is theoretically capable of resolving layers about 1.5 feet thick. The reflection of the signal off the sea floor, however, is so strong that it obscures any layering that may exist within several feet of the surface. Dredged areas or dredged spoil deposits are examples of surfaces that are often acoustically opaque. Penetration into the Bay floor is typically less than 170 feet and discrete reflectors are rarely continuous for more than a mile (Kastens, Fray, and Schubel, 1978). To interpret the records it is necessary either to associate a particular reflector on the records with a change in sediment type in a core or boring or to trace a reflector to where it outcrops at the surface and sample it directly. Because of the discontinuous nature of the reflectors observed in the Lower Bay, this can be done in only a few places in the Bay. Furthermore, the quality of different records made in the same place is often very different because of changes in the instrument settings, the sea state, or the towing configuration.

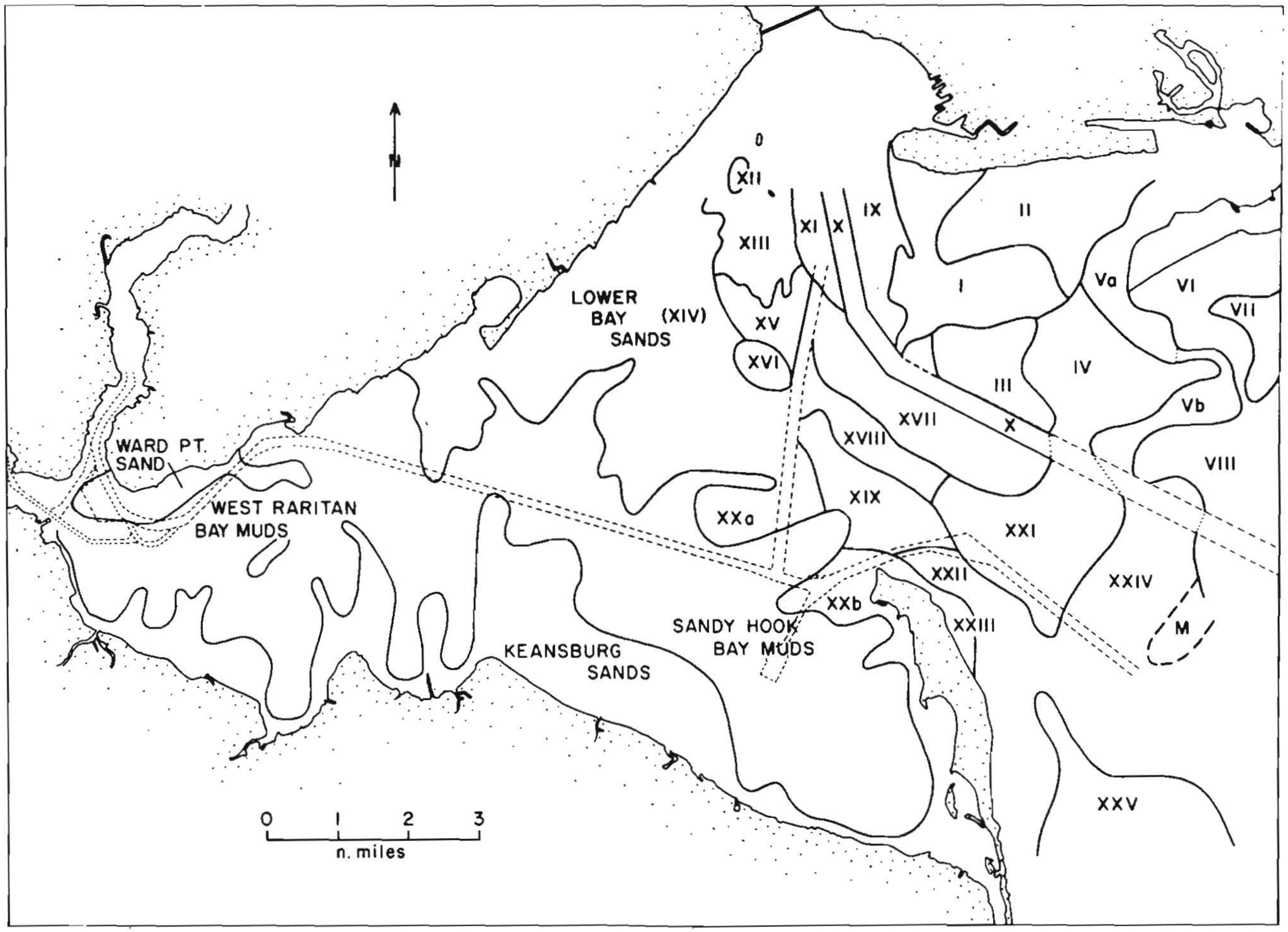
Geology of Surrounding Areas

Although many excellent investigations have been done, six publications were found to be most useful for this report. These are Minard (1969); MacClintock and Richards (1936); Perlmutter and Arnow (1953); Richards, Olmsted, and Ruhle (1962); Williams and Duane (1974); and Suter, deLaguna, and Perlmutter (1949). All of these except Williams and Duane discuss the stratigraphy of those areas of New York and New Jersey bordering the Bay. The geology has been determined by surface mapping supplemented with the study of well logs and, in the case of Minard (1969), borings along Sandy Hook. Williams and Duane (1974) studied the sediments in the New York Bight using seismic techniques and cores. The comparative stratigraphy of northern New Jersey and western Long Island was summarized by Williams and Duane and is repeated here (Table 1).

RESULTS

Cross-sections

We will begin by presenting three interpreted sections through the floor of the Lower Bay (Fig. 4). Two of these (AA'A" and BB'B") are based primarily on


N
LOWER
BAY
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BAY MUDS
I
II
III
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Va
Vb
VI
VII
VIII
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X
XI
XII
XIII
XV
XVI
XVII
XVIII
XIX
XXa
XXb
XXI
XXII
XXIII
XXIV
XXV
M
0 1 2 3
n. miles

Fig. 2. Surficial sand deposits in the Lower Bay

I.	medium sand
II.	fine sand
III.	fine sand
IV.	coarse-to-very coarse sand with pebbles and shell
Va.	medium sand with shell
Vb.	medium sand
VI.	medium sand
VII.	very fine sand
VIII.	fine sand
IX.	fine sand and mud
X.	fine-to-medium sand
XI.	fine sand
XII.	mud and very fine sand
XIII.	mud
XIV.	Lower Bay Sands, fine-to-medium sand
XV.	fine-to-very fine sand
XVI.	mud
XVII.	medium sand
XVIII.	mud, mussel shells, hydrocarbons
XIX.	medium sands
XXa,b.	fine sand
XXI.	medium-to-very-coarse sand with pebbles
XXII.	medium sand
XXIII.	fine sand
XXIV.	medium sand
XXV.	coarse sand with pebbles and shell
M.	soft muck with organic matter

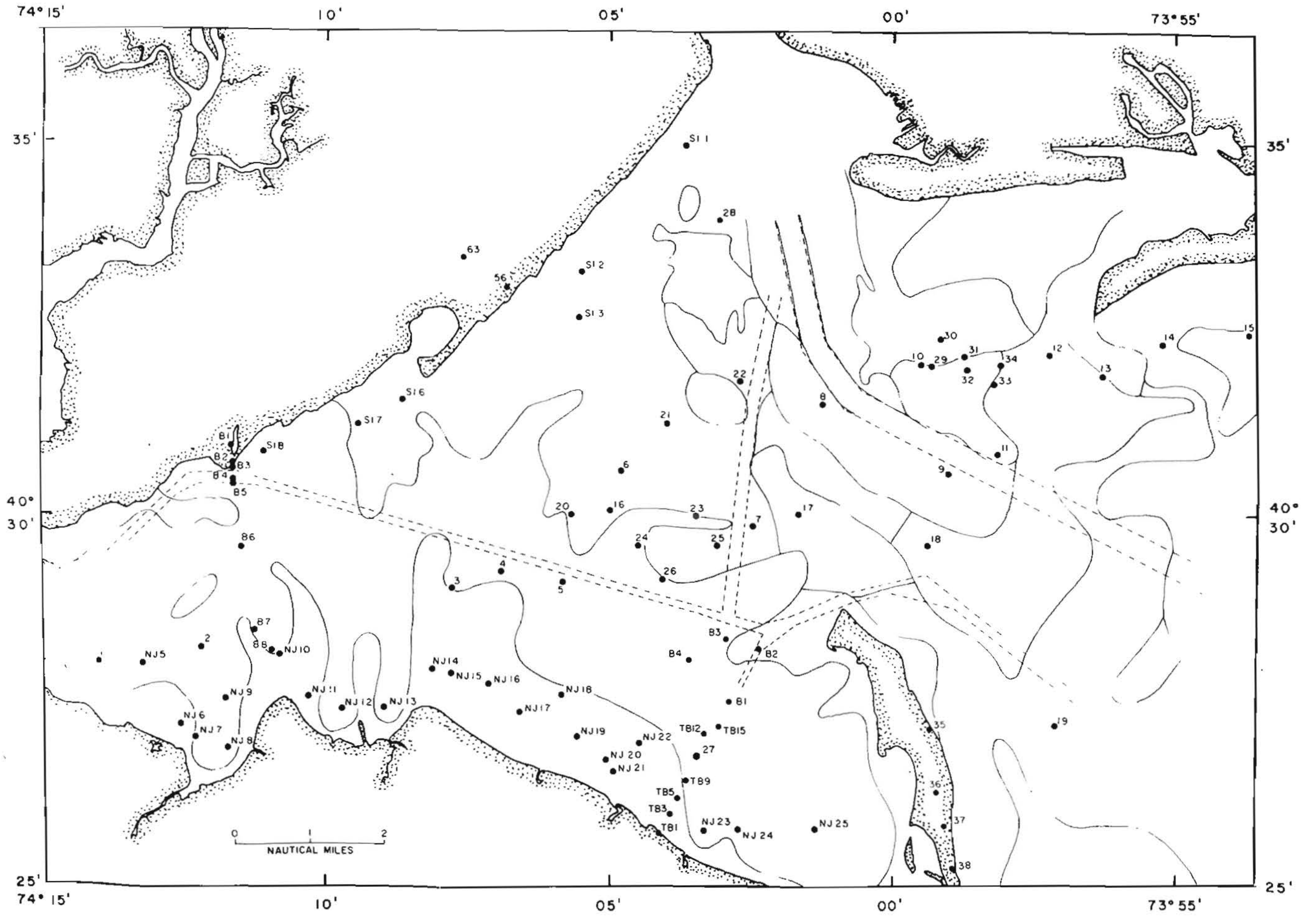

Fig. 3. Locations of cores and borings included in this project. The positions of the sand bodies described in Fig. 2 are also shown.

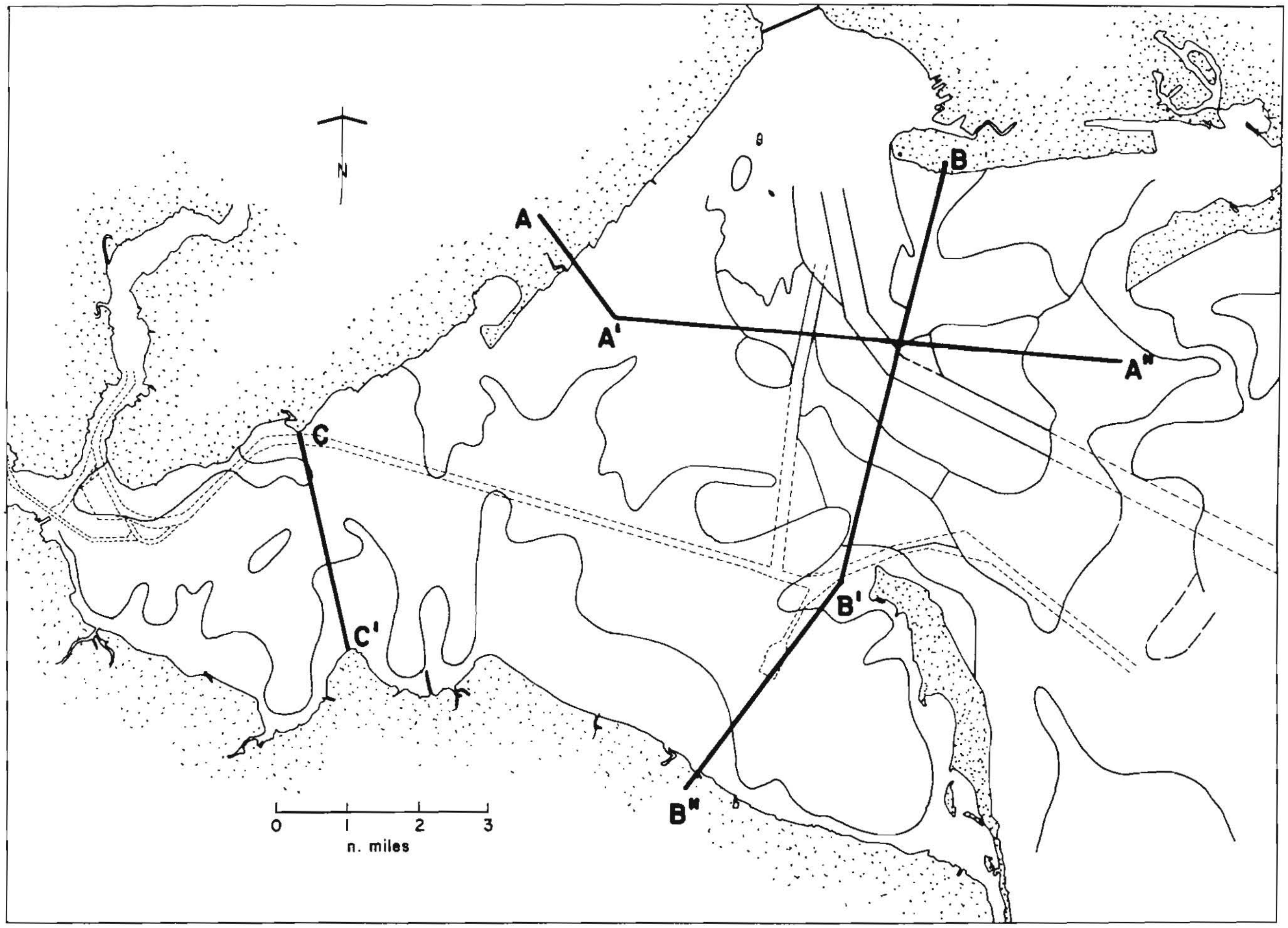

Fig. 4. Location of the cross-sections. The positions of the sand bodies described in Fig. 2 are also shown.

Table 1. Stratigraphy of the Lower Bay, New York Harbor (after Williams and Duane, 1974)

Period	Epoch	Age (Years)	Northern New Jersey	Western Long Island
Quarternary	Holocene	$<12.0 \times 10^3$	Silt and reworked alluvial detritus	Silt and reworked glaciofluvial detritus
	Pleistocene	$< 1.5 \times 10^6$	Alluvial sand and gravel	Harbor Hill
				Glacial Till
				Ronkonkoma
				Glacial Till
			Cape May Sand*	Gardiners Clay*
				Jameco Gravel*
Tertiary	Pliocene	6.0×10^6	Cohansey Sand	
	Miocene	17.0×10^6		
	Paleocene	60.0×10^6	Vincentown Sand	
			Hornerstown Sand	
Cretaceous	Upper Cretaceous	75.0×10^6	Tinton Sand	
			Red Bank Sand	
			Navesink Sand	
			Mt. Laurel Sand	
			Wenonah Sand	
			Marshalltown Sand	
			Englishtown Sand and Clay*	
			Woodbury Clay	
			Merchantville Sand	
			Magothy Sand*	Magothy Sand*
				Raritan Clay*
				Lloyd Sand

*Specifically referred to in this report

two seismic reflection profiles of Kastens, Fray, and Schubel (1978). These records have been supplemented with records of nearby cores and borings, records of adjacent or intersecting seismic reflection profiles, and the onshore stratigraphy. The third section (CC') was drawn by MacClintock and Richards (1936) from the records of borings between Conaskonk, New Jersey and Seguine Point, Staten Island.

Section AA'A", Fig. 5

This section begins at A on Staten Island. It overlaps a geological cross-section through Staten Island given by Perlmutter and Arnow (1953). The onland part of AA'A" is based on two well logs and the interpretation of these logs by Perlmutter (Perlmutter and Arnow, 1953). The locations of the wells are labelled 63 and 56 on Figs. 3 and 5. On Staten Island, a thin soil layer is underlain by a layer of red sand about 8 feet thick. The Bay floor along the western shore of Staten Island to a depth of about 8 feet probably is composed of this sand. Below this layer is a layer of fine-to-medium sand about 25 feet thick. The fine-to-medium sand layer becomes progressively

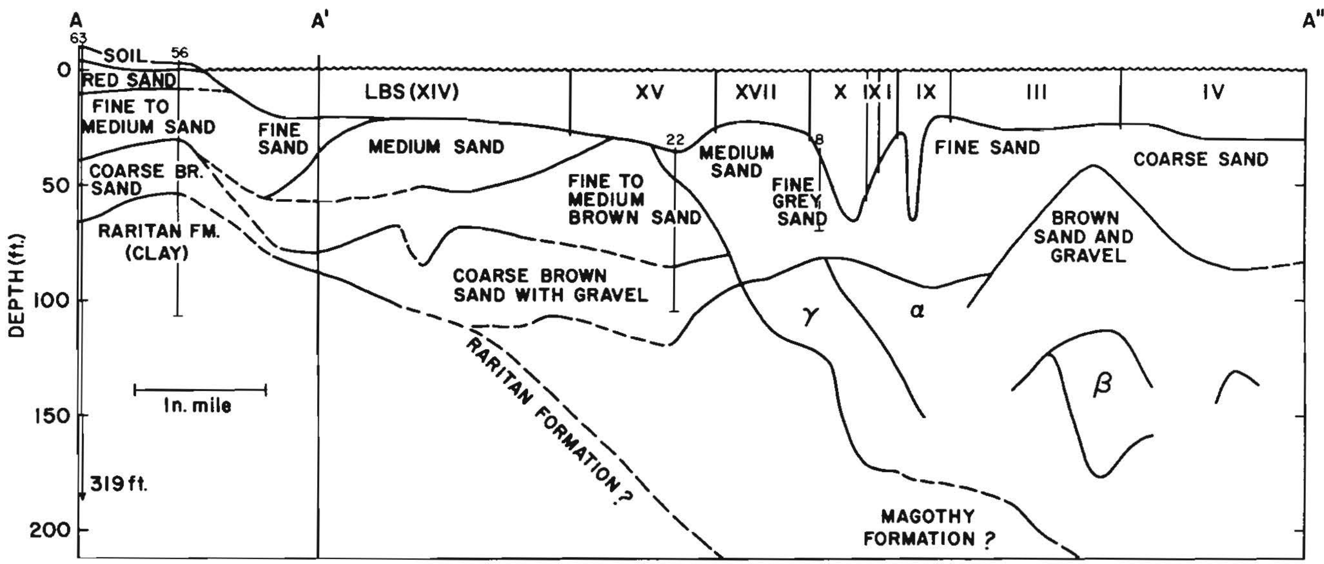

Fig. 5. Cross-section AA'A" from Staten Island to the East Bank. The positions of the surficial sand bodies are indicated by the appropriate Roman numerals and LBS (Lower Bay Sands). Thin vertical lines within the section show the locations of nearby cores and borings.

thinner seawardly, and its upper surface forms the Bay floor out to a distance of about 1.4 n. miles at which point it grades into a layer of medium sand about 30 feet thick. These two sand bodies comprise the Lower Bay Sands. Under Staten Island, the fine-to-medium sand is underlain by brown or reddish brown, coarse sand and gravel that are about 25 feet thick. This sand and gravel has been identified as glacial outwash sand by Perlmutter and Arnow (1953). To the east, the outwash sand layer underlies the Lower Bay Sands and achieves a maximum thickness of 85 feet about 3.5 n. miles offshore. At this point it apparently outcrops to form a small section of the Bay floor in the No. XV Sand and it is subdivided into two layers, a layer of fine-to-medium sand overlying a layer of coarse sand and gravel. Two layers are seen as acoustic reflectors on the seismic profile and the composition of these layers is inferred from Core 22 which shows a thin layer of gray (marine) sand over brown sand which coarsens downward. The outwash sands overlie Cretaceous sands, silts, and clays of the Raritan Formation under Staten Island. The surface of the Raritan slopes to the east. A reflecting horizon seen between 0.6 and 1.6 n. miles offshore at a depth of 85 to 105 feet may be the top of the Raritan under the Bay floor. Further to the east the position of the Raritan has been inferred from the interpolation of the contours of the Raritan surface under Staten Island (Perlmutter and Arnow, 1953), under New Jersey (Richards, Olmsted, and Ruhle, 1962) and under Long Island (Suter, deLaguna, and Perlmutter, 1949). Romer Shoal (No. XVII Sand) is made of medium-to-fine sands. Core 8 showed no changes in sediment type, at least to a depth of 61 feet, and the first acoustic reflector is at -82 feet. This horizon is the top of a layer labelled "gamma" (γ) on Fig. 5. The composition of this layer is not known but it may be clay (the Gardiners Clay?). The identification of γ is, unfortunately, uncertain and it will be discussed in more detail later in this report. The lower boundary of γ corresponds to the location of the top of the Magothy Formation as inferred from the onshore stratigraphy.

East of the Ambrose Channel, the Bay floor is composed of the top of a layer of marine sands about 66 feet thick. This layer becomes more coarse to the east and is penetrated, but not interrupted, by a subsurface mound of coarse, brown sand and gravel. This mound comes to within 17 feet of the Bay floor and is not only evident on the seismic records but also is seen in the bottoms of Cores 9, 11, 12(?), 29, 30, 31, 32, 33, and 34 which are within three-quarters of a mile north of the section. The acoustic horizons seen below the mound and immediately to the west are unidentified. These two subsurface layers (α and β) will be discussed later.

Section BB'B", Fig. 6

This section starts at B (Fig. 4) on Coney Island. There is only one deep well record available on Coney Island but from other well logs in Kings County, Suter, deLaguna, and Perlmutter (1949) have constructed contour maps of the surfaces of the major geologic formations. These show glacial sands to a depth of 144 feet overlying the Gardiners Clay that, in turn, sits on the Jameco Gravel at -190 feet. Offshore we find a layer of gray fine sand (No. I Sand) reaching a maximum thickness of 48 feet. The seismic record is obscured just north of the Ambrose Channel but, based on Cores 29 and 30, we infer that the gray sands overlie brown sands and gravels and that the surficial layer thins to a thickness of less than 15 feet by the time it reaches the Channel. On the seismic record the top of the Gardiners Clay is seen briefly at -148 feet near the Coney Island Shore. The nature of the sediment between the top of the Gardiners Clay and the bottom of the outwash sands and gravels at -59 feet is unknown. The horizon interpreted as the top of the

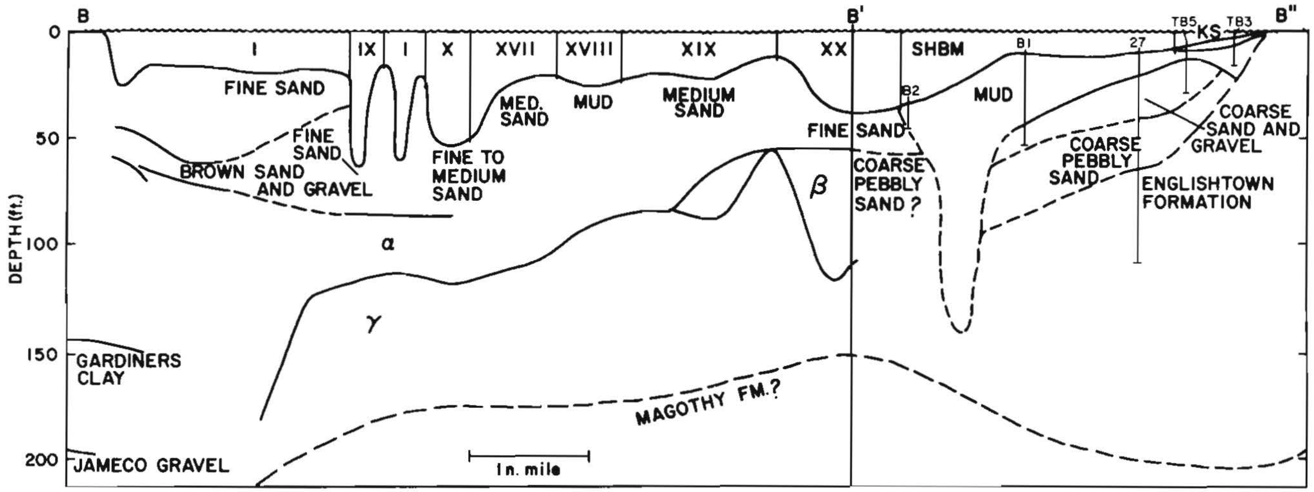

Fig. 6. Cross-section BB'B" from Coney Island to New Jersey. The positions of the surficial sand bodies are indicated by the Roman numerals, SHBM (Sandy Hook Bay Muds) and KS (Keansburg Sands). Thin vertical lines within the section show the locations of nearby cores and borings.

Gardiners Clay disappears on the seismic record and is replaced about 1.4 n. miles offshore by a strong reflector that rises sharply from depth to a level of about -115 feet. This is the top of the γ layer. This reflector continues to the Raritan Channel rising slightly. No other structure is seen above it. This implies that the surficial, marine sands achieve a thickness over 80 feet in some places between the Ambrose and Raritan channels. The subsurface structure seen just north of the Raritan Channel remains unidentified.

There are no seismic records available between B' and B". This part of the section is inferred from the layering found in Core 27 and interpreted by Minard (1969), the borings along the Naval Weapons Station Earle Pier (Northern Division, Naval Facilities Engineering Command, 1979), the contour maps of the surfaces of geologic formations in New Jersey (Richards, Olmsted, and Ruhle, 1962), a section through the length of Sandy Hook done by Minard (1969), and the section CC' (Fig. 7) from MacClintock and Richards (1936). The section CC' (Fig. 7) shows a very thick deposit of marine mud, filling a trench about 1 mile south of Staten Island. This trench was evidently excavated by the ancestral Raritan River before the Bay became an arm of the sea (MacClintock and Richards, 1936). The valley was subsequently filled with muds, which have also accumulated to a thickness of 10 to 15 feet over the bottom of the Bay outside of the ancient channel. The location of this filled channel further eastward is uncertain. The muds at, or very near, the Bay floor are acoustically opaque; the type of reflection seen on the seismic records through this area is usually identified with gaseous sediments and may be buried or submerged marsh deposits. Core 5, however, shows mud to a depth of at least 69 feet which suggests that it was taken near the axis of the buried channel. Under Sandy Hook, about midway along its length, two mud bodies are found (Minard, 1969). These deposits are about 10,000 years old and they lie at depths of -100 and -131 feet. On the ocean side of Sandy Hook, the Highland Channel extends in a southwest orientation from the midpoint of Sandy Hook. This channel appears to be the remnant of the ancient Raritan River (Williams and Duane, 1974). It seems likely that the mud deposits under Sandy Hook are remnants of the mud infilling of the ancient channel that have subsequently been eroded and overlain with the beach sands of Sandy Hook. It seems reasonable, therefore, that the Sandy Hook Bay Muds and the West Raritan Bay Muds mark the position of the buried channel and that these muds can be expected to be between 100 and 160 feet thick. South of the inferred position of the old Raritan River valley a thin layer of mud overlies the sands of the Keansburg sand body which appears to be about 35 feet thick at Core 27 overlying Cretaceous clays (Englishtown Formation, Minard, 1969).

Volume of Surficial Sand Reserves

Based upon the data and the interpretations presented in the cross-sections, the volumes of each sand body on the Bay floor may be estimated. Some of the deposits described by Kastens, Fray, and Schubel (1978) lie outside of the study area of this report. Within the study area, the estimates in some places will be better than in others because the information is not uniform either in extent or quality. Nevertheless, the detailed estimates presented here are the best available at this time.

No. I Sand. This sand deposit covers an area of 2,680 acres. This deposit is penetrated by three cores (29, 30, and 31). Although the No. I Sand is described as medium sand, the cores show medium-to-coarse sand. The seismic reflection profiles through the area show a homogeneous surficial layer 36 feet thick reaching a depth of about 52 feet below sea level. The total volume of sand in this deposit is

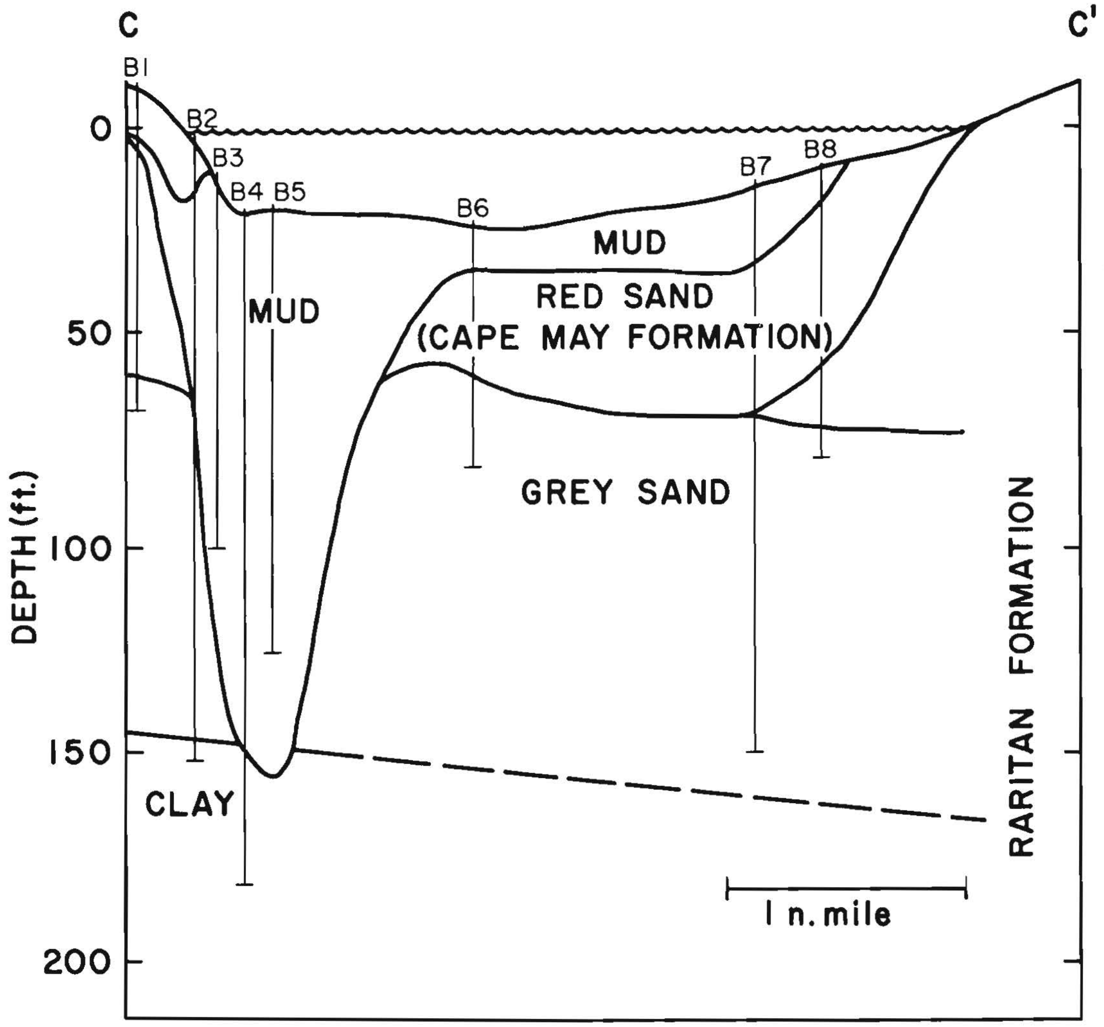

Fig. 7. Section CC' from Staten Island to New Jersey (after MacClintock and Richards, 1936). Thin vertical lines show the positions of borings along this section.

then 156 million cubic yards. Under this deposit there is a layer of brown, coarse sand and gravel 20 feet thick extending to a depth of 72 feet. From here to the buried surface of the Gardiners Clay at about -148 feet is an acoustically homogeneous layer (α) which may also be sand and gravel. Under the southern part of the No. I Sand, the α layer lies upon the γ layer at -115 feet.

No. II Sand. There are no cores available in this area of fine sand. A seismic profile through this area suggests that the subsurface structure is similar to that under the No. I Sand (Kastens, Fray, and Schubel, 1978). Fine sand would, therefore, be found from the Bay floor (-16 feet) to about -52 feet, a thickness of 36 feet. The area of this sand deposit is 2,960 acres, so that the volume of sand contained here is 172 million cubic yards. This sand body sits on a layer of brown, coarse sand and gravel about 5 feet thick. The top of the sand and gravel layer lies at -49 feet in the north and at -59 feet in the south under the No. II Sand. Sands and gravels would probably be found to a depth of about -150 feet where the top of the Gardiners Clay is likely to be found.

No. III Sand. The No. I Sand grades to the south into a deposit of fine sand, the No. III Sand. This deposit covers an area of 1,250 acres. It is sampled in five cores (8, 10, 11, 29, and 33). In the north and west of the No. III Sand, fine sand apparently is found from the Bay floor at -16 feet to a depth of about 85 feet. In the south, the water depth increases to 66 feet and the sand layer is only 20 feet thick. The eastern edge of this deposit overlies a mound of brown, coarse sand and gravel (Fig. 4). The thickness of the surficial fine sand deposit is about 23 feet thick over the peak of the mound. The typical thickness of the No. III Sand is about 40 feet, hence the total volume is 81 million cubic yards.

No. IV Sand. The No. IV Sand lies in Rockaway Inlet. The seismic reflection profiles over this area are poor although, in places, a horizon at -130 feet can be seen (Gardiners Clay?). Two cores (12 and 13) were taken in this deposit and each shows several thin layers of sand, silty sand, silt, and gravel (see Appendix). Because of this complicated layering more detailed information would be needed in order to estimate the volume of the surficial deposit.

No. Va Sand. The No. Va Sand lies at the end of Rockaway Point. No cores were taken here and the seismic reflection records are of poor quality. On the records, however, it appears that the bottom of the surficial layer lies at a depth of 66 feet in the north and drops regularly to -100 feet in the south. The average thickness is about 30 feet. The No. Va Sand has an area of 1,200 acres and, therefore, its volume is 58 million cubic yards. On some sections of the seismic reflection profile through this area, a reflector is seen at about -165 feet; this may be the top of the Gardiners Clay.

Nos. Vb, VI, VII, VIII Sands. These four sand bodies lie outside of the study area. The subsurface structure was not investigated and no volume estimates were made here.

No. IX Sand. No cores were available in this sand body. The seismic profiles through the area show that this layer of fine sand and mud has an average thickness of 44 feet; its bottom boundary lies at -74 feet in the north and about -92 feet in the south. The No. IX Sand covers an area of 1,420 acres and has a volume of about 101 million cubic yards. The composition of the sediments below this layer is not known. The buried surfaces of the α and γ layers lie at about -85 and -120 feet respectively.

No. X Sand. This fine-to-medium sand makes up the floor of the Ambrose Channel. The seismic reflection profiles show the channel floor to be covered with large underwater dunes or sand waves. These may be over 6 feet high. They are asymmetric with their steep slopes facing up-channel toward New York City. Since the Channel has been dredged, these bedforms indicate present-day tidal transport of sand into the Bay. The No. X Sand covers an area of 1,425 acres and the typical thickness of the surficial layer is about 30 feet thick. The total volume in this deposit is, therefore, about 69 million cubic yards.

No. XI Sand. This layer of fine sand is adjacent to the Ambrose Channel and the subsurface structure disclosed in the seismic records (Kastens, Fray, and Schubel, 1978) suggests that it may be a sand deposit that has infilled an older channel. In the south of this area, the No. XI Sand fills a trough that extends to a depth of 87 feet. The average thickness is 30 feet but the thickness ranges from 22 feet in the north to 54 feet in the south over the subsurface trough. The No. XI Sand covers an area of 570 acres and has a volume of about 28 million cubic yards. This surficial layer may be underlain by another layer of sand, but no core samples have been taken. In Core 28 just to the west of the No. XI Sand, clay is found at a depth of -49 feet. This clay may extend at depth under the No. XI Sand.

Nos. XII, XIII, and XVI Muds. These pockets of mud are found on the floors of dredged pits. Thin layers of marine mud have accumulated naturally in Areas XII and XIII. In Area XII the mud is about 1 foot thick. It is about 3 feet thick in Area XIII (Bokuniewicz, 1979). Areas XII and XIII cover 93 acres and 1,025 acres respectively, so that the total volumes of mud are 0.15 million cubic yards and 5 million cubic yards. These pits have been mined into the Lower Bay Sands which probably lie immediately under the mud layers. The No. XVI Muds are, in part, dredged sediments that have been used to backfill a dredged hole. Mud has probably also accumulated naturally here to a thickness comparable to that of Deposits XII and XIII. The floors of all of these mined pits are opaque to the seismic signals and, as a result, the subsurface structure cannot be seen. There is, however, seismic evidence to suggest that the clay layer found in Core 28 extends under the No. XII Mud at a depth of about 50 feet. Dredging operations in the area uncovered mud at about this depth (James Marotta, New York Office of General Services, personal communication). The southern extent of this clay layer remains, however, undetermined.

No. XIV or the Lower Bay Sands. The Lower Bay Sands cover an area of 12,880 acres. Further sampling would probably show that this area could be subdivided into smaller distinct sand bodies. Near Staten Island, a layer of fine sand is found with an average thickness of 27 feet and farther to the east there is a layer of medium sands about 24 feet thick. These thicknesses are based on the seismic reflection profile that was used to construct the cross-section AA'A". They do not account for variations in the section to the north and south. The seismic records parallel to the Staten Island shore are poor and no definite trends were identified. If the typical thickness of the composite sand body is taken to be 26 feet, the volume of both fine and medium sand in this deposit is 540 million cubic yards. Under the surficial layers, there is a wedge of outwash sand that thickens to the east. The outwash sand apparently sits on top of the Raritan Clay. The surface of the Raritan Clay is at a depth of about 82 feet in the west of the area covered by the Lower Bay Sands and at 115 feet in the east.

No. XV Sand. The subsurface wedge of brown outwash sand under the Lower Bay Sands outcrops to form part of the No. XV Sand. These are fine sands which coarsen downward. The average thickness is 79 feet here and these sands presumably lie on Cretaceous sediments (clays?) at a depth of 115 feet. The area of the No. XV sand body is 1,000 acres and the total volume is 127 million cubic yards.

No. XVII Sand. This sand deposit makes up Romer Shoal. Core 8 penetrates the Shoal and shows a uniform sand layer throughout its length. The Shoal appears to be a single sand deposit about 60 feet thick. It covers an area of 2,510 acres and has a volume of 243 million cubic yards. It sits on the γ layer at -85 feet.

No. XVIII Muds. These muds lie on the bottom of the Swash Channel. No cores were taken here and the seismic records are poor. It is likely that the mud is a thin blanket that has accumulated in the Channel over medium sands as are found at the Bay floor both north (No. XVII Sand) and south (No. XIX Sand) of the No. XVIII Muds. The bottom of the sand layer is at -89 feet overlying the γ layer. The area of this deposit is 1,025 acres and it has a thickness of about 64 feet. If the mud layer is, in fact, very thin, the volume of medium sand under the Swash Channel is 106 million cubic yards.

No. XIX Sand. This is a deposit of medium sand although Core 17 which penetrates this deposit shows a layer of silt. This layer probably indicates a transition zone between the No. XIX Sand and the Sandy Hook Bay Muds. The exact location of the boundary between these two deposits might be expected to vary. The layering seen in the cores is not discernible in the seismic reflection records. The seismic profiles show that the surficial sediment layer has a mean thickness of 52 feet extending to a depth of 85 feet in the north of the No. XIX Sand and 50 feet in the south where it is thinner. This deposit covers an area of 1,720 acres and has a volume of about 144 million cubic yards. Most of this volume is likely to be medium sand.

No. XXa Sand. The XXa Sand has been included in the Lower Bay Sands. Cores taken in this area (Nos. 7, 23, and 25) show a surficial layer of fine sand 8 to 11 feet thick. The layering is complicated, however; Core 7 shows a layer of clay, as well as sand and pea gravel, and clayey gravel. This probably indicates that the area is one of transition between the different types of sediment around it. In general the fine sands are expected to lie on brown sands and gravels (for example, Core 25). The seismic records show the average thickness of the surficial layer here to be about 25 feet. This is consistent with the thickness of the Lower Bay Sands measured farther to the north.

No. XXb Sand. The XXb Sand lies at the point of Sandy Hook. There is no core or seismic data from this area, but Minard(1969) expects a thick layer of "beach sand" to be found here. His generalized section along Sandy Hook shows sand to a depth of 160 feet. The XXb Sand covers an area of 1,700 acres. If its average thickness is 140 feet, the volume of this deposit is 439 million cubic yards.

No. XXI Sand. There are no seismic reflection tracks across this sand body and the only core (18) that penetrates this deposit is very short. Core 18 shows an 8 foot thickness of medium-to-coarse sand over a 2 foot layer of silty sand. More medium sand was found under the silty sand at the bottom of the core. The area of this deposit is 2,975 acres. If it is at least 8 feet thick, the total volume would be 38 million cubic yards.

Nos. XXII and XXIII Sands. The vertical extent of these deposits is expected to be similar to the thickness of "beach sand" under Sandy Hook as inferred by Minard (1969). Minard's section shows this layer of sand to reach a depth of 190 feet just north of Sandy Hook; typically the thickness is about 140 feet. The Nos. XXII and XXIII Sands cover 3,465 and 510 acres respectively and, therefore, should contain 783 million and 115 million cubic yards. Minard (1969) encountered clay pockets at depth midway along Sandy Hook, and clay may underlie the No. XXII Sand in the vicinity of the Highland Channel.

Nos. XXIV and XXV Sands. These sand bodies lie outside of the study area of this report and no estimates of their volumes will be made.

Sandy Hook Bay Muds and the West Raritan Bay Muds. As discussed earlier, these muds have probably been deposited in an ancient channel of the Raritan River. The mud layers should be expected to be very thick (150 feet) along the axes of these deposits with thinner layers along the edges. This layer of marine mud overlies the red sands of the Cape May Formation under Raritan Bay. Under Sandy Hook Bay it overlies a pebbly sand (Cape May Formation?).

Keansburg Sands. This sand body follows the New Jersey coast and it has been sampled by many short cores. In some places, cores show this sand deposit to be at least 23 feet thick. The sand is often found interlayered with mud. The Keansburg Sands probably have an average thickness of about 14 feet, but this value is interpolated from the generalized cross-sections and has not been verified with cores or seismic reflection profile. The Keansburg Sands cover an area of 8,815 acres. If the thickness of this deposit is 14 feet, its volume would be 199 million cubic yards.

Ward Point Sand. This sand body covers an area of 1,440 acres at the southern tip of Staten Island. It is probably a thin layer extending from Staten Island over the Raritan Bay Muds. The borings along Section CC' show such a sand layer about 13 feet thick. If the Ward Point Sand has the same thickness, its volume is 30 million cubic yards.

SUMMARY AND DISCUSSION

Table 2 summarizes the areas, the probable thicknesses and the estimated volumes of the eighteen surficial sand deposits in the Lower Bay. These sand deposits have a total volume of about 3,429 million cubic yards and there is undoubtedly more sand and gravel below these layers. In some areas the bottoms of the sand and gravel deposits have been identified. Under the north and east part of the East Bank, the sand deposits lie on the Gardiners Clay and the thickness of the sand deposits is limited to about 117 feet (Kastens, Fray, and Schubel, 1978). Seaward of Staten Island the sands extend to the top of the Raritan Formation, and the sand reserves therefore have a thickness of 62 feet near the Staten Island shore and probably over 100 feet farther offshore. In the northern part of the West Bank, sand sits on a clay layer at -49 feet; and near the New Jersey shore in Sandy Hook Bay, sand and gravel layers overlie sandy clays of the Englishtown Formation at a depth of 66 feet. Future investigations should better define the extent and subsurface topography of these clay deposits.

In the center of the Lower Bay, sand layers overlie three unidentified layers. These are called α, β, and γ on the cross-sections (Figs. 5 and 6). On section BB'B", the α layer overlies the Gardiners Clay in the north. No extensive clay layers have been described in this area above the Gardiners Clay, and α is most likely composed primarily of sands and gravels. Near point B', the β layer appears under the surficial sands. It infills an irregular topography below it. This layer may be the northward extension of the coarse sediments found in Core 27, and it is possibly the Cape May Sand. It is also possible, however, that it is a clay layer, perhaps a remnant of the muds which infill the old Raritan River valley. Both the α and β layers overlie γ. Near Coney Island the surface of γ is approximately at the same level as the Gardiners Clay. It is not continuous with the reflector that had been identified as the surface of the Gardiners Clay. Based on fragments of seismic records to the east and west of the BB'B" section, we believe

Table 2. Estimated volumes of surficial sand deposits under the Lower Bay of New York Harbor

Deposit (Fig. 2)	Description	Area (Acres)	Thickness (Feet)	Volume (Millions of Cubic Yards)
I	medium sand	2,680	36	156
II	fine sand	2,960	36	172
III	fine sand	1,250	40	81
Va	medium sand	1,200	30	58
IX	fine sand and mud	1,420	44	101
X	fine-to-medium sand	1,425	30	69
XI	fine sand	570	30	28
LBS	fine and medium sand	12,880	26	540
XV	fine-to-very-fine sand	1,000	79	127
XVII	medium sand	2,510	60	243
XVIII	medium sand(?)	1,025	64	106
XIX	medium sand	1,720	52	144
XXb	fine sand	1,700	160	439
XXI	medium-to-very-coarse sand	2,975	8	38
XXII	medium sand	3,465	140	783
XXIII	fine sand	510	140	115
KS		8,815	20	199
WPS		1,440	13	30
			TOTAL	3,429

that the Gardiners Clay pinches out and is replaced by γ. The composition of γ, however, remains unknown, and it should be the subject of future studies.

Sand and gravel resources under the Lower Bay are plentiful. The total resource, however, is not available to be exploited. There are many reasons for this. First of all, the Bay is a diverse resource and there are many conflicting, but equally important, uses of this resource. Submarine mining must coexist with shipping, fishing, recreational boating, and other activities. Mining must be carefully controlled to insure that it does not have a significant adverse effect on the environment; mining too close to the shore, for example, might aggravate shore erosion. The amount of sand and gravel that is available to be mined is also limited by the quality of the sediment. The subsurface information is not adequate to say how much of the total resource is usable for a specific need. Further exploration and study is needed to establish acceptable mining zones and regulations.

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APPENDIX

CORES AND BORINGS IN THE LOWER BAY OF NEW YORK HARBOR

Compiled by K. A. Kastens

LOCATION OF CORES

Report Core No.	Original Core No.	Latitude	Longitude	Source
1	243	40°28'02.37"	74°14'04.80"W	Sieck, 1965. Boring by McClelland Engineers.
2	15	40°28'13.21"N	74°12'12.40"W	"
3	8	40°29'03.93"N	74°07'47.98"W	"
4	5 1/2	40°29'14.62"N	74°06'51.61"W	"
5	45	40°29'05.13"N	74°05'51.36"W	"
6	190	40°30'34.80"N	74°04'48.52"W	"
7	363	40°29'50.74"N	74°02'28.70"W	"
8	162	40°31'29.44"N	74°01'14.83"W	"
9	328	40°30'33.99"N	73°59'14.14"W	"
10	148	40°32'03.00"N	73°59'30.79"W	"
11	77	40°30'48.95"N	73°58'07.66"W	"
12	143	40°32'08.42"N	73°57'14.61"W	"
13	610	40°31'54.13"N	73°56'18.41"W	"
14	460	40°32'17.59"N	73°55'13.18"W	"
15	1/2 38-87	40°32'22.06"N	73°53'40.62"W	"
16	A4	40°30.4'N	74°05'W	Fray, 1969. Also reported in Williams and Duane, 1974.
17	A3	40°30.4'N	74°02.1'W	"
18	A1	40°29.6'N	73°59.4'W	"
19	A9	40°27.9'N	73°57.1'W	"
20	B-A	40°30.0'N	74°05.7'W	Borings for proposed Recap Island. Mr. Joseph Hellman, Pope, Evans & Robbins, Inc., written communication.
21	B-B	40°31.2'N	74°04.0'W	"
22	B-C	40°31.8'N	74°02.8'W	"
23	2	40°30.0'N	74°03.5'W	"
24	3	40°29.6'N	74°04.5'W	"
25	6	40°29.6'N	74°03.1'W	"
26	7	40°29.1'N	74°04.1'W	"
27	1	40°26.7'N	74°03.5'W	Minard, 1969
28	None	40°34.0'N	74°03.0'W	Mike Flood, U.S. Coast Guard, written communication.
29	None	40°30.0'N	73°59.3'W	Cores for Rockaway Beach Restoration Project, U.S. Army Corps of Engineers, James Marotta, N.Y. State Office of General Services, written communication.
30	None	40°32.4'N	73°59.2'W	"
31	None	40°32.2'N	73°58.8'W	"
32	None	40°32.0'N	73°58.8'W	"

Report Core No.	Original Core No.	Latitude	Longitude	Source
33	None	40°31.8'N	73°58.3'W	"
34	None	40°32.1'N	73°58.2'W	"
35	2	40°27.2'N	73°59.3'W	Minard, 1969.
36	3	40°26.2'N	73°59.2'W	"
37	4	40°25.8'N	73°59.1'W	"
38	6	40°25.2'N	73°58.9'W	"
SI 1	Same	40°34.90'N	74°03.86'W	U.S. Army Engineer District, New York.
SI 2	Same	40°33.54'N	74°03.37'W	"
SI 3	Same	40°32.79'N	74°05.77'W	"
SI 6	Same	40°31.54'N	74°08.68'W	"
SI 7	Same	40°31.15'N	74°09.43'W	"
SI 8	Same	40°30.85'N	74°11.12'W	"
NJ 5	Same	40°27.90'N	74°13.04'W	U.S. Army Engineer District, New York.
NJ 6	Same	40°27.20'N	74°12.61'W	"
NJ 7	Same	40°27.00'N	74°12.27'W	"
NJ 8	Same	40°26.87'N	74°11.76'W	"
NJ 9	Same	40°27.62'N	74°11.83'W	"
NJ 10	Same	40°27.98'N	74°10.67'W	"
NJ 11	Same	40°27.46'N	74°10.14'W	"
NJ 12	Same	40°27.36'N	74°09.76'W	"
NJ 13	Same	40°27.43'N	74°09.11'W	"
NJ 14	Same	40°27.81'N	74°08.18'W	"
NJ 15	Same	40°27.74'N	74°07.90'W	"
NJ 16	Same	40°27.69'N	74°07.22'W	"
NJ 17	Same	40°27.18'N	74°06.50'W	"
NJ 18	Same	40°27.29'N	74°05.65'W	"
NJ 19	Same	40°26.85'N	74°05.57'W	"
NJ 20	Same	40°26.55'N	74°05.07'W	"
NJ 21	Same	40°26.37'N	74°04.50'W	U.S. Army Engineer District, New York.
NJ 22	Same	40°26.72'N	74°04.35'W	"
NJ 23	Same	40°25.65'N	74°03.26'W	"
NJ 24	Same	40°25.65'N	74°02.63'W	"
NJ 25	Same	40°25.84'N	74°02.10'W	"
TB 1	Same	40°25.7'N	74°04.1'W	"
TB 3	Same	40°25.9'N	74°03.9'W	Northern Division Naval Facilities Engineering Command, 1979.
TB 5	Same	40°26.1'N	74°03.8'W	"
TB 9	Same	40°26.6'N	74°03.6'W	"
TB 12	Same	40°27.0'N	74°03.3'W	"
TB 15	Same	40°27.1'N	74°03.0'W	"
B 1	Same	40°27.5'N	74°02.9'W	"
B 2	Same	40°28.2'N	74°02.4'W	"
B 3	Same	40°28.3'N	74°03.0'W	"
B 4	Same	40°27.9'N	74°03.6'W	"

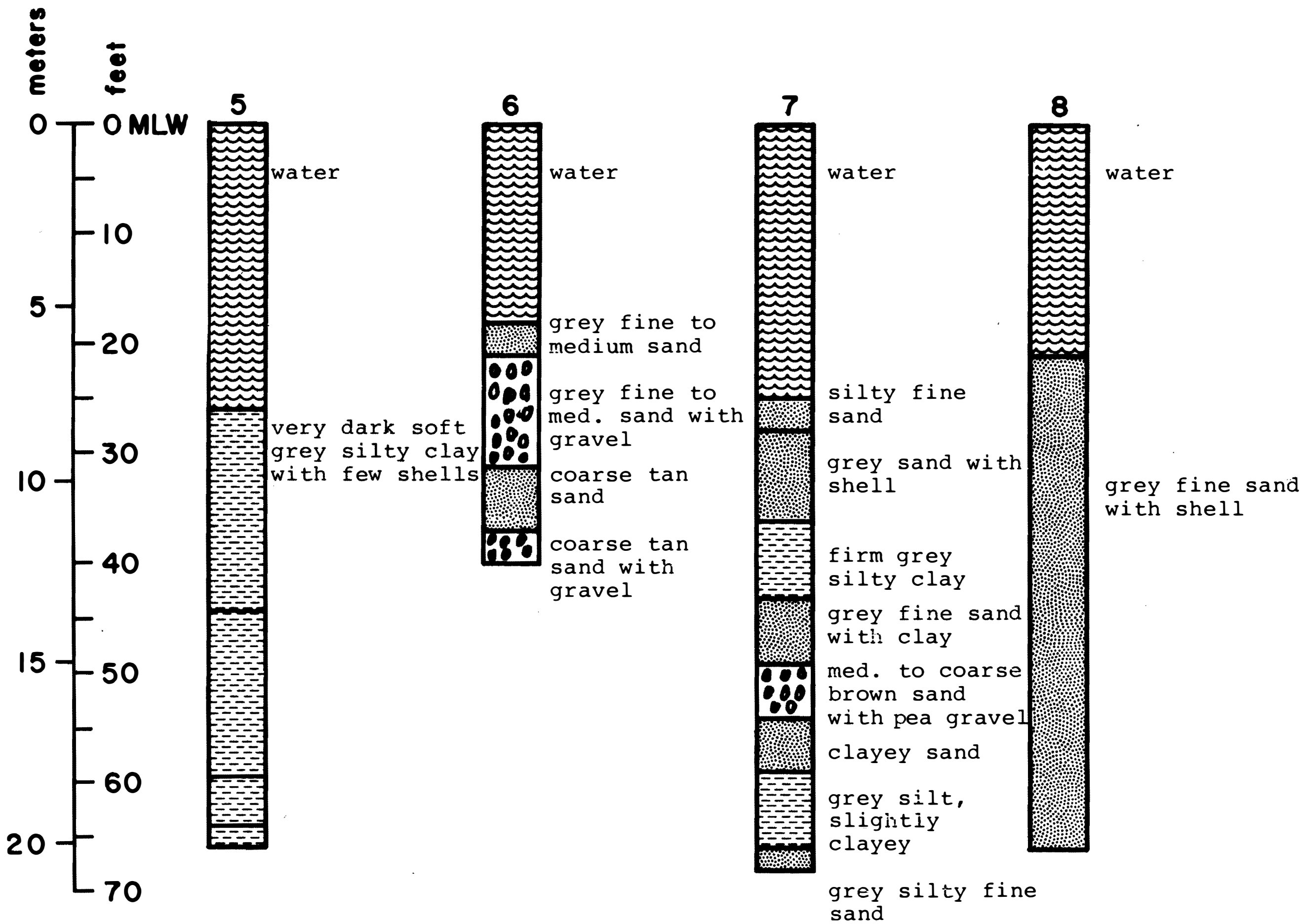


Fig. 1A. continued

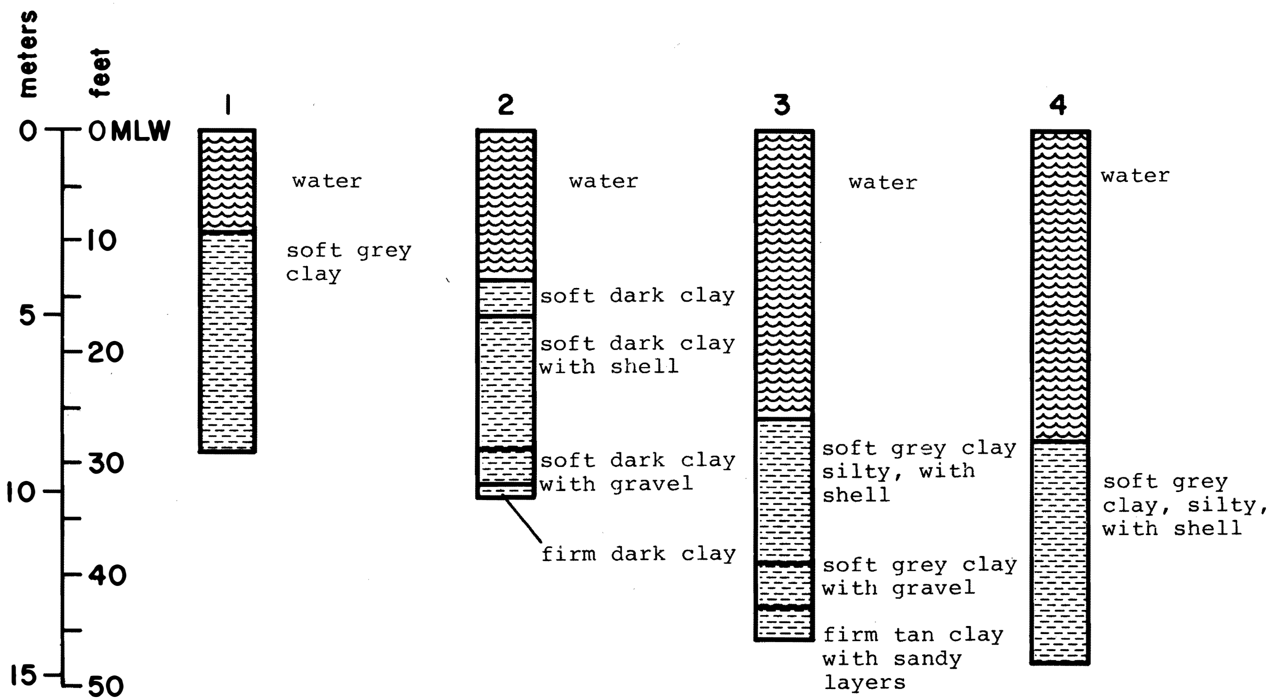
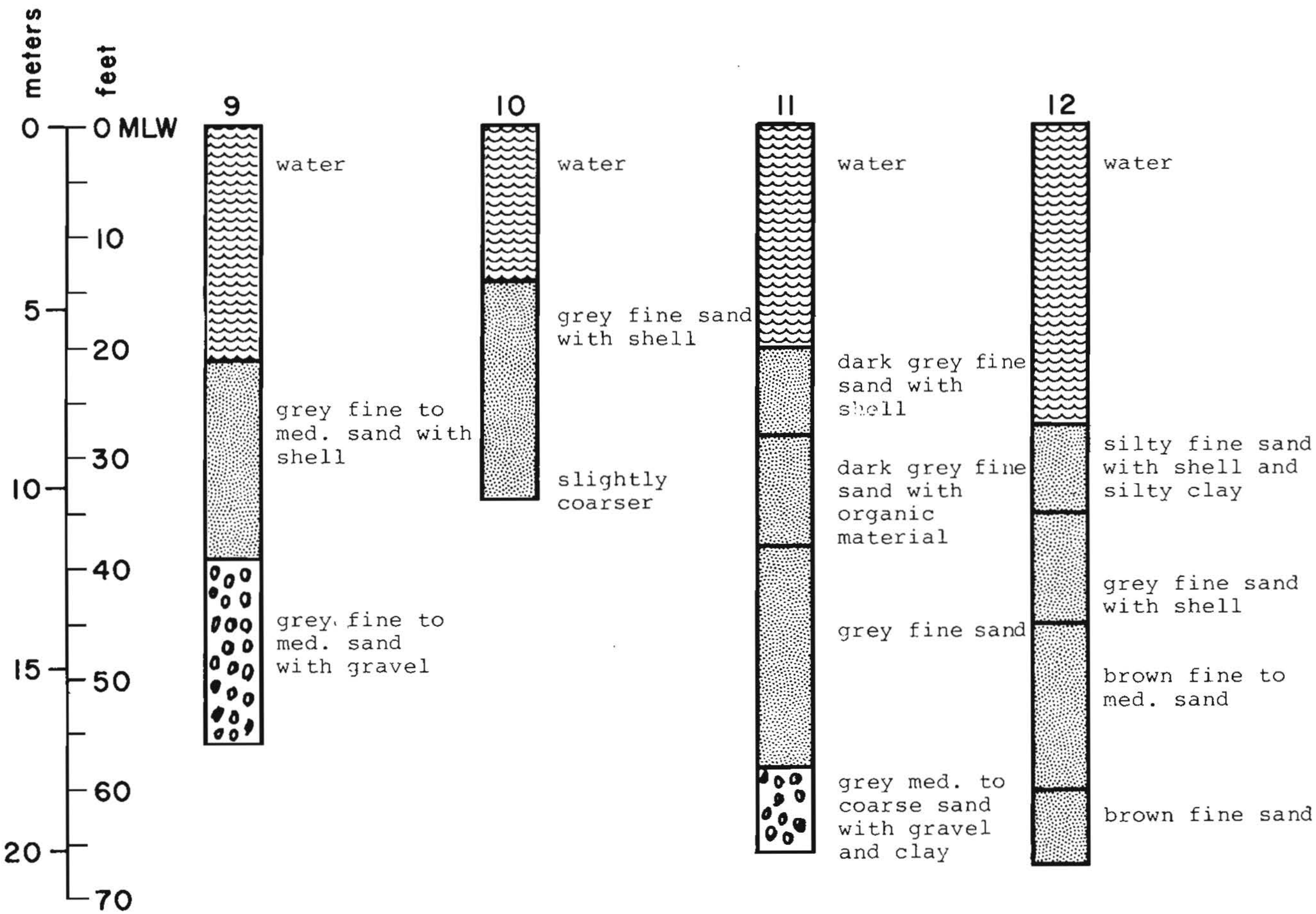


Fig. 1A. Descriptions of cores and borings in the Lower Bay.



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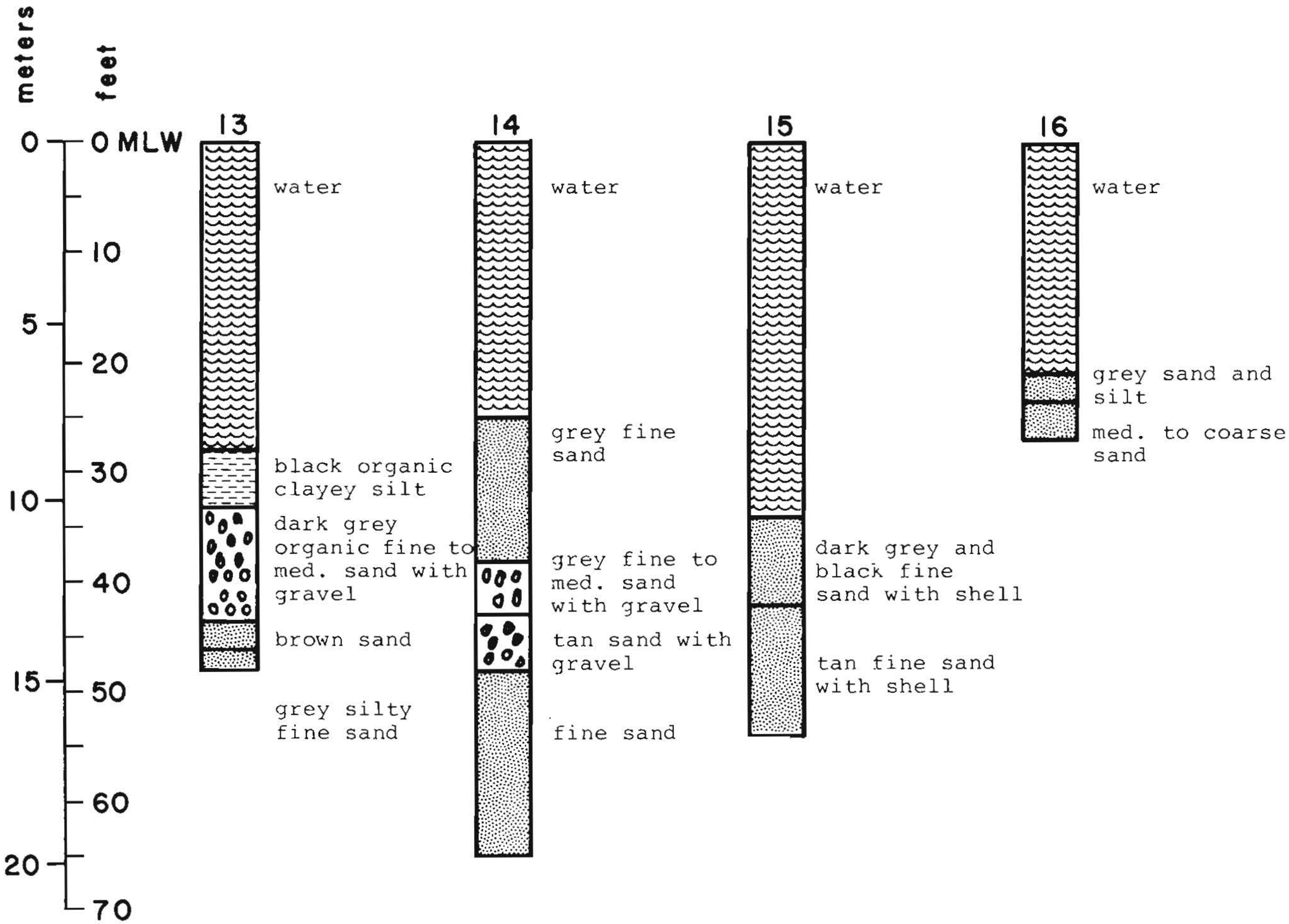

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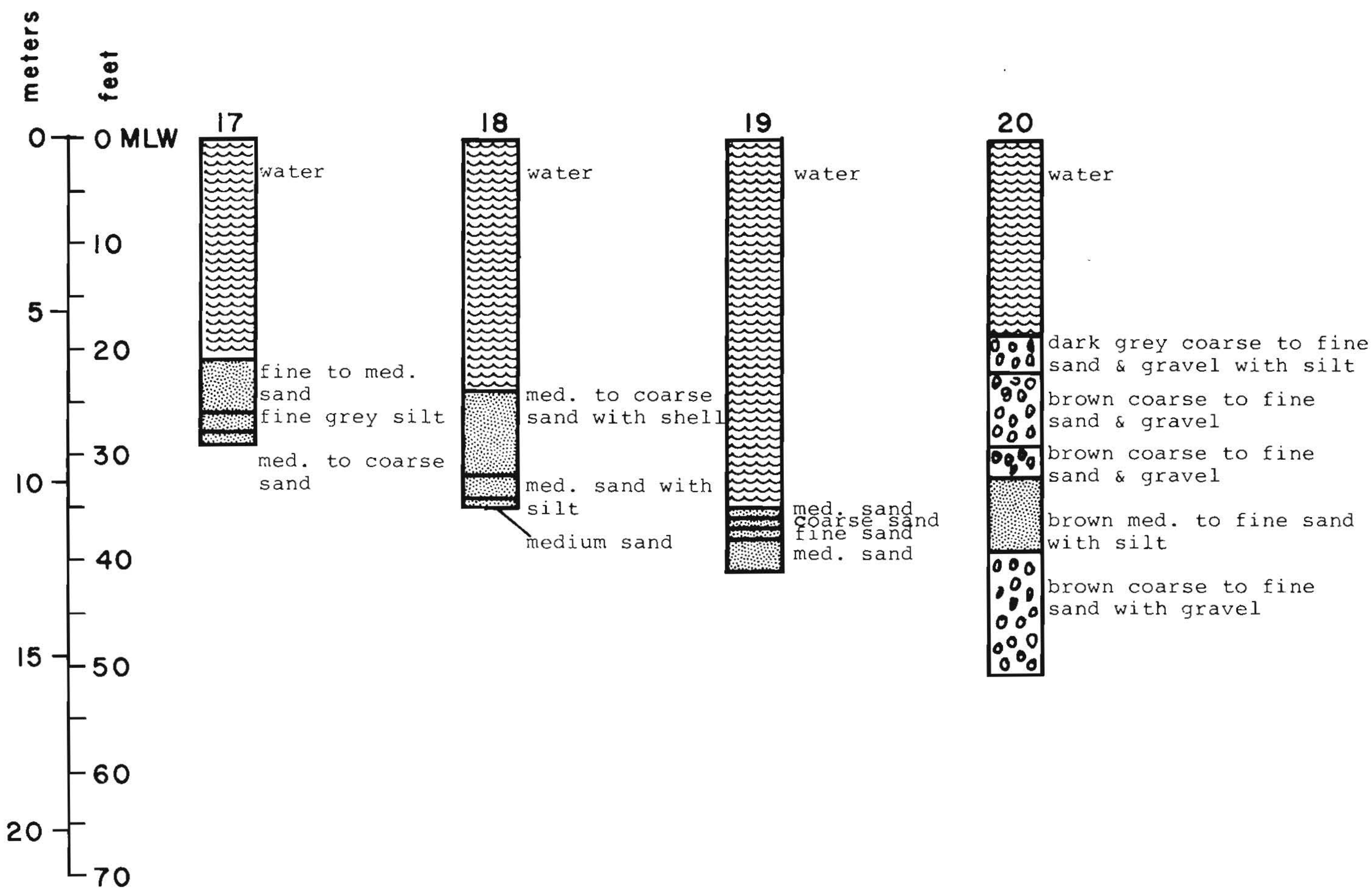

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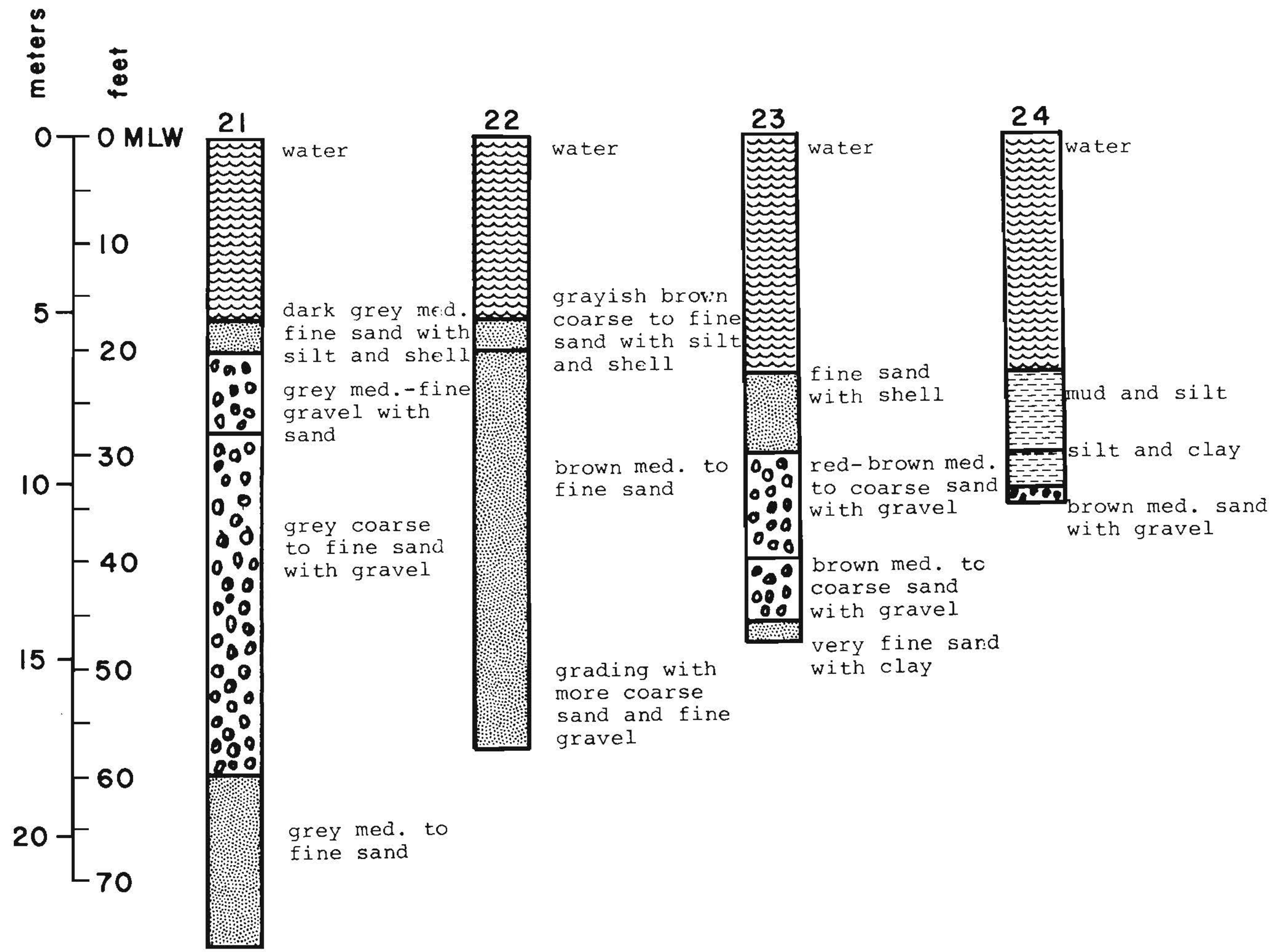

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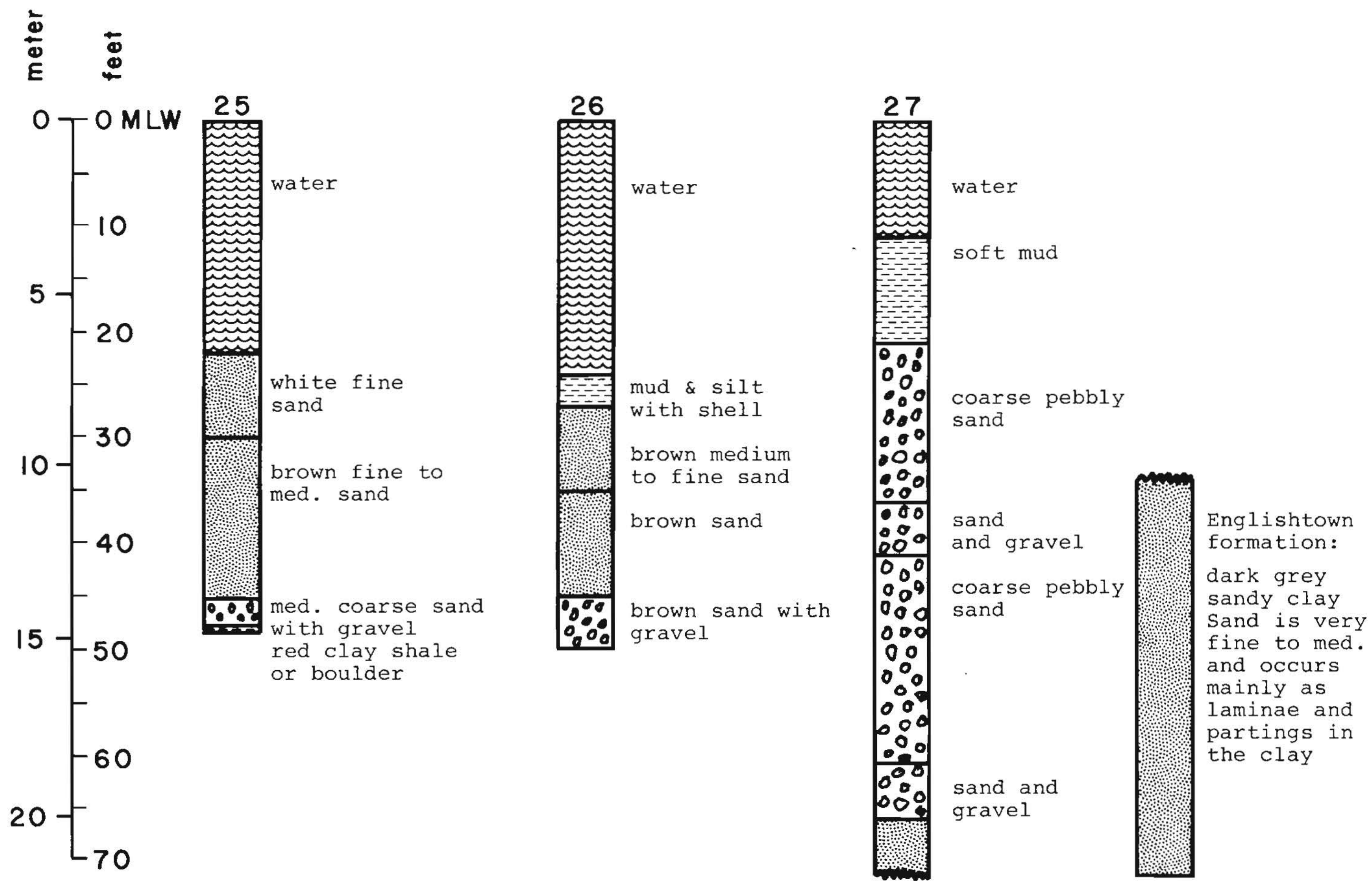

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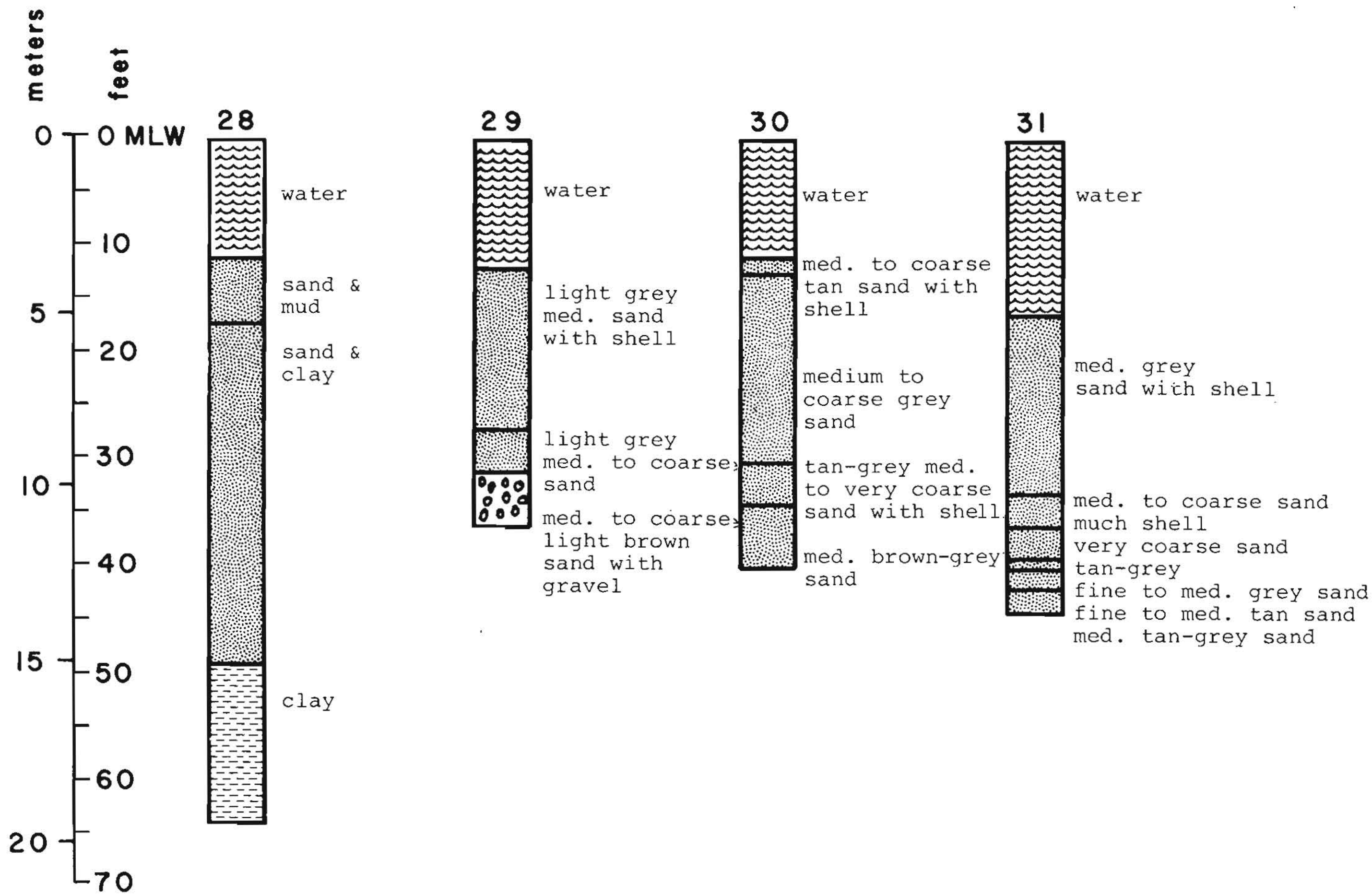

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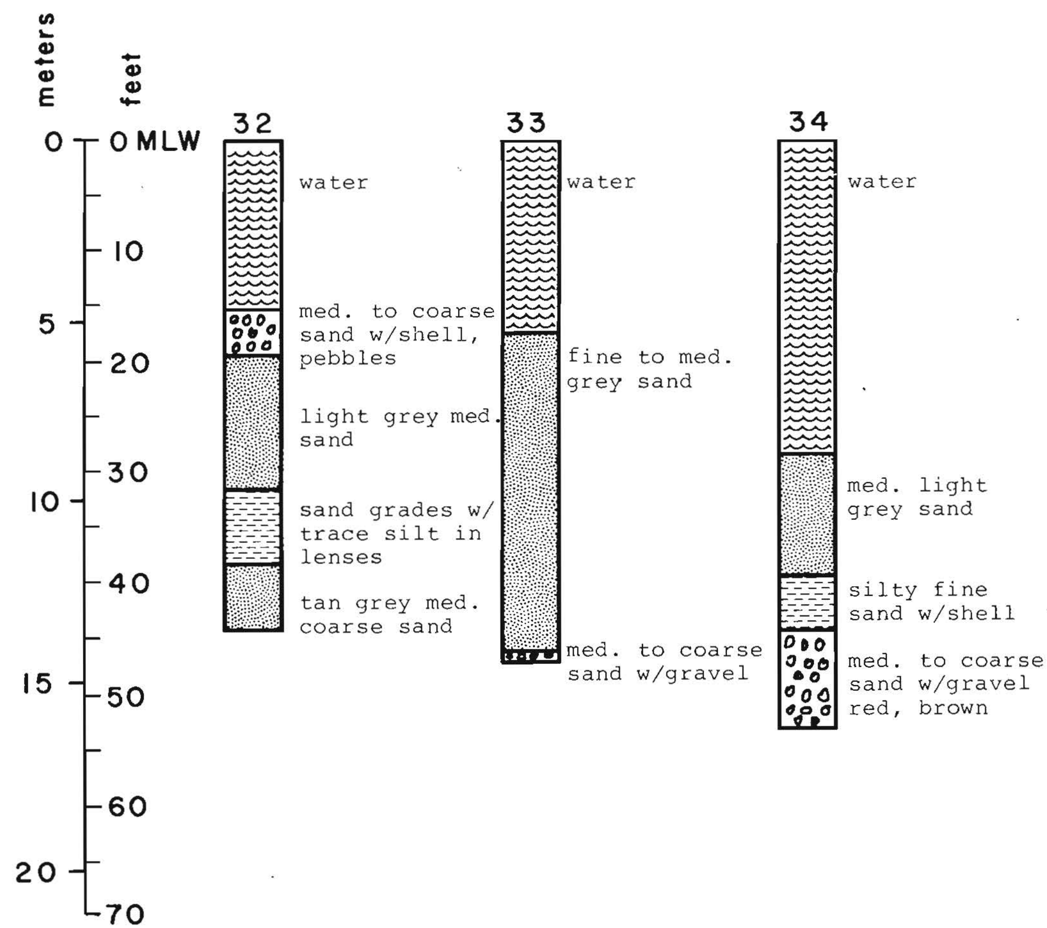

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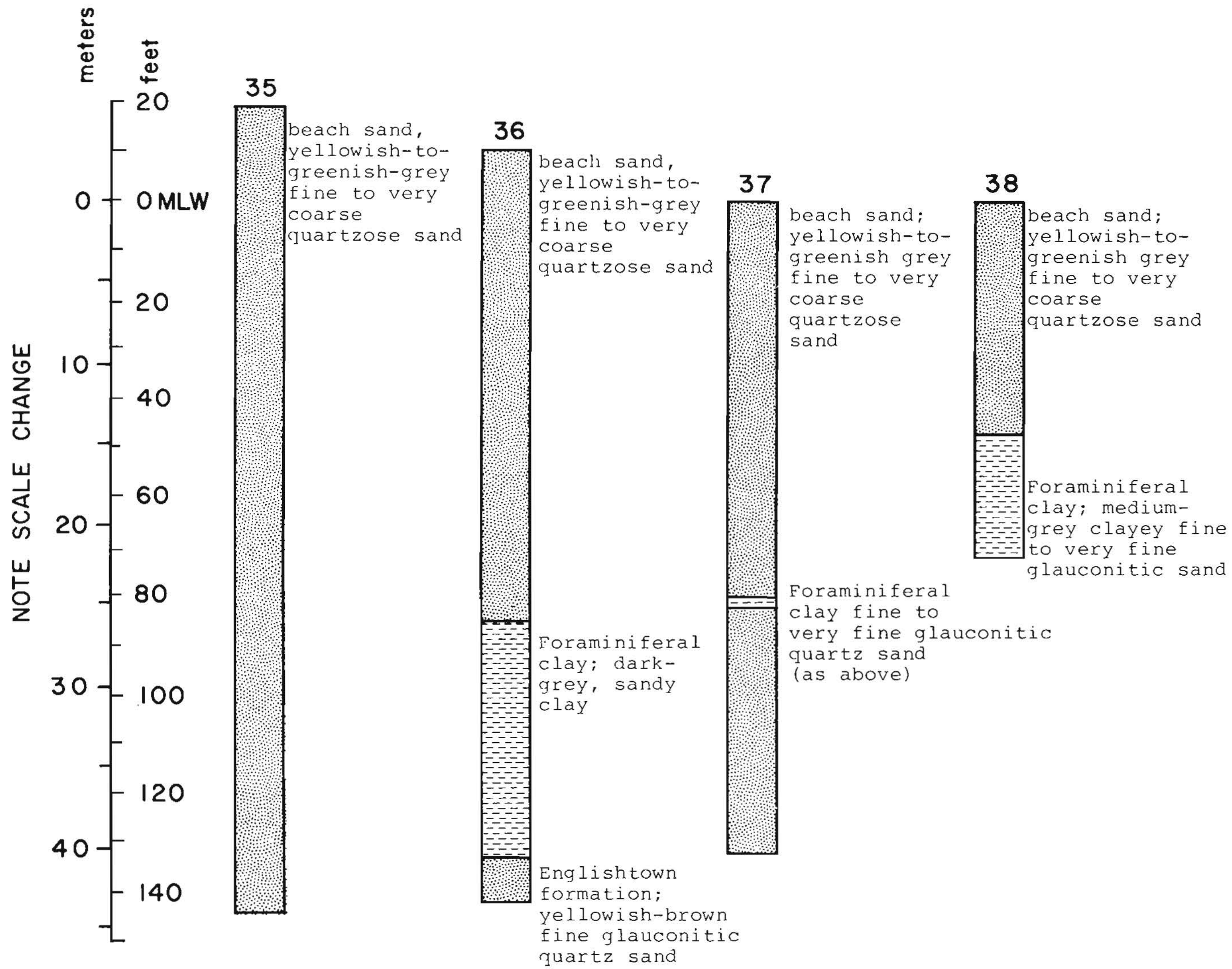

Fig. 1A. continued