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THE MINERALOGY OF FINE-GRAINED SEDIMENT IN THE NEW JERSEY NEARSHORE REGION: IMPLICATIONS FOR SEDIMENT SOURCES AND DISPERSAL PATTERNS

by

Peter L. Sudano

A Thesis Presented to the Graduate Committee
of Lehigh University in Candidacy for the
Degree of Master of Science
in
Department of Geological Sciences
Lehigh University
1982

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This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

Sept. 24, 1982
(date)

Professor in Charge

Chairman of Department

ACKNOWLEDGMENTS

The author would like to thank Dr. Bobb Carson for his guidance and assistance with all aspects of this study. Special thanks are also extended to Dr. James Parks for assistance with statistical analysis programs, and Dr. Charles Sclar for helpful discussions.

The author would also like to thank his fellow geologists at Lehigh University, especially Tom Schroeder and Keith Carney who helped with sampling, and Geoffrey Seibel, James Cotter, Franklin Sine, and Joseph Kelley for helpful discussions and assistance.

Financial support was provided by the Office of Sea Grant under grant number NA-79AA-0063 to the New Jersey Marine Sciences Consortium, and by Sigma Xi, the Scientific Research Society.

Finally, particular gratitude is due to my wife Nancy, and my parents, for their encouragement and confidence.

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ABSTRACT

The fine (<62 um) fraction of New Jersey beach and inner shelf sediments is derived from both local and regional sources. Coastal and shoreface erosion released significant amounts of mineralogically distinguishable fine sediment into the nearshore zone. Fine clay (<0.5 um) is dominated by illite and kaolinite and/or chlorite, with lesser amounts of quartz and smectite. The heavy mineral fraction of silt-sized sediment (8-32 um) is dominated by hornblende and chlorite.

North of Long Branch, fine clay is derived from erosion of glauconite-rich upper Cretaceous and early Tertiary coastal plain formations, and transported northward to Sandy Hook. The fine clay on the beaches and in the nearshore region of Cape May Peninsula is apparently derived from erosion of Cape May Formation (Pleistocene) clays, which probably crop out on the inner shelf and in Delaware Bay. These clays contain measurable amounts of smectite. Between Little Egg Inlet and Long Branch, beach and nearshore clays may receive some input from erosion of the kaolinite-rich Kirkwood and Cohansey Formations (Miocene).

Hornblende-enriched silt is derived from the (Miocene?) Bridgeton Formation, and appears to be transported northward of its probable source area (little Egg Inlet to Cape May Peninsula). This transport pattern may result from summer and fall nearshore flow toward the northeast, which is opposite to the previously observed

direction of net sand transport (SW).

INTRODUCTION

The beaches and continental shelf of New Jersey (figure 1) are part of the Middle Atlantic Bight, one of the most intensively studied continental margins in the world (Milliman, 1972). Many investigations (Shepard and Cohee, 1936; McMaster, 1954; Emery, 1968; Swift and others, 1971; Frank and Friedman, 1973; Schroeder, 1982) have focused on the composition and origin of nearshore sediments within this region.

The ultimate source of beach and inner shelf sediments is probably the igneous, metamorphic, and sedimentary rocks of the Appalachian Province, but it is unlikely that appreciable amounts of present nearshore material have come directly from these source areas. The textural and compositional maturity of these sediments indicates that they have undergone more than one cycle of erosion and deposition (McMaster, 1954; Cataldo, 1981; Schroeder, 1982). Emery (1968), Swift and others (1971), Meade (1972), and Milliman and others (1972) suggest that the beaches and shelf off New Jersey receive little modern sediment from the large rivers that drain the Appalachian Province. As a result, other recent sources for New Jersey nearshore sediment need to be considered in studying the modern deposits.

The fine fraction (less than 64 um) has been largely ignored in studies of New Jersey nearshore sediments. The sources of suspended matter on the continental shelf have been studied by Meade (1969),

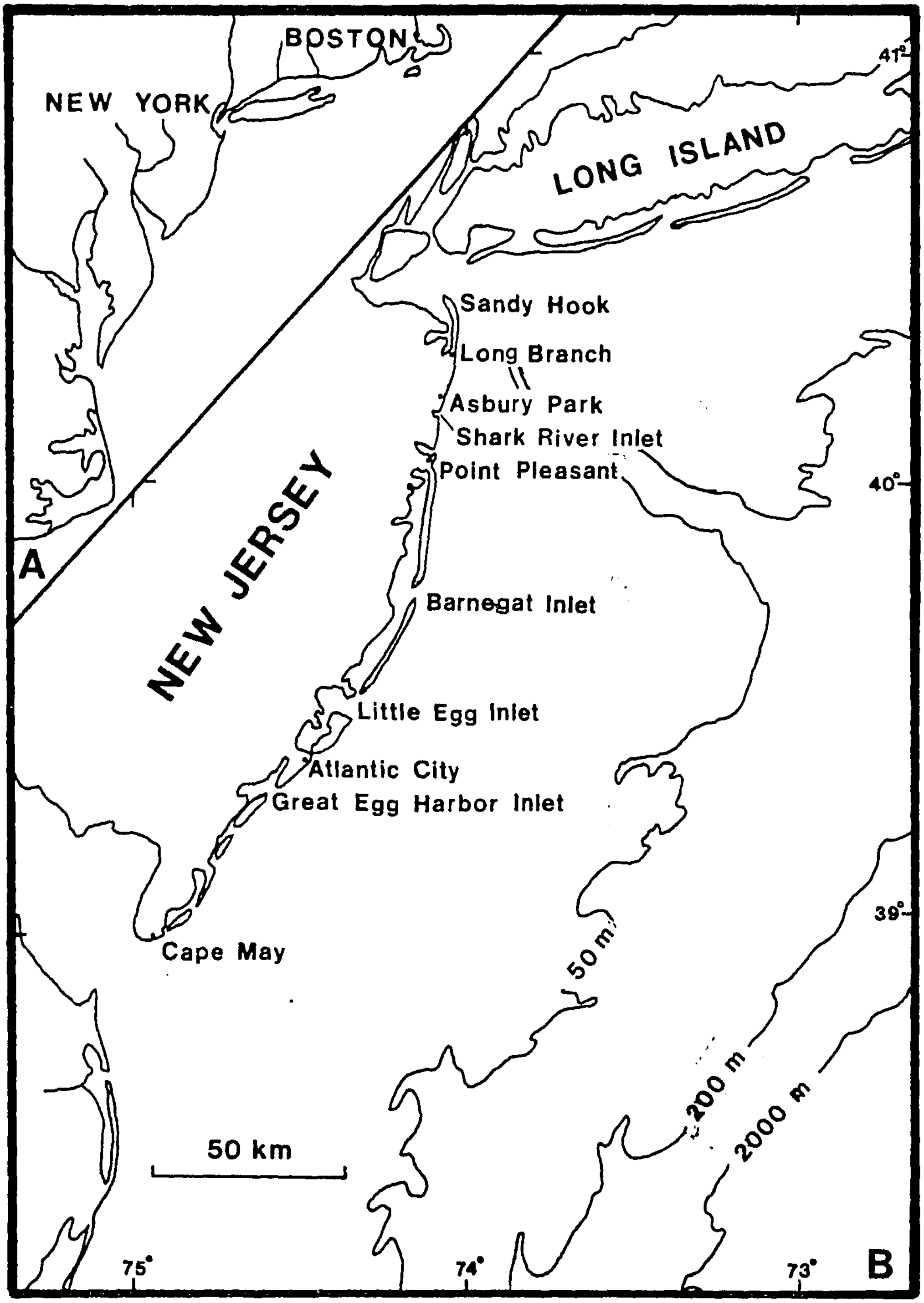


Figure 1. A) The Middle Atlantic Bight. B) The New Jersey shoreline and continental shelf. Bathymetry from Uchupi, 1968.

Manheim and others (1967), and Drake (1976). Most of the suspensate in shelf waters consists of organic matter and resuspended bottom sediment (Meade and others, 1975). Hathaway (1972) described the mineralogy and origin of east coast continental slope and estuary clays, but neglected large areas of the shelf, including that portion off New Jersey. Although regional clay mineral studies have been made on the continental shelf off the southeastern United States (Neiheisal and Weaver, 1967; Peaver, 1972; Murray and Sayyab, 1955), only local studies (Kelley, 1980, in press; Hall, 1981) have been carried out off New Jersey.

Despite problems (small percentage of fines, probable limited suite of minerals, lack of quantitative precision) associated with collection and analysis of fine sediment from the nearshore zone, the clay and silt fraction can be useful in a provenance study. The fines extracted from beach and nearshore sediments can be used as tracers for sediment transported primarily in suspension. Because fines are more easily entrained than coarser sediment, they are more mobile, and can be a subtle indicator of low velocity currents.

PURPOSE OF THIS INVESTIGATION

This study examines the mineralogy of the New Jersey beach and inner shelf clay and silt fractions, in an attempt to determine modern sources and dispersal patterns of this sediment. In addition, sediment mineralogy is related to texture, color and bathymetry, in order to better understand the recent sedimentary history of the region.

GEOLOGIC BACKGROUND

REGIONAL GEOLOGY AND PHYSIOGRAPHY

New Jersey Coastal Plain

The Coastal Plain province of New Jersey consists of a series of seaward-dipping and thickening Cretaceous to Recent sediments, unconformably overlying Pre-Cambrian to Triassic basement rocks (Wolfe, 1977; figures 2 and 3). Coastal Plain deposits consist of unconsolidated to partially consolidated sands, gravels, and muds (primarily of marine origin), which are presumed to have been derived from older formations of the Piedmont, New England Highlands, Valley and Ridge, and Appalachian Plateau provinces (figure 2). Coastal Plain stratigraphy is summarized in figures 3 and 4, and table 1. The geology of this region is summarized from Spangler and Peterson (1950), Johnson and Richards (1952), Widmer (1964), Richards and others (1969), Owens and Sohl (1969), Wolfe (1977), Owens and Minard (1979), and Rhodehamel (1979).

Sediments of the inner Coastal Plain (figure 2, inner lowland) consist of Cretaceous glauconitic sands, clays, and marls, which crop out along the shore of Raritan Bay, and behind Sandy Hook spit (figure 3). Eocene sediments of similar composition crop out along the New Jersey shore between Long Branch and Point Pleasant (figure 3).

The Kirkwood (early Miocene) and Cohansey (middle to late

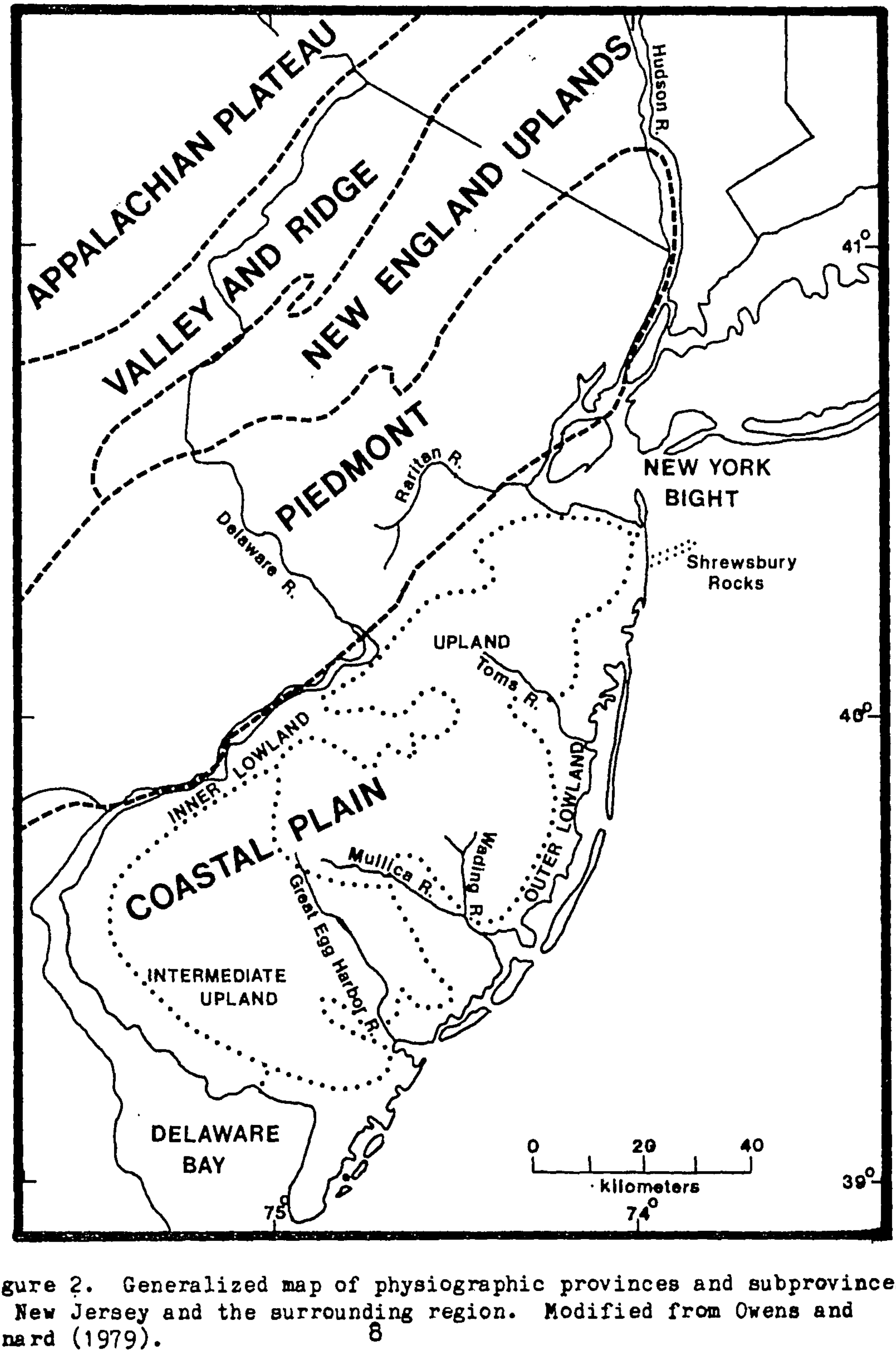
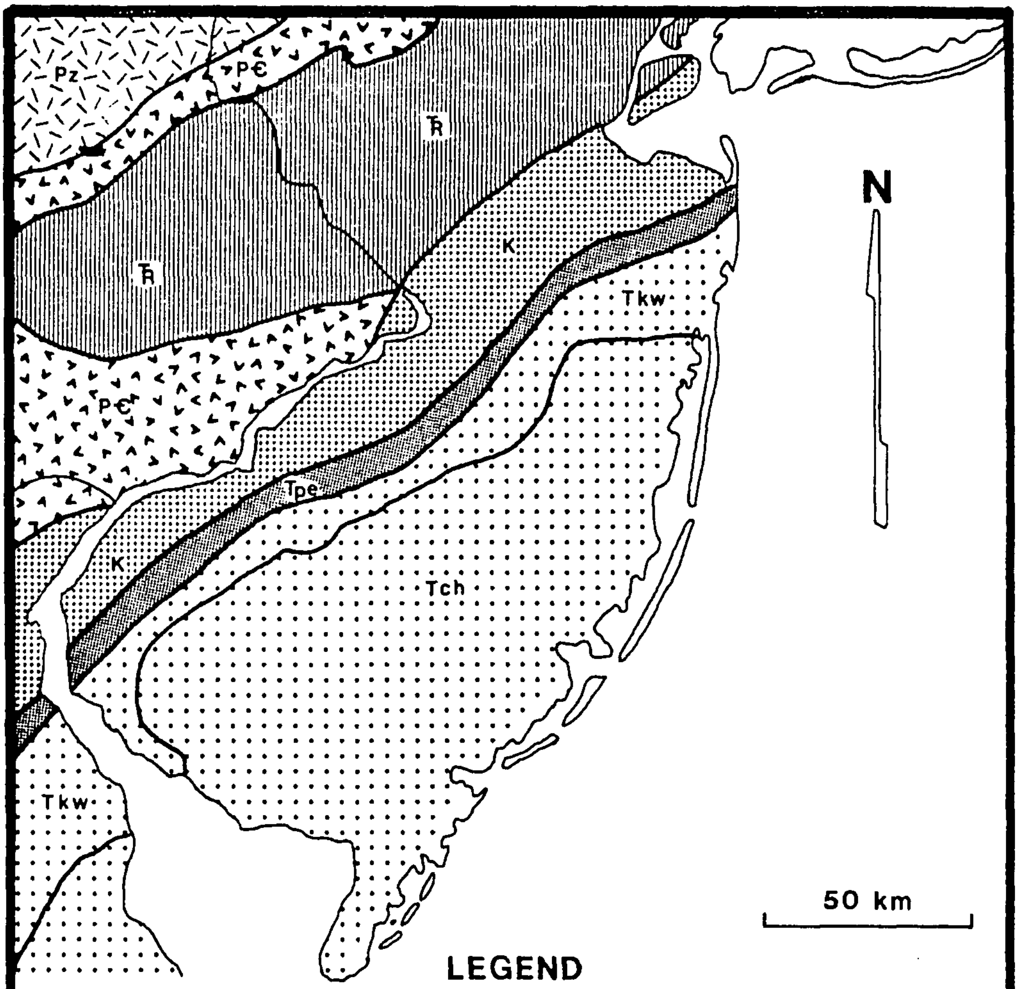


Figure 2. Generalized map of physiographic provinces and subprovinces of New Jersey and the surrounding region. Modified from Owens and Minard (1979).



LEGEND

Tch Tkw	Miocene or Pliocene Cohansey Formation - quartz sand with local clay and gravel beds. Miocene Kirkwood Formation - micaceous sands with local clay beds.
Tpe	Paleocene and Eocene glauconitic sands, clays, and marls.
K	Cretaceous glauconitic sands, clays, and marls.
₸R	Triassic arkosic sandstones, conglomerates, and red shales, with diabase and basalt intrusions.
Pz	Early Paleozoic sedimentary rocks.
PЄ	Precambrian and early Paleozoic metamorphic and igneous rocks.

Figure 3. Generalized Pre-Quaternity geologic map of New Jersey and the surrounding region. After Lewis and Kummel (1912) and Owens and Minard (1979).

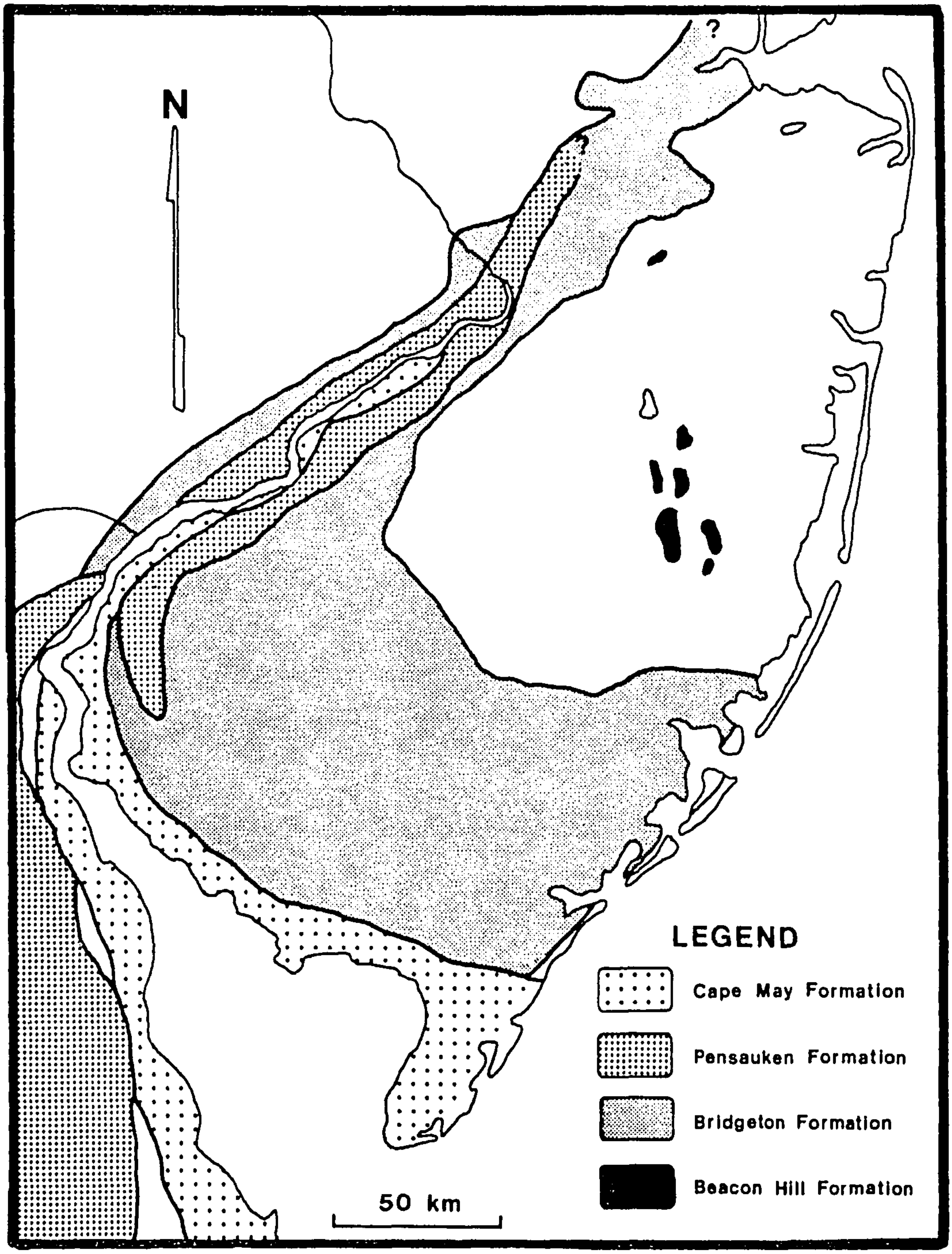


Figure 4. Late Miocene? to Pleistocene formations of the New Jersey Coastal Plain. Boundaries represent presumed original limits of each formation, which are locally very speculative (after Owens and Minard, 1979). The Cape May Formation includes the Spring Lake Beds and Van Sciver Lake Beds defined by Owens and Minard (1979) which are time equivalent glaciofluvial deposits. See text for discussion, and table 1 for formation ages.

EPOCH		FORMATION	
		JOHNSON (1950)	OWENS AND MINARD (1979)
RECENT		Fluvial and barrier complex deposits	
PLEISTOCENE		Cape May Fm. Pensauken Fm. Bridgeton Fm.	Cape May Fm. and associated river terrace deposits
PLIOCENE		Beacon Hill Fm.	
MIOCENE	LATE	Cohansey Fm.	Pensauken Fm. Bridgeton Fm. Beacon Hill Fm. Cohansey Fm.
	MIDDLE	Kirkwood Fm.	Kirkwood Fm.
	EARLY		

Table 1. Late Cenozoic stratigraphy of the New Jersey Coastal Plain.

EPOCH		FORMATION	
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	MIDDLE	Kirkwood Fm.	Cohansey Fm.
	EARLY		Kirkwood Fm.

Table 1. Late Cenozoic stratigraphy of the New Jersey Coastal Plain.

Miocene?) Formations are the surficial strata of most of the Coastal Plain province (figure 3; Owens and Sohl, 1969). The Kirkwood is a transgressive formation consisting of a basal marine clay overlain by a finely laminated clayey silt, and an orange to white silty sand (Wolfe, 1977). The Cohansey Formation consists of laminated and interbedded sand and clay facies, and was deposited over the Kirkwood Formation as a series of regressive barrier and barrier protected deposits (Carter, 1978).

The Bridgeton and Pensauken Formations (Pleistocene - Salisbury and Knapp, 1917; late Miocene - Owens and Minard, 1979), and the Beacon Hill Gravel (Pliocene - Richards and others, 1969; Miocene - Owens and Minard, 1979), are dissected sand and gravel deposits with a patchy distribution on the higher elevations of the Coastal Plain (figure 4). These formations are fluvial in origin, and possibly result from stream channel deposition in ancient courses of the Hudson River (Rhodehamel, 1979; Owens and Minard, 1979).

The late Pleistocene (Sangamon) Cape May Formation is a fluvial to marine deposit of sand and gravel, which comprises the surface sediments of Cape May peninsula, and occurs as bordering terraces and overbank deposits along coastal New Jersey streams (figure 4; Salisbury and Knapp, 1919; MacClintock, 1943; Rhodehamel, 1979). These sediments were derived from older, reworked Coastal Plain sediments, and Pleistocene glacial outwash. In the lower Delaware River valley, deposits of this age are termed the Trenton Gravels, and consist of two distinct gravelly sand units (Owens and Minard, 1979). Near Cape May peninsula, basal sand and gravel channel fill is overlain by a thick estuarine clay, which is, in turn, overlain by modern marsh and beach sediment (Gill, 1962). MacClintock (1943), McMaster (1954), and Kelley (1980), suggested that the Cape May Formation clays may crop out on the inner shelf off New Jersey from Point Pleasant to south of Cape May.

Nearshore Zone

The New Jersey Atlantic shoreline extends northeast-southwest for about 200 kms, flanked by the Delaware and Hudson River estuaries (figure 2). The small streams that drain the Coastal Plain province discharge into small coastal estuaries, lagoons, or through tidal inlets. Most of the shoreline consists of a barrier island-lagoon-tidal marsh complex, which protects the mainland from wave attack. Coastal formations are exposed along the shore on Cape May, and between Long Branch and Point Pleasant (figure 1). Most of the exposed formations which were formerly subject to coastal erosion, are now, at least partially, protected by a series of sea walls and groins.

MacCarthy (1922) and McMaster (1954) described the texture of New Jersey beaches. The coarsest sand (median grain size greater than 0.4mm) is found on beaches where the mainland is exposed to coastal erosion (Point Pleasant to Sandy Hook, and on the Delaware Bay side of Cape May. Median sand size decreases south of Point Pleasant, with the finest sand (median grain size less than 0.2 mm) found between Atlantic City and Cape May.

McMaster (1954) examined the heavy minerals of New Jersey beach sands, and divided the shoreline into four compositional zones (figure 5). He attributed the source of the glauconite zone (Sandy Hook to Shark River) to the Tertiary formations between Asbury Park and Monmouth, and the source of the northern part of the adjacent black opaque zone (Shark River to Point Pleasant) to local outcrops of the Cape May Formation. The source of the sands for the major length of New Jersey (Point Pleasant to Cape May) was attributed to the continental shelf, with the black opaque zone (north of Little Egg Inlet) derived from Cape May material, and the hornblende zone (south of Little Egg Inlet) derived from glaciofluvial deposition. The source of the southern black opaque zone on the Delaware Bay side of Cape May County was thought to be the Pleistocene Cape May Formation.

Schroeder (1982) reexamined McMaster's data using multivariate analysis, redefined the boundaries of the heavy mineral zones, and extended these zones offshore (figure 5). He suggested that a major Pleistocene(?) river system was responsible for deposition of the shelf sediments which are currently supplying the hornblende zone.

Continental Shelf

The New Jersey continental shelf is the seaward extension of the Coastal Plain province. The texture, morphology, and shallow stratigraphy of shelf deposits have been greatly influenced by

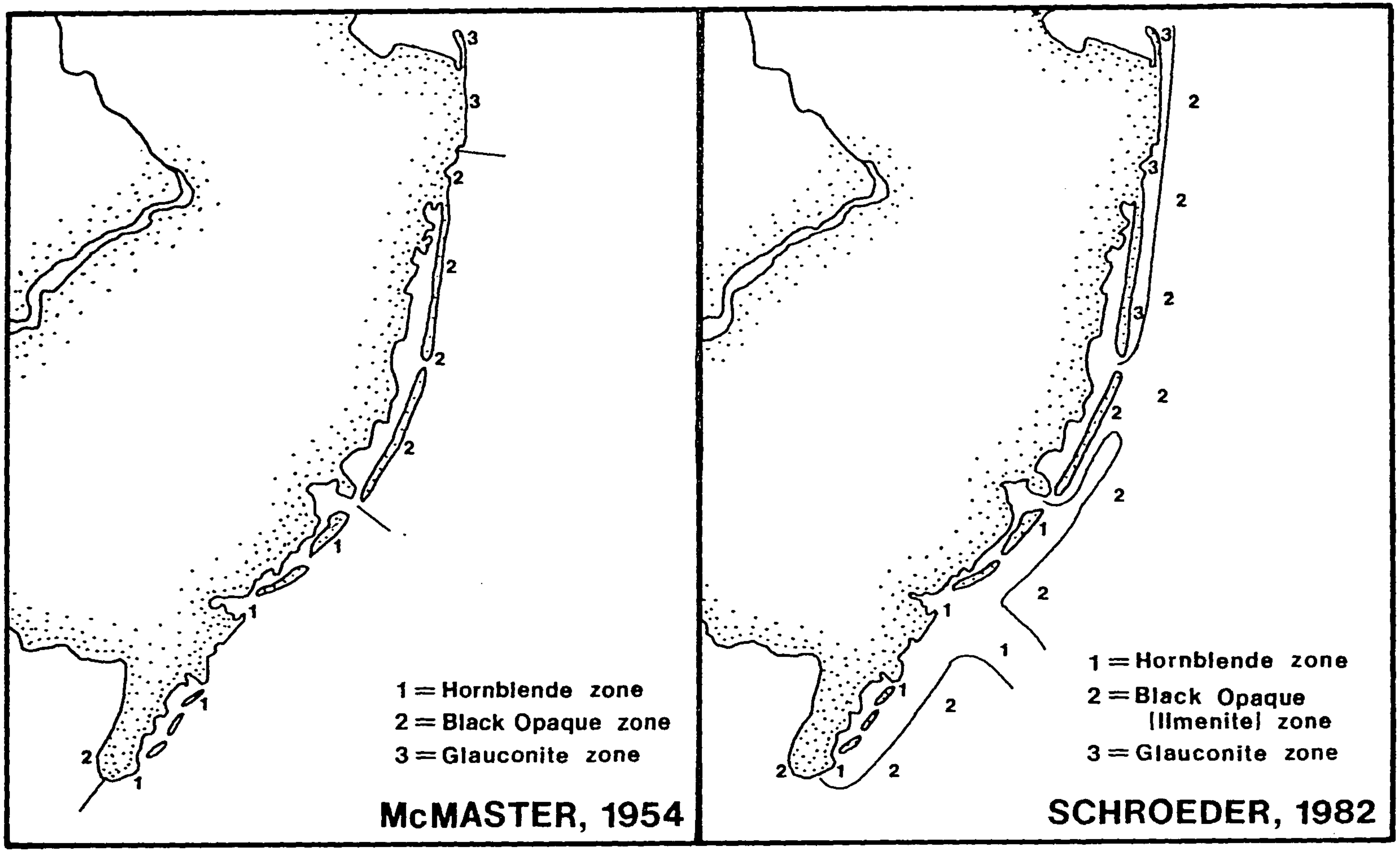

Figure 5. Sand-size heavy mineral zones of the New Jersey beaches (McMaster, 1954), redefined to include the inner shelf (Schroeder, 1982).

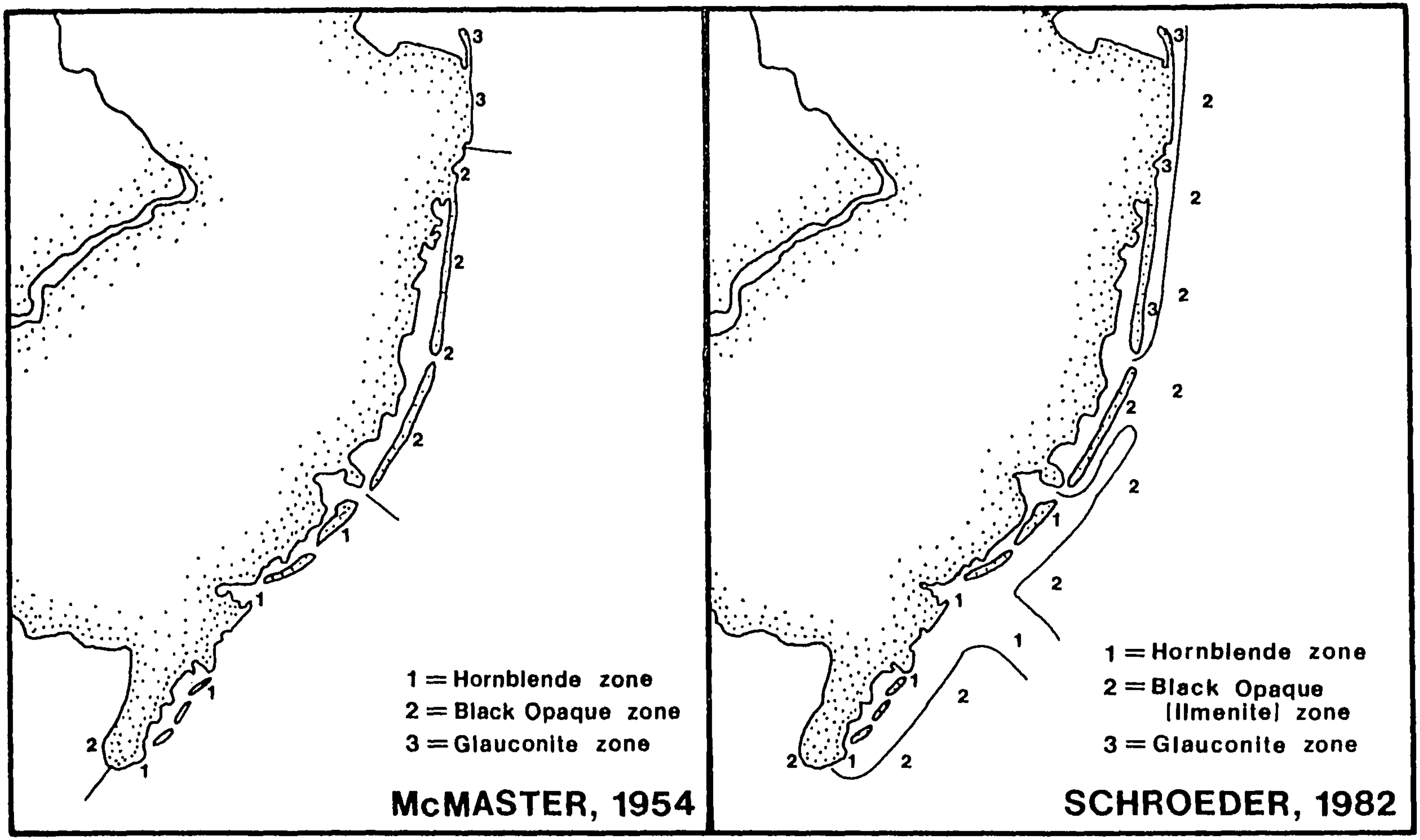

Figure 5. Sand-size heavy mineral zones of the New Jersey beaches (McMaster, 1954), redefined to include the inner shelf (Schroeder, 1982).

Pleistocene sea level fluctuations, and the subsequent Holocene transgression.

The surficial sediments of the New Jersey continental shelf consist of arkosic to subarkosic fine to medium grained sands, with occasional patches of gravel, silty sand, and mud. Most of the original fine-grained material has been winnowed out; either by shoreface erosion, or in the modern hydraulic regime (Milliman and others, 1972). Where the sand is thin or discontinuous, previously undisturbed Holocene, Pleistocene, or earlier sediments are exposed (Stubblefield and Swift, 1976).

Shepard and Cohee (1936) suggested that sediment texture on the Middle Atlantic continental shelf is not in equilibrium with the present shelf environment, and that shelf sediments were deposited during the Pleistocene stages of lowered sea level. Emery (1968) stated that most surficial shelf sediments of the Middle Atlantic Bight were deposited in fluvial, paludal, or lacustrine environments. Erosional shoreface retreat reworked these Pleistocene and early Holocene sediments, and deposited a discontinuous sand sheet (0 to 10 meters thick) on the shelf (Swift, 1976a). Emery described these sediments as relict; deposited in a previous sedimentary environment (nearshore), but out of equilibrium with the present shelf hydraulic regime. Milliman and others (1972) stated that while shelf sediments are not in compositional equilibrium, they may be in partial textural equilibrium. Swift and others (1971) describe shelf sediments as "palimpsest"; exhibiting the petrographic attributes of both an ancient and a modern environment.

A conspicuous topographic feature of the New Jersey shelf is the ridge and swale topography, described in detail by Duane and others (1972). Ridges are found on all parts of the shelf but are more numerous on the inner shelf, occurring individually or in clusters. Ridges are typically 3 to 12 meters high, 500 meters wide, tens of kilometers long, and have side slopes of less than 5 degrees. They form angles of 20 to 85 degrees with the shoreface, with a general southwest-northeast trend.

Stubblefield and others (1975) described the texture of ridge and swale sediments on the central New Jersey shelf. Medium to fine sand with moderate sorting is found on the crests, while fine sand with moderate sorting is found on the flanks. Trough sediments consist of two types; coarse, poorly sorted sands, and very fine, well sorted sands. Other studies relating shelf topography to sediment texture were performed by Frank and Friedman (1973), and Hall (1980).

NEARSHORE SEDIMENT CHARACTERISTICS

Sediment Color

Several workers have attempted to relate the color of continental shelf sediments to their depositional environment. Emery (1968) and Stanley (1969) believed that coarse, well sorted, yellow to brown iron stained sands are relict sediments that were deposited subaerially during the Pleistocene, and are unrelated to the present sedimentary environment. Stanley (1969) found no correlation between color and physiography or texture of shelf sediments between Cape Cod and Cape Hatteras. The olive-green color of some sediments is ascribed to coatings of ferric iron- rich clay minerals (Keller, 1953), rather than oxidation or reduction of iron rich minerals in the sediment (Stanley, 1969). Sanders and others (1970) inferred that brown, coarse-grained shelf sands were subaerially oxidized, while gray, fine-grained sands generally remained below the water table of the exposed continental shelf during Pleistocene lowered sea levels.

Swift and Boehmer (1972) concluded that shelf sediment color is largely a function of grain size, which influences the chemical microenvironment of the depositional site. Coarse sands which are commonly found on ridges are inherently more permeable than fine sands, and are likely to have oxidized yellow to brown iron coatings. Fine sands with typically poorer sorting and higher percentages of clay minerals, are likely to be less permeable and less oxidized than coarse sands, and are colored olive or gray. Thus, Swift and Boehmer reject the use of pigment as the only criteria for distinguishing between relict and recent shelf sediment.

Hall (1981) found a good correlation between color and bathymetry on the southern New Jersey inner shelf. Ridge samples range from yellowish brown to orange, while troughs contain olive-gray to grayish black sediment. This color distribution is also related to texture: the olive gray to grayish black sands tend to be finer, with larger mud fractions, while the yellowish brown to orange sands tend to be coarse.

Clay Mineralogy

A number of provenance studies using clay mineralogy as tracers have been performed on the eastern United States inner shelf, and in the adjacent Atlantic Ocean (Biscaye, 1965; Berry and Johns, 1966; and Hathaway, 1972). These studies have shown that illite and chlorite dominate the clay mineralogy of the northern Atlantic Ocean ("northern assemblage"), while kaolinite and smectite (montmorillonite) dominate the clay mineralogy of the southern Atlantic Ocean ("southern assemblage"; Hathaway, 1972). The northern assemblage clays also contain traces of kaolinite, hornblende, smectite, and plagioclase.

Kelley (1980, 1982), and Hall (1981) studied the fine sediments of the southern New Jersey inner shelf, and noted the similarity between the clay mineralogy of this region, and the "northern assemblage" of Hathaway (1972). Kelley (1982) found slight differences between beach, bottom, and suspended sediment mineralogy near Cape May peninsula. He suggests that beach and bottom material may receive input from eroding Cape May peninsula sea cliffs. Hall used the distributions of adsorbed trace metals as evidence for a

Delaware Bay source for southern New Jersey inner shelf clays. However, no comprehensive study of the clay mineralogy of the entire New Jersey inner shelf exists.

CIRCULATION AND SEDIMENT TRANSPORT

Nearshore Zone

Within the surf zone, longshore currents are produced when waves break at an angle to the shoreface (Komar, 1976). The direction of the resulting littoral drift on the New Jersey coast diverges near Manasquan (Duane and others, 1972; figure 6). North of this area the drift is northerly toward Sandy Hook; south of this area the drift is southerly toward Cape May.

While the net longshore flow patterns on the New Jersey coast are fairly well established, short term and seasonal flow reversals are common. The dominance of fair-weather swells may produce a northward shore-parallel drift on the entire New Jersey coast during the late summer, while dominance of storm related circulation produces a southerly shore parallel drift during the winter (Bumpus and Lauzier, 1965).

The New Jersey shoreline is classified as mesotidal, with a semi-diurnal tidal range of 2 to 4 meters (Davies, 1964). Tidal currents consist of both reversing currents in and near coastal inlets, bays, estuaries, and rotary currents in the nearshore zone (Charlesworth, 1968). Reversing tidal currents near the large

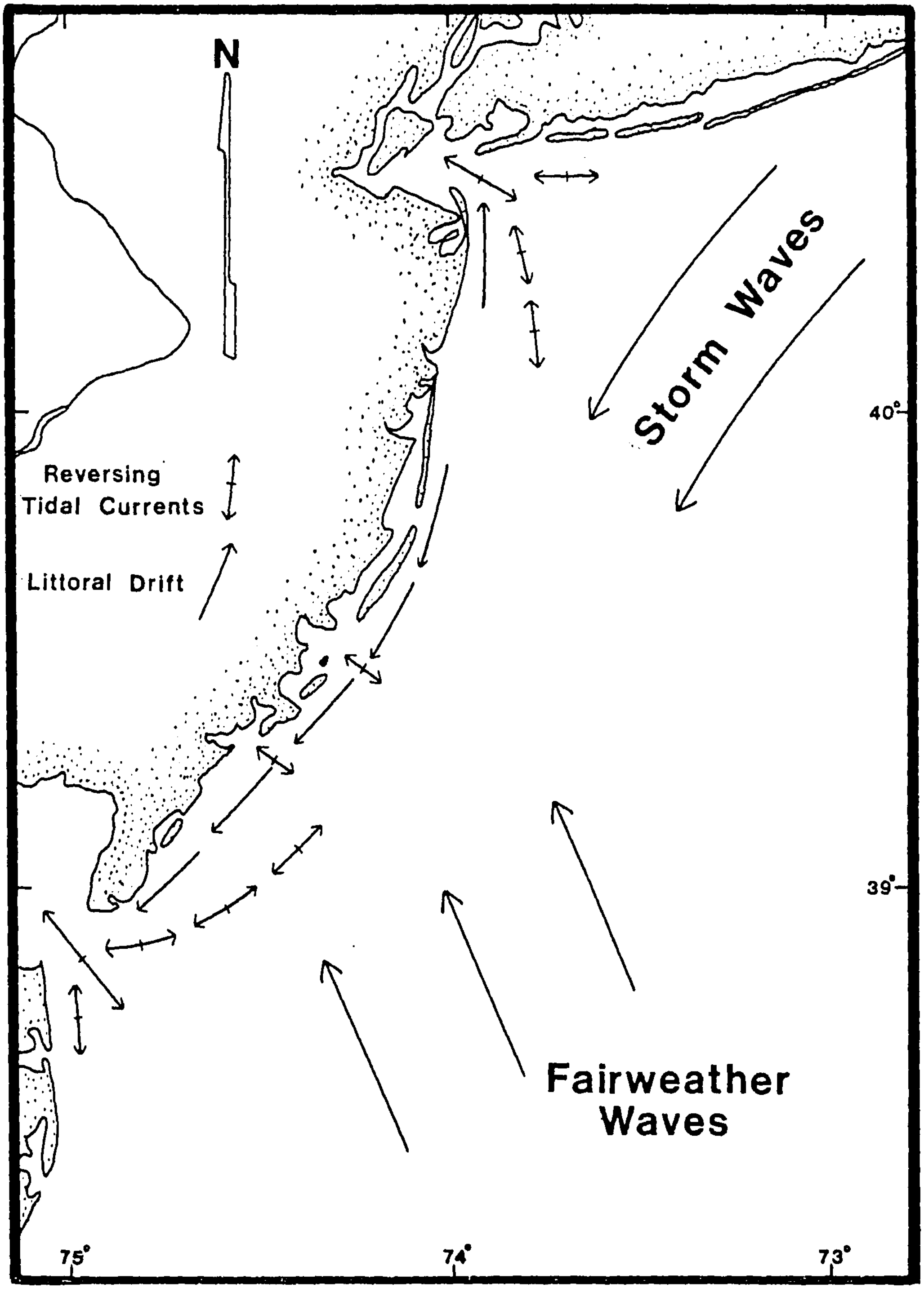

Figure 6. Net littoral drift, tidal current, and offshore wave directions on the New Jersey coast (after Bumpus and Lauzier, 1965; Duane and others, 1972; and Lynch-Blosse and Kumar, 1976).

estuaries create an oscillatory shore parallel flow. Flood tides draw water into Delaware Bay and the Hudson River estuary, with a reverse flow direction during ebb tides (figure 6; Kelley, 1980).

DeAlteris and Keegan (1977) measured coastal drift between Cape May and Little Egg Inlet with current meters, and surface and sea bed drifters. With drifters released about 3 kms offshore, they noted average onshore surface drift rates of 2 cm/sec (1600 m/day), and average onshore bottom drift rates of 0.5 cm/sec (400 m/day). The average shore parallel oscillatory currents in this area are about 30 cm/sec, with a range of from 0.3 to 45 cm/sec . Therefore, the velocity of drifters from release point to the beach is generally much less than absolute longshore current velocities at the release point. A shoreward moving parcel of water undergoes many shore-parallel and onshore-offshore cycles before reaching the beach. DeAlteris and Keegan attribute this current pattern to the boundary effect of land on the nearshore circulation pattern, which results in a decreasing onshore velocity as water approaches the shoreline.

Fine-grained sediment may be kept in suspension in the nearshore zone by shore-parallel advective currents (Drake, 1976; McCave, 1972), and/or by a "littoral energy fence" (Swift, 1976a), which results from the landward directed asymmetery of wave surge in nearshore waters. Fine sediment reaches the nearshore zone from rivers, onshore transport from the continental shelf, and through shoreface erosion of older deposits. Concentrations of suspended sediment are greater in nearshore waters (> 1 mg/l), than on any other part of the shelf (Manheim and others, 1970). At the present time, little suspended matter bypasses the inner shelf (Meade, 1972).

subheading(Rivers and Estuaries) The Delaware and Hudson River estuaries strongly influence circulation patterns and sedimentation on the New Jersey coast. Both rivers have a relatively high freshwater discharge (>550 cubic meters/sec, or 20 cubic kms/yr), and a relatively low sediment discharge (<1 * 10E6 metric tons/yr) compared to the major rivers of the southern Atlantic Coastal Plain (Meade and others, 1975).

Lowered Pleistocene sea levels and increased runoff from glacial meltwater enabled the Delaware and Hudson rivers to erode deep valleys. The Holocene transgression inundated the Hudson and Delaware River channels, creating large estuaries which trap much of the river sediment (Meade, 1969). In contrast, southeastern Atlantic coast rivers tend to be smaller, travel through deeply weathered terrain, carry a greater suspended load, and have largely filled their estuaries (Meade, 1969; Milliman and others, 1972).

Meade and others (1975) estimate that more than 90 percent the suspended sediment carried by rivers between Cape Cod and Chesapeake Bay is deposited in estuaries. Meade (1969), however, suggested that river-borne sediments may be transported out of estuaries during the flood stage of a river. Drake (1977) observed surface water containing 2-5 mg/l suspended matter moving out of Raritan sediment are greater in nearshore waters (> 1 mg/l), than on any other part of the shelf (Manheim and others, 1970). At the present time, little suspended matter bypasses the inner shelf (Meade, 1972).

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Bay, and south along the New Jersey coast on ebb tides. Kelley (in press) observed sediment plumes in satellite imagery moving southwest to northeast out of Delaware bay on ebb tides. Although the composition and depositional sites of this material are unknown, Kelley (in press) believes that this material is derived from resuspension of inner shelf and northeast Delaware Bay mud.

In addition to the retention of continental sediment in the Delaware and Hudson River estuaries, recent evidence suggests that these basins are sinks for continental shelf sediments (Meade and others, 1975). Net longshore drift patterns on the New Jersey coast carry beach and nearshore sediment into these estuaries (Meade, 1969). Sea bed drifter studies indicate net movement of continental shelf bottom waters into estuaries (Bumpus, 1965). Hathaway (1972), and Sawhney and Frank (1978), noted that fines in the lower reaches of Middle Atlantic Bight estuaries are often more similar in composition to continental shelf clays than river clays, indicating the dominance of a shelf source in estuaries.

The small rivers and streams of the New Jersey Coastal Plain appear to contribute little sediment to the nearshore region. These rivers travel over an unconsolidated substrate of sand and gravel with a low topographic gradiant (Patrick and others, 1979). The Mullica River system is one of the larger drainage basins in the area. The average discharge of the Mullica River is about 2 cubic meters/sec, and the river is diluted by sea water at least 20 kms upstream (Durand, 1979). Damaging floods are infrequent, as the high permeability of the substrate allows for absorption of excess precipitation. Most coastal rivers discharge into back barrier lagoons or small estuaries. Sediment contribution from these rivers is probably very small, and most material is probably deposited in the lagoons, or in the upper reaches of the estuaries.

Inner Continental Shelf

Bumpus (1965, 1973) and Bumpus and Lauzier (1965) summarized the surface and bottom drift on the Middle Atlantic shelf (figures 7 and 8). Surface drift off New Jersey has a net southwesterly (shore parallel) flow of 10 to 20 km/day (10 to 20 cm/sec) or less. A late summer-early fall flow reversal is common, with a net northeasterly drift of less than 10 km/day (10 cm/sec) within 40 kilometers of shore. Northerly drift toward New York Harbor off the northern third of New Jersey is strongest in the summer months, diminishing during the winter. There is a net offshore component to the surface drift on the outer two thirds of the shelf during the late autumn and winter.

The data for sea bottom drift indicates a net onshore water movement over the inner two thirds of the New Jersey shelf of roughly 0.4 to 1.0 km/day (0.4 to 1.0 cms/sec). Bottom drift diverges between Long Branch and Point Pleasant similar to longshore drift; flow north of this region enters New York Harbor, and southerly flow trends toward Delaware Bay (figure 8).

Winter storm conditions produce southwesterly flows that are

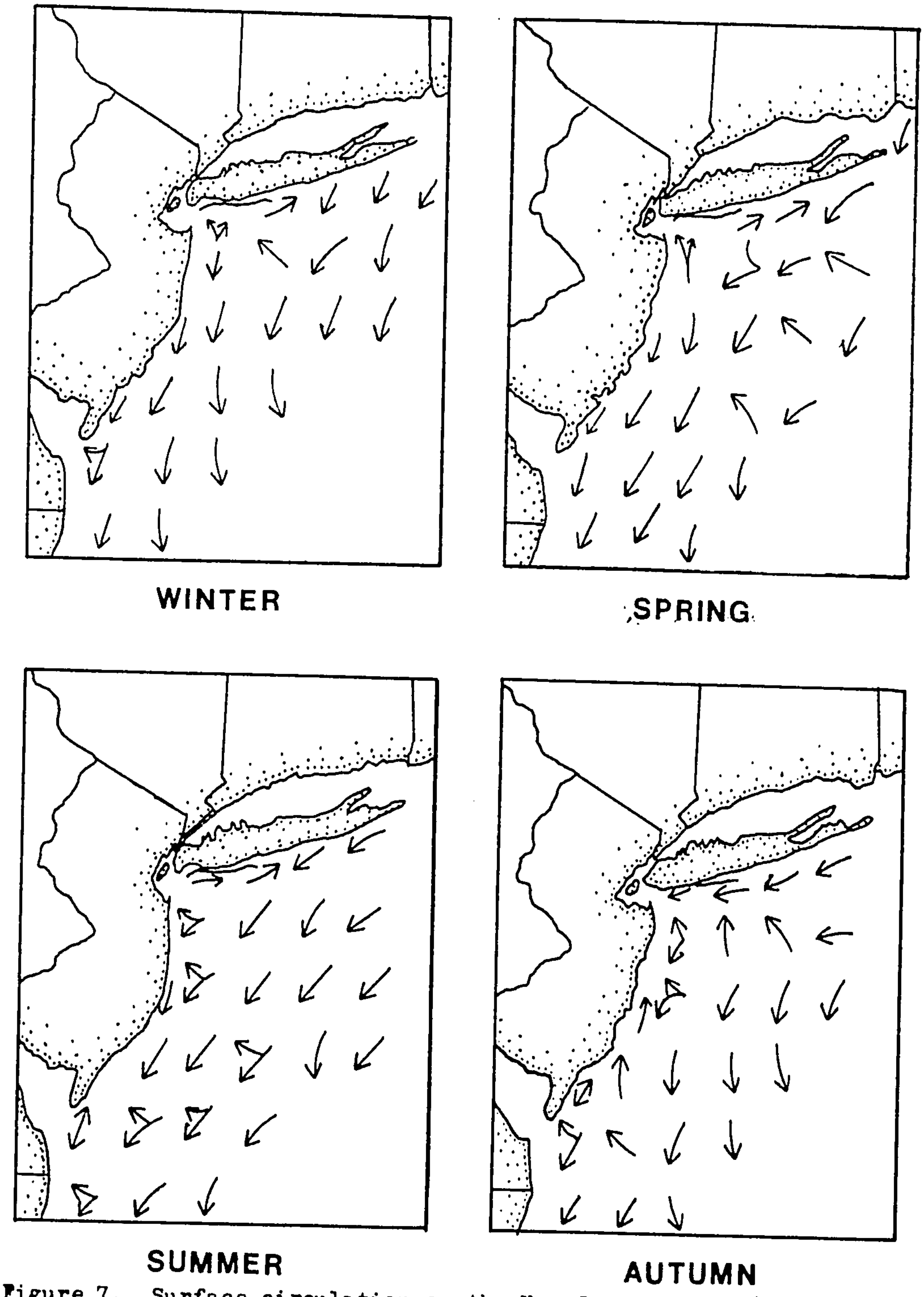

Figure 7. Surface circulation on the New Jersey shelf (from Bumpus and Lauzier, 1965).

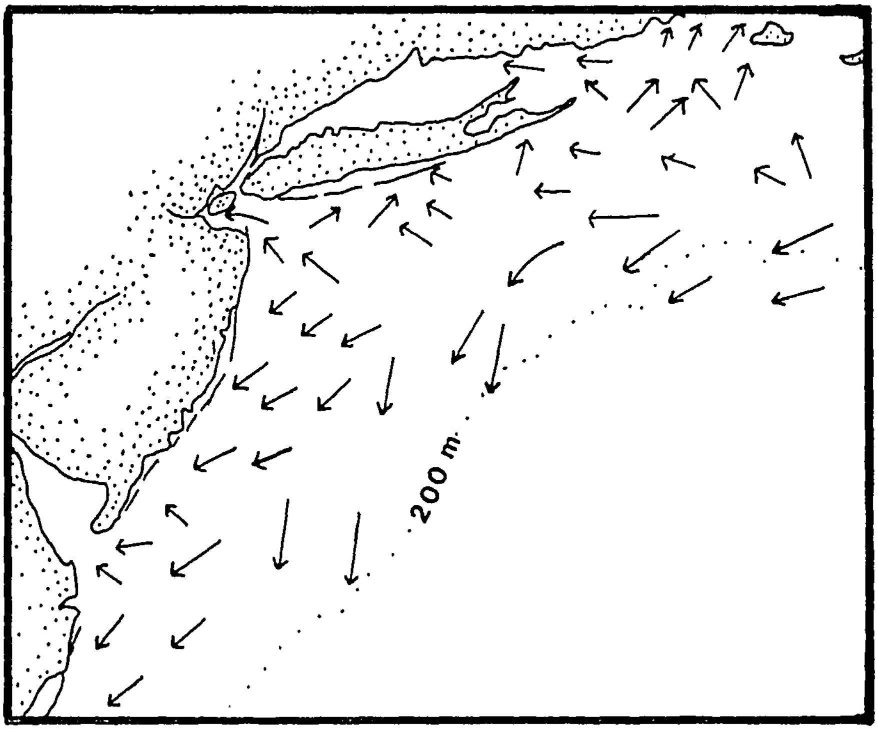

Figure 8. The net bottom current directions as determined form sea bed drifter studies (from Bumpus, 1965).

more intense and more uniform than fairweather flow patterns. Near bottom (<2 m) currents on the Middle Atlantic shelf range from less than 5 to 20 cms/sec for calm periods during the summer and winter, and 30 to 60 cms/sec during typical winter storms (McClennan, 1973; Butman and others, 1976; Lavelle and others, 1978).

The summer fair weather current regime on the shelf is competent to winnow and rework bottom sediments, and transport fine material already in suspension (Swift, 1976b). McClennan (1973) calculated that sediment entrainment by waves and/or currents is possible up to 30 percent of the time on the central and outer New Jersey shelf. Lavelle and others (1978) noted that fair weather motion of tracer sand on the Long Island inner shelf is mainly diffuse in nature, with no primary fair weather movement direction observed. A single two day storm produced the greatest amount of unidirectional sand transport.

Despite the evidence for shelf sediment movement, readily apparent compositional boundaries for certain sediment parameters (for example; percent feldspar (Milliman and others, 1972), heavy mineral suites (Schroeder,1981)) indicates that net transport of sand size material on the shelf may be small.

SAMPLE COLLECTION

Beach samples were collected during the summer of 1979. The sites were chosen to correspond as closely as possible to locations selected by McMaster (1954). Relocation of McMaster's sampling sites was probably only accurate to within several hundred meters, due to changes in beach configuration, and restricted access to certain beaches (B1-B27, figure 9).

At each site, 2-3 kg of beach sediment was collected. A plastic shovel was used to scrape off less than 1 cm of beach sediment at an elevation 0.3 to 0.6 m below the high tide line, in order to insure that only the most recent sedimentation layers were sampled (MacPherson and Lewis, 1978).

Continental shelf sediments were collected during the summer of 1980, using a Smith-McIntyre grab sampler. Samples were selected along a nearshore (2 to 6 kms offshore; A31-A49) and an offshore (7 to 20 kms offshore A2-A24) traverse (figure 9). Water depth at each site was recorded with a fathometer, and position was determined by Loran A.

The color of each sample was recorded with a Munsell color chart (appendix 1). Color determinations were repeated in the laboratory after a year of storage in sealed plastic bags at 2 degrees C with little change in the values observed.

Several samples previously collected by Hall (1981) were examined in this study (samples MJ3, MJ22-MJ27, figure 9). These

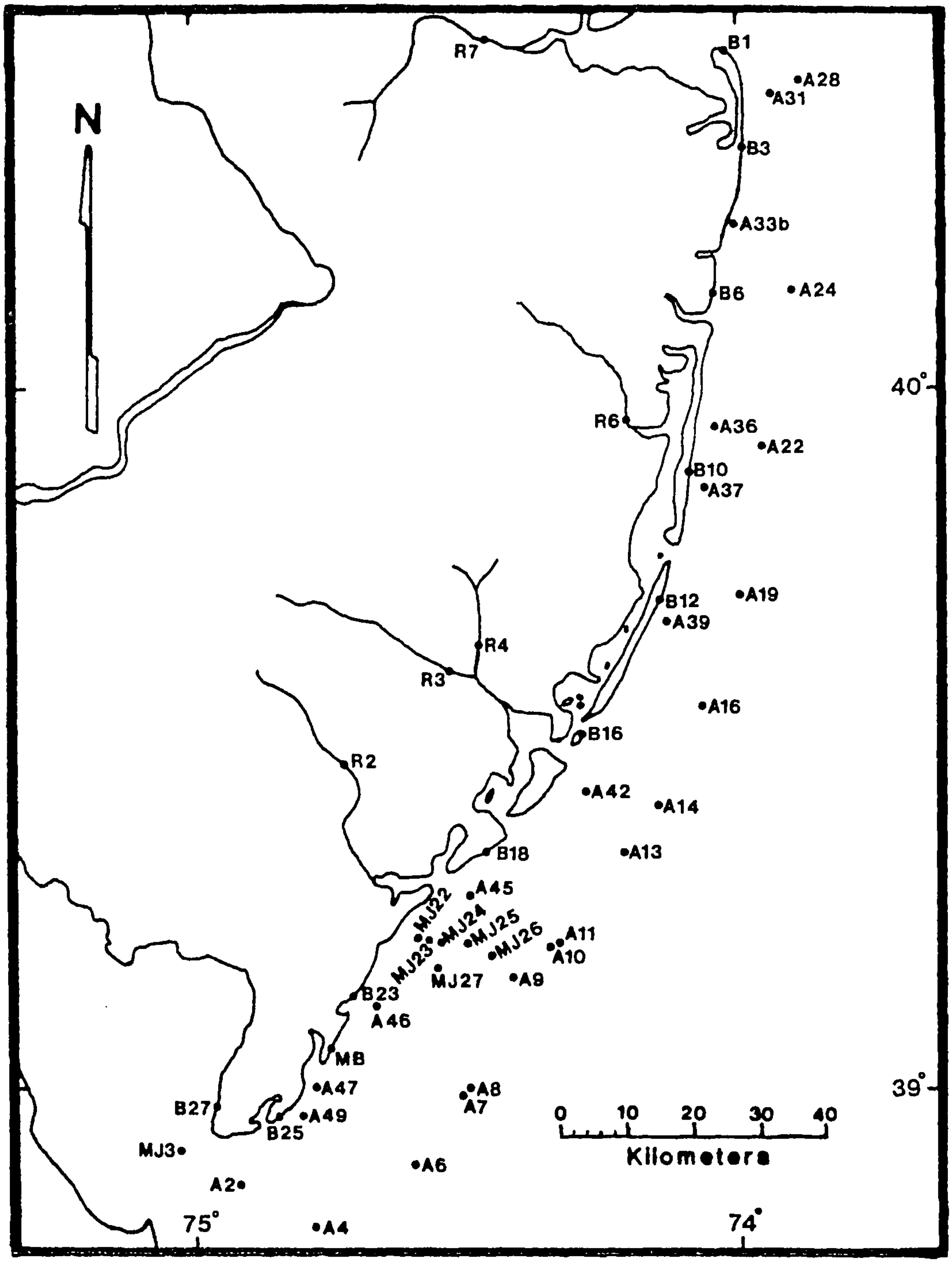

Figure 9. Location of beach (B1-B27), offshore (A2-A49, MJ22-MJ27), mudball (MB), and river (R2-R7) samples.

include six samples from the southern New Jersey inner shelf, and one from the mouth of Delaware Bay. Five of the shelf samples (MJ22-MJ26) make up a coast-perpendicular traverse from 4 to 16 kms offshore near Great Egg Harbor Inlet (figure 9).

A mudball (MB, figure 9) collected from a washover fan at Stone Harbor, New Jersey was also examined. This material has been radiocarbon dated at between 20,000 and 25,000 years BP, and is thought to be a fragment of a Pleistocene continental shelf clay layer that was eroded from the shelf and emplaced on the beach during a storm (Meza and Paola, 1977).

Several rivers that drain the Coastal Plain province were also sampled (R2-R7) using a VanVeen grab sampler (figure 9).

PHYSICAL CHARACTERISTICS OF SEDIMENT TEXTURE

TEXTURAL ANALYSIS

Size analysis of beach and shelf samples was performed using standard techniques of sieve and pipette analysis (Ingram, 1971; Galehouse, 1971). The fraction weights of each sample were entered into a computer program (SEDAN), which calculated fraction weight percentages, and other statistical parameters (appendix 2). In addition, the textural distribution (weight percentages in each phi size class) of each sample were subjected to an R-mode factor analysis, in order to identify characteristic size fractions in beach and inner shelf sediments.

Pipette analyses were initiated on 41 samples, but it quickly became apparent that only a few samples contained a significant amount of fine sediment. For samples with little fine fraction (<2 percent material finer than 4 phi (62 um)), it was impossible to accurately resolve the weight of each size fraction using the pipette technique. Samples which contained less than 2 percent fines were run through the SEDAN program in three separate trials. The unresolved fines were grouped in either the 7-8 phi (4-8 um) size class, the >11 phi (<.5 um) size class, and in one trial, were omitted altogether. The resulting values for mean and standard deviation (computed using the method of Folk, 1966) computed for each trial never deviated by more than 0.03 phi. The results which assumed unresolved fines at 8 phi are used in this study (appendix

3).

The size distribution of beach and shelf sediments is shown in figure 10. Sand-sized material dominates most samples. All of the beach samples contain >98 percent sand, and 22 of 30 shelf samples contain >94 percent sand. Two southern shelf samples (MJ3, MJ24) and the mudball sample (MB) contain significant amounts of mud (>15 percent material finer than 4 phi (64 um)), and 5 shelf samples (A4, A16, A19, A22, A24) contain greater than 20 percent gravel (material coarser than -1 phi (2 um)).

A plot of sorting (standard deviation) versus mean grain size clearly separates the sand-rich samples from the samples with significant mud and gravel fractions (figure 11). Sandy samples have the best sorting (<1.2 phi-units), and mean phi sizes between 0.8 and 3.5 phi. Gravel and mud rich samples have high standard deviations (>1.4 phi-units), and low (<0.0 phi) and high (>4.0 phi) mean phi sizes respectively (figure 11).

The beach samples (average sorting value = 0.36 phi-units) tend to be better sorted than the shelf sands (average sorting value = 0.62 phi-units). An analysis of variance test of standard deviations shows that the beach and shelf samples comprise two distinct populations at the 95 percent confidence level. There is, however, considerable overlap, and some shelf samples are as well or better sorted than some beach sands.

The sand-rich samples are divided into two populations by their mean grain size (figure 11). The coarsest group has means in the

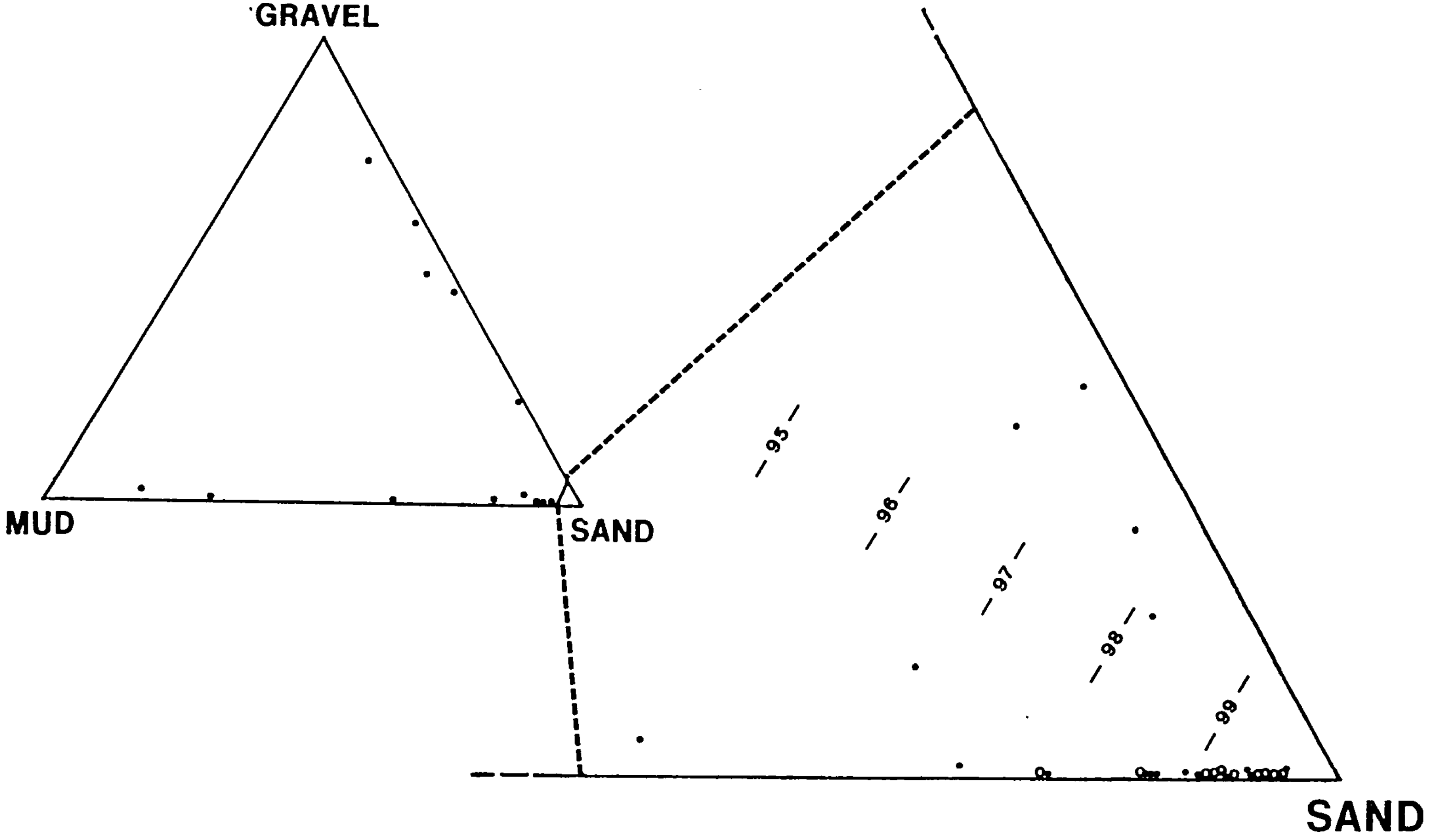

Figure 10. Textural distribution of beach and inner shelf samples. Dots represent shelf samples, while circles represent beach samples.

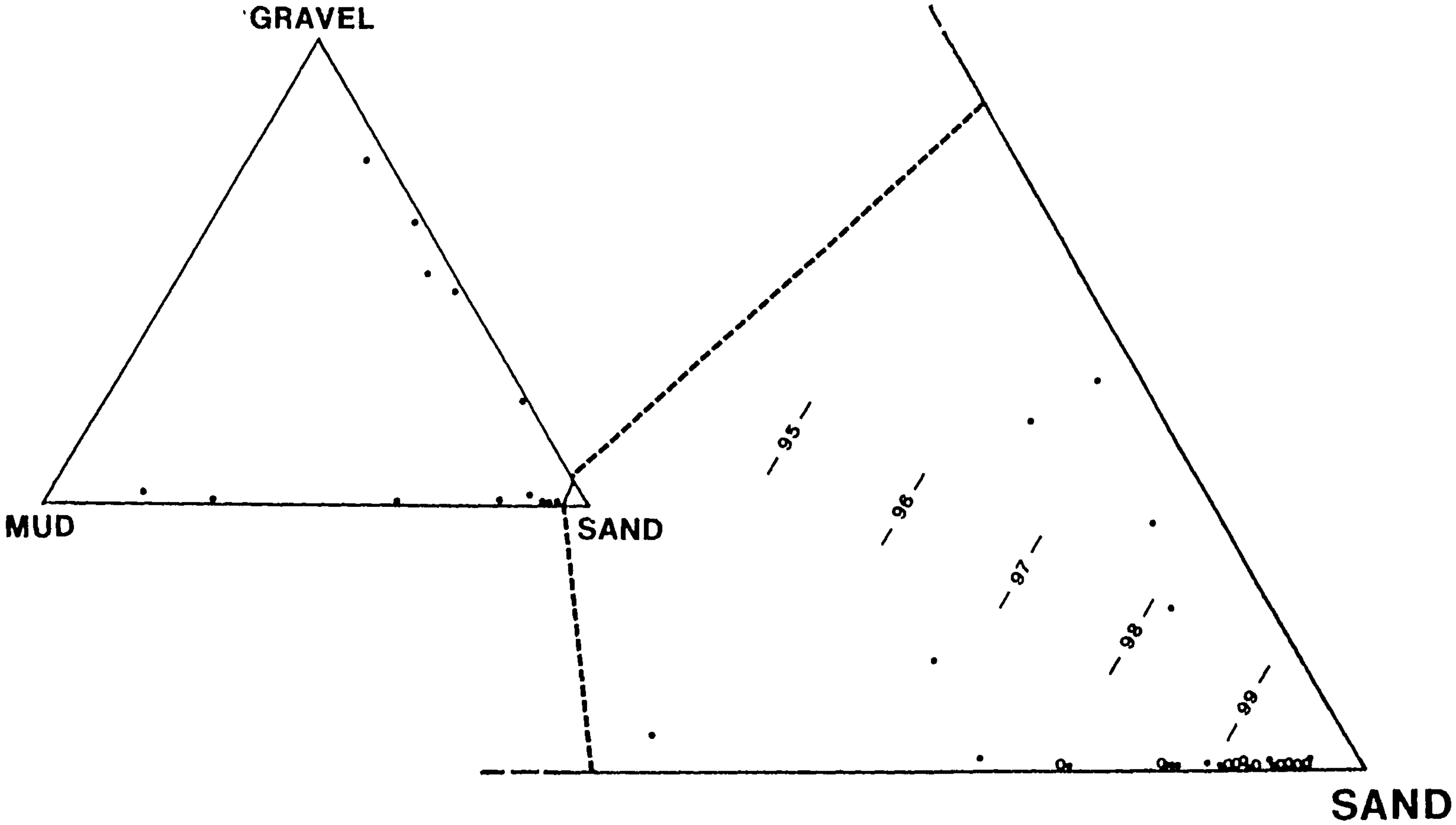

Figure 10. Textural distribution of beach and inner shelf samples. Dots represent shelf samples, while circles represent beach samples.

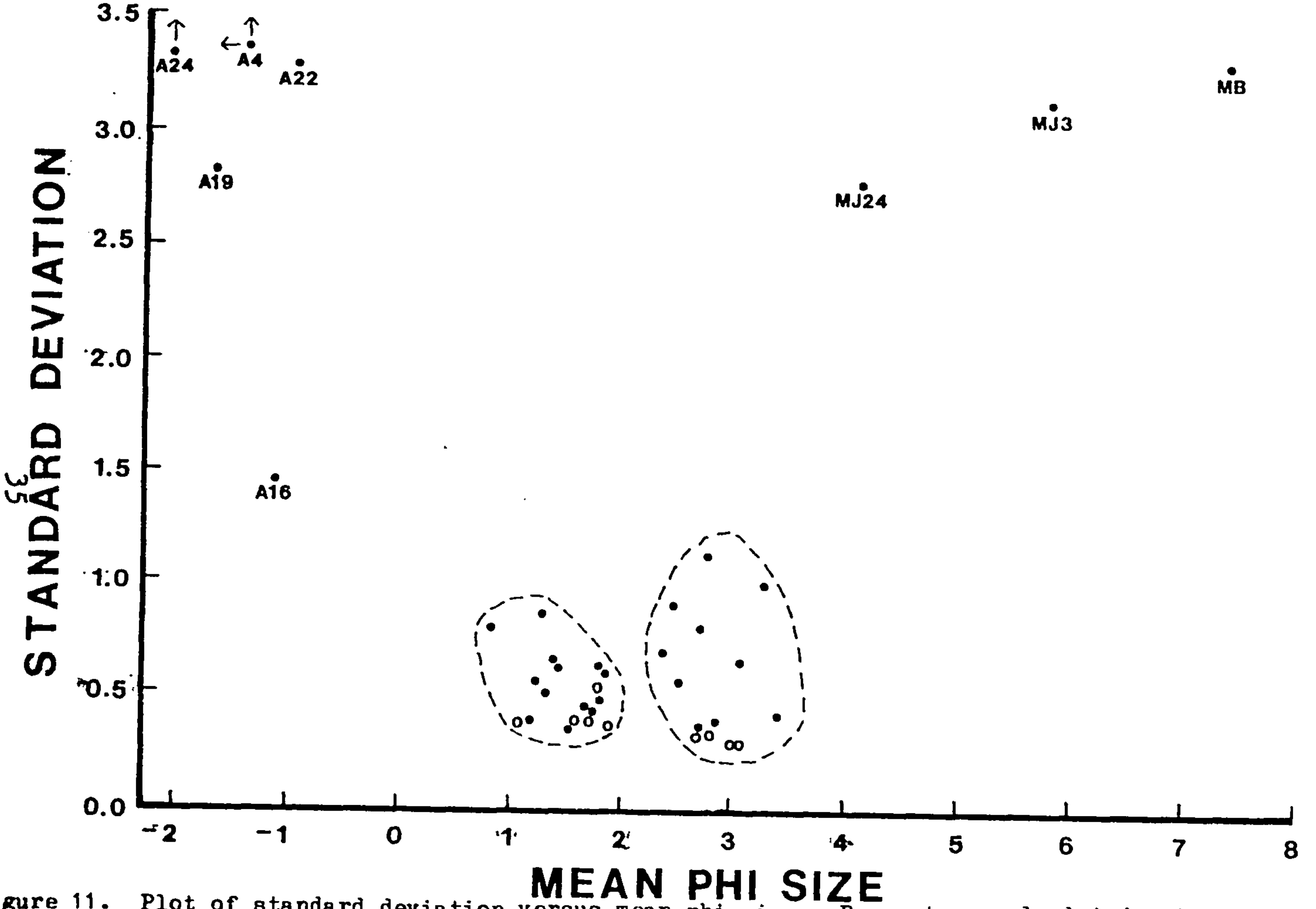

Figure 11. Plot of standard deviation versus mean phi size. Parameters calculated using the method of Folk and Ward (1954). Dots represent shelf samples; circles represent beach samples. Sample locations given in figure 9.

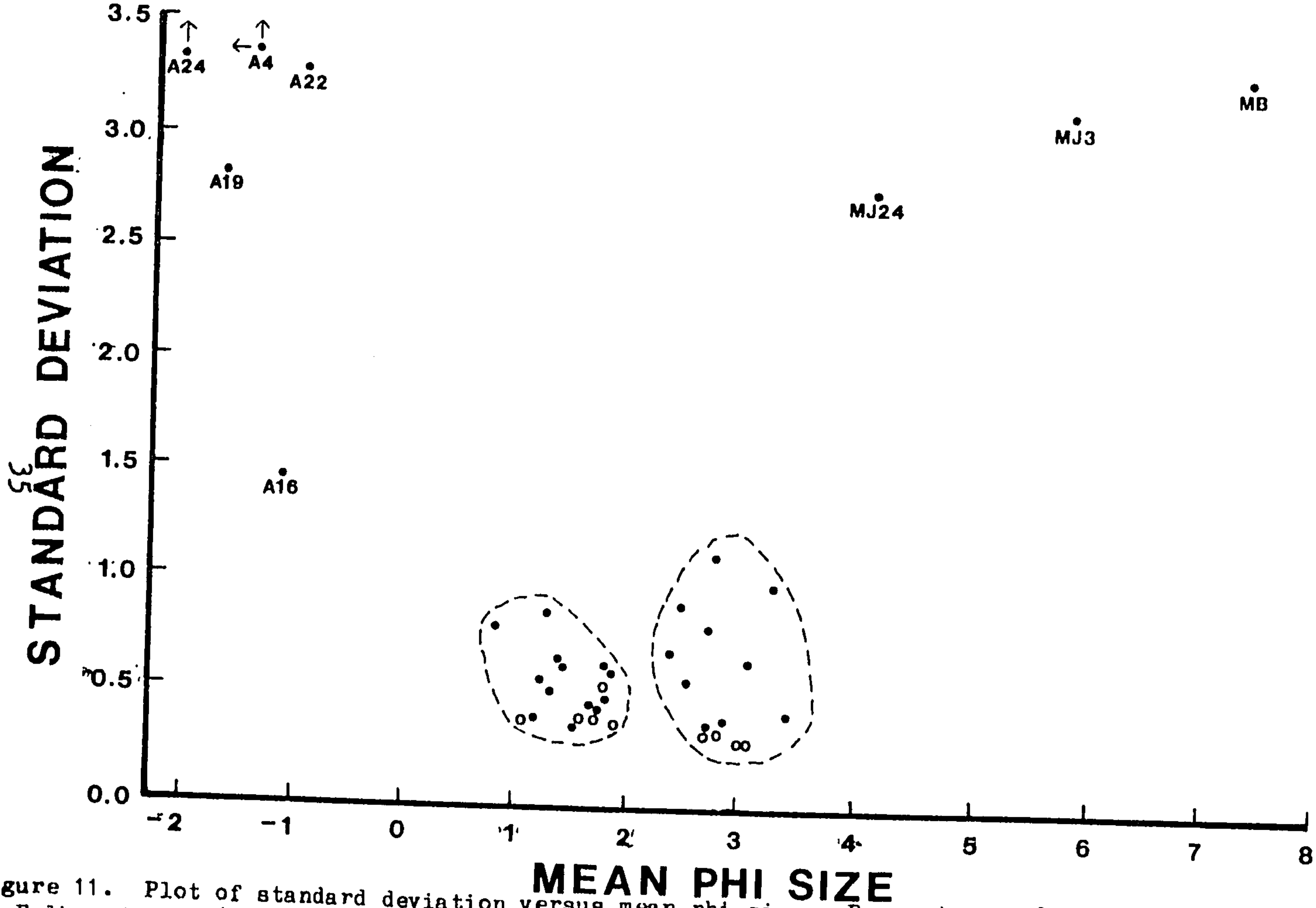

Figure 11. Plot of standard deviation versus mean phi size. Parameters calculated using the method of Folk and Ward (1954). Dots represent shelf samples; circles represent beach samples. Sample locations given in figure 9.

range of 0.7 to 1.9 phi (0.60 to 0.28 mm), while the fine group ranges from 2.3 to 3.4 phi (0.20 to 0.09 mm). A typical example of a size distribution for each sand-rich sediment type is shown in figure 12. Sand-rich samples are unimodal, with a mode in either the medium (A6), or fine (A9) to very fine sand fraction.

The gravel-rich samples (A4, A16, A19, A22, A24; figure 11) are bimodal. Each sample has a mode in the coarse to fine sand region, in addition to a gravel mode.

The textural distribution of the ten samples which contain significant amounts of fine fraction is presented in appendix 3. Kelley (1980, in press) found that the textural distribution of the mud fraction of shelf and mudball samples near Cape May is fairly uniform. Each sample possesses a primary mode finer than 11 phi, and several samples possess a secondary mode at 7 phi. He also found a positive correlation between the percent sand and the amount of fine (>11 phi) clay. The samples in the present study possess a primary mode in the >11 phi fraction, and several samples have a secondary mode at 5 or 6 phi. Beyond these similarities, the textural distribution of the samples is diverse, exhibiting no uniform pattern. Furthermore, there is no clear relationship between the amount of sand and fine clay in the present study.

R-mode factor analysis defines a series of factors, or linear combinations of variables. Each factor emphasizes one or more variables which can be used to recognize differences or similarities between samples. This technique was used to determine whether

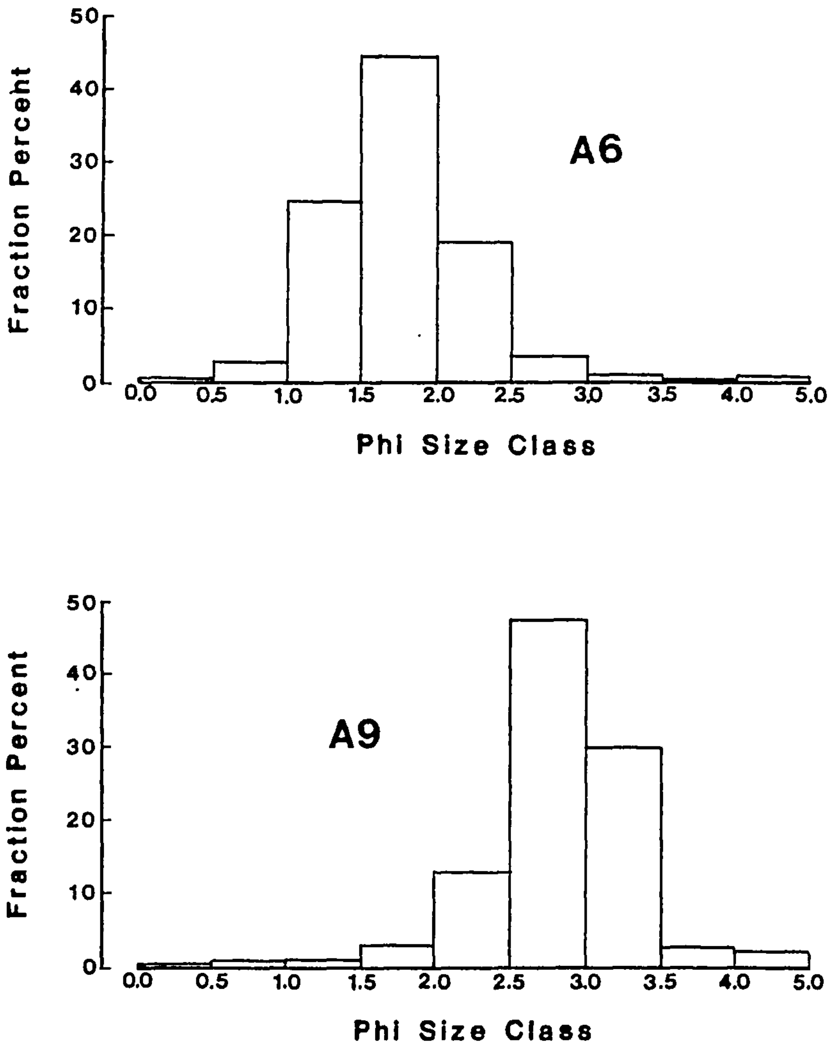

Figure 12. Histograms of a medium (A6) and a fine (A9) shelf sand, typical of the two types of sand found on New Jersey beaches and inner shelf. Sample locations given in figure 9.

significant groupings of similar sediment types exist on the New Jersey shoreline. The twelve variables used were the weight percent of each phi size from <-1.0 phi to >4.0 phi, in half phi intervals (appendix 3) (figure 13).

The R-mode factor analysis produced five factors which account for more than 88 percent of the total textural variability (figure 13). Factor one is characterized primarily by an enrichment in the -1.0 and -0.5 phi fractions. Factor two is enhanced in 3.0 and 3.5 phi material, and depleted in the 1.5 and 2.0 phi sizes. Factor three is slightly enhanced in 2.5 phi material, and depleted in sizes 3.5 and 4.0 phi. Factor four is enriched in sizes 0.0, 0.5 and 1.0, while factor five is enriched in greater than 5.0 phi material.

The normalized factor scores (factor values for each sample) are presented in appendix 4. Factors 1, 2, and 5 proved to be diagnostic for use in differentiating sediment types, while factors 3 and 4 produced ambiguous and inconclusive groupings. Figure 14 is a plot of normalized factor scores for factor five (enhanced 5.0 phi) vs. factor one (enhanced -1.0 and -0.5 phi). This plot simply separates the coarse (A4, A16, A19, A22, A24) and fine-grained (MB, MJ3, MJ24) samples (high in factor one and five respectively) from the sand rich samples (low in factors one and five).

Figure 15 divides the sand rich samples into the two populations first observed in figure 11. Samples with high factor two values are dominated by fine sand, while low factor two values

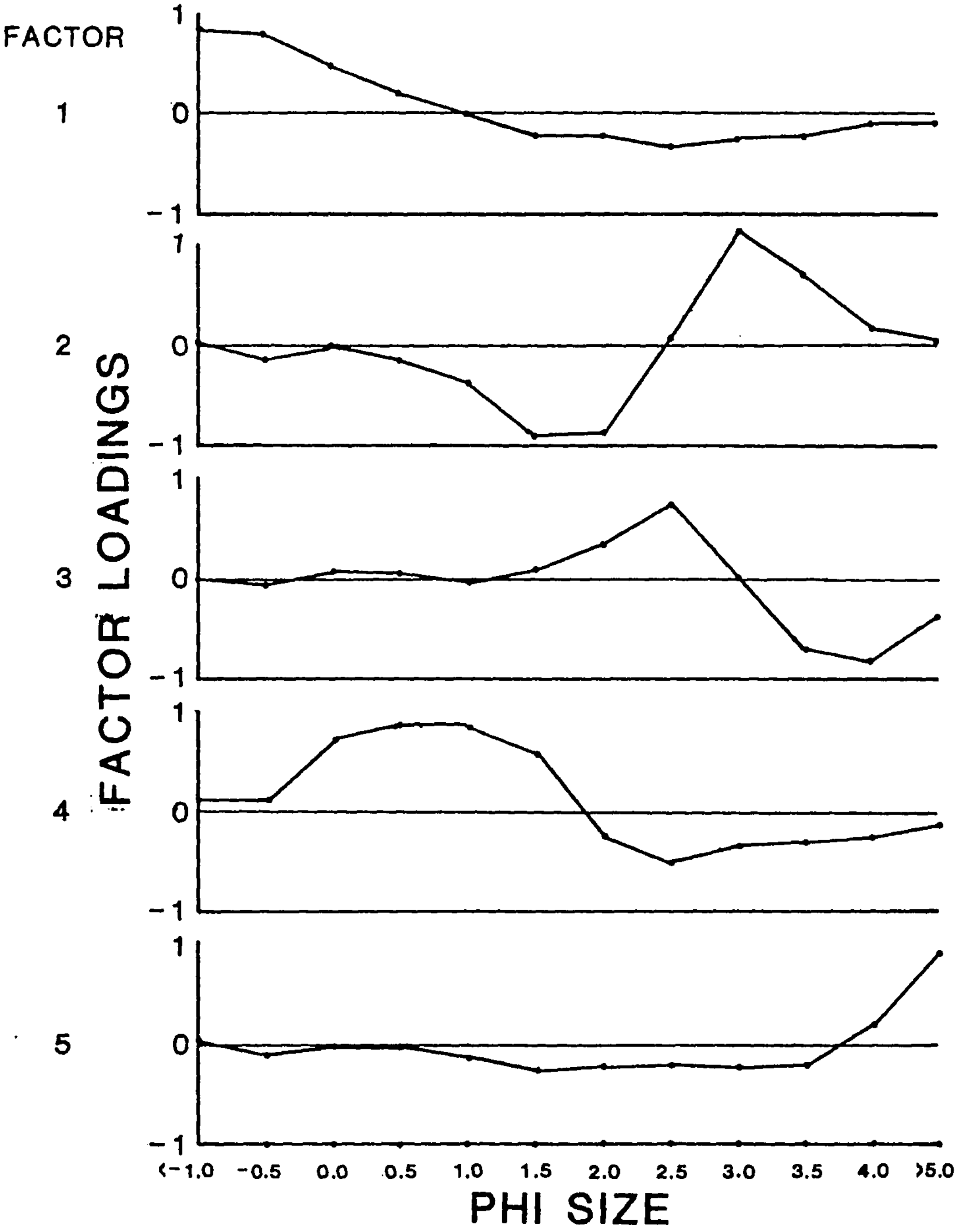

Figure 13. Factor loadings plotted against phi size for R-mode factor loadings.

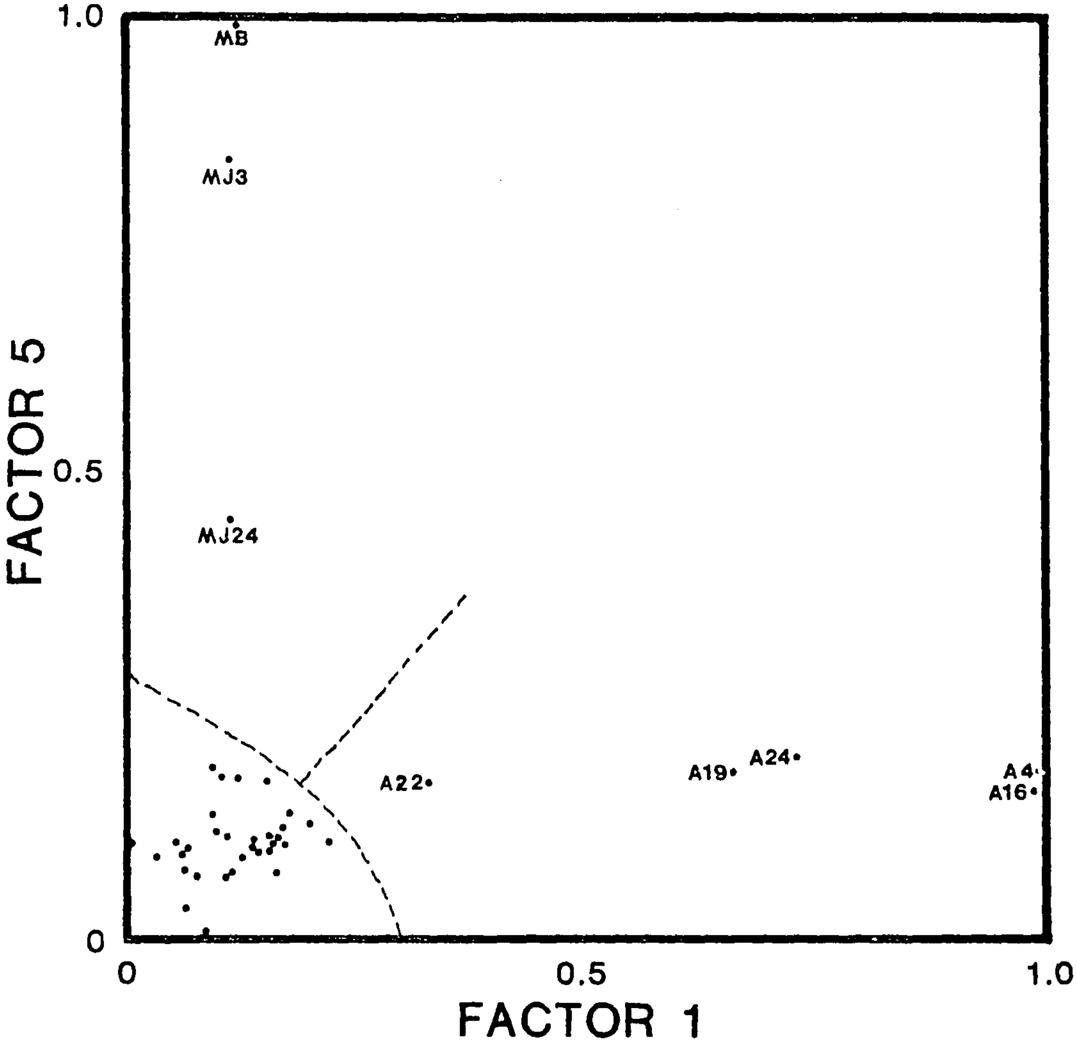

Figure 14. R-mode factor scores for factor five (enhanced 5.0 phi) verses factor one (enhanced -0.5 and -1.0 phi) for textural analysis. Sample locations given in figure 9.

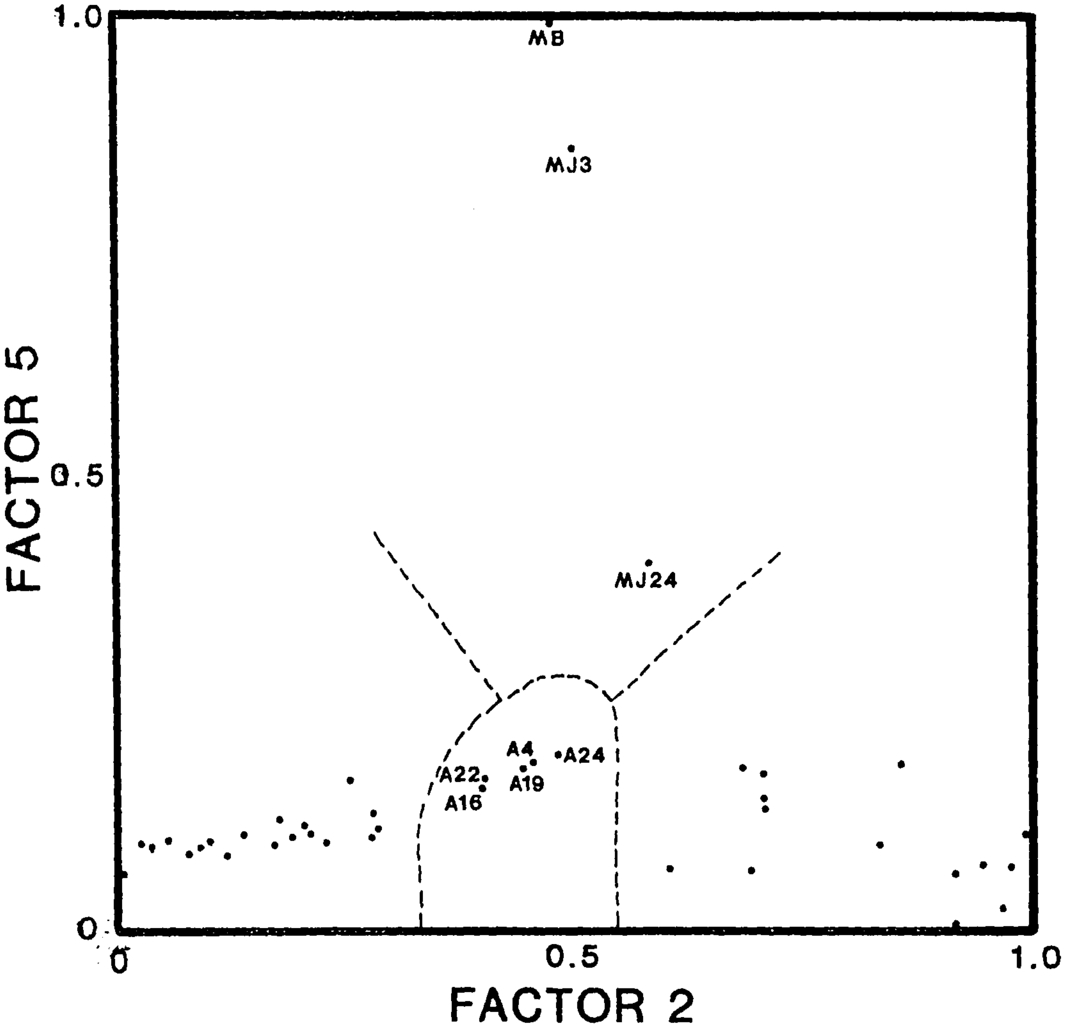

Figure 15. R-mode factor scores for factor five (enhanced 5.0 phi) verses factor two (enhanced 3.0 and 3.5 phi) for textural analysis. Sample locations given in figure 9.

indicate a dominance of medium sand. Samples with intermediate values for factor two (near 0.5) contain significant amounts of coarse or fine fraction, so the size distribution of their sand fraction is not diagnostic with respect to factor two.

The size fractions emphasized by R-mode factors 1, 2, and 5 were plotted on location maps to determine the areal distribution of sediment types on the New Jersey shore. Figure 16 displays the percentage of coarse sediment (-1.0 + -0.5 phi, emphasized by factor 1) in each sample. High concentrations (>20 percent) of coarse material are found offshore between Point Pleasant and Little Egg Inlet, and south of Cape May. Little or no coarse sediment is found on beaches, in nearshore samples, and in most of the offshore samples south of Little Egg Inlet.

The percentage of silt and clay in each sample (emphasized by factor 5) is plotted in figure 17. Greater than five percent fines are found in several of the nearshore samples, primarily off southern New Jersey. Few fines were found in offshore, or beach samples.

Samples dominated by fine sand (3.0 and 3.5 phi) occur on the beaches between Little Egg Inlet and Cape May, in some of the nearshore and offshore samples in this region, and in two northern samples (figure 18). Medium to coarse sands are found on the northern beaches and nearshore regions, on a Delaware Bay beach, and offshore south of Great Egg Harbor (figure 19).

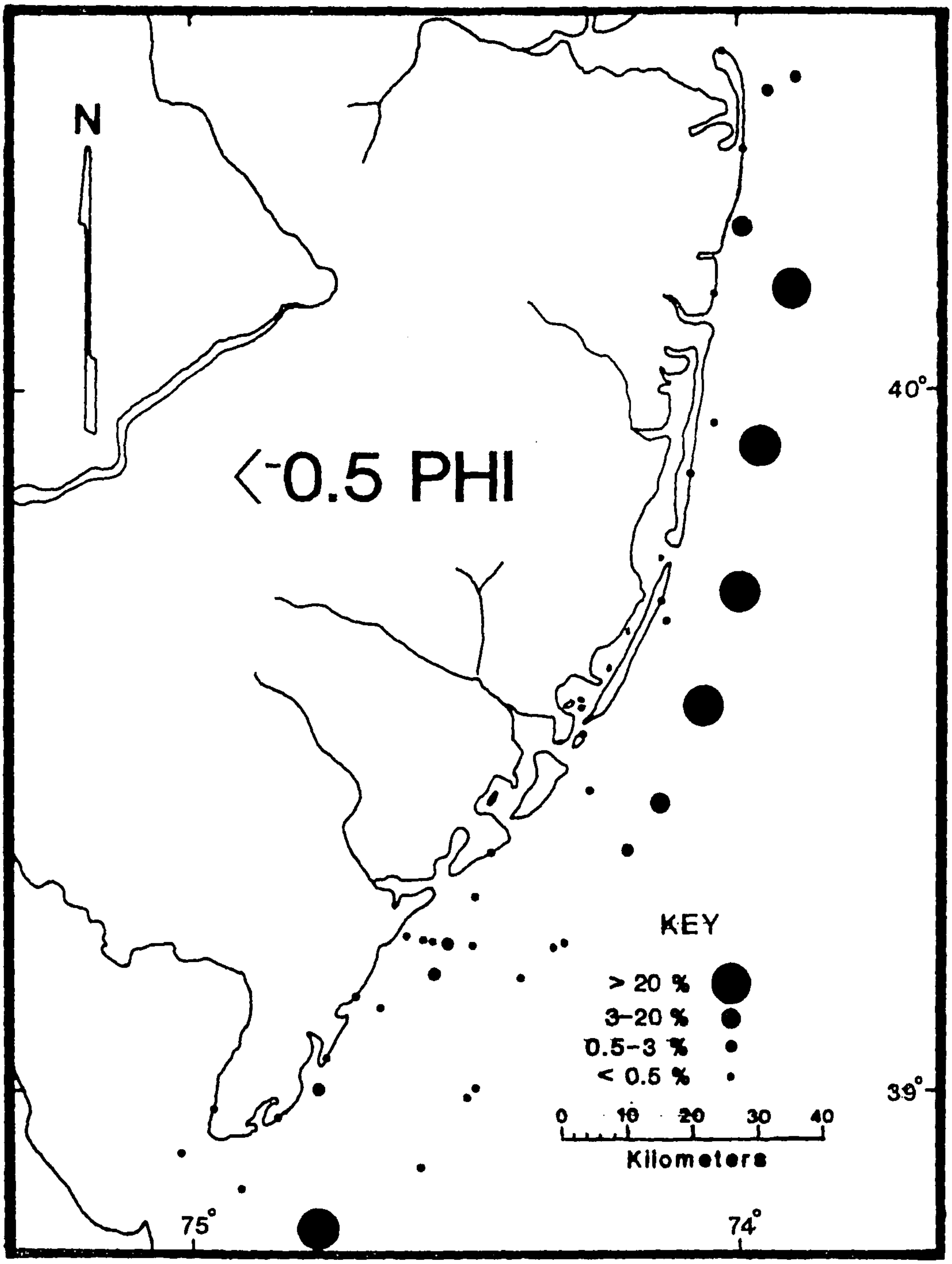

Figure 16. Percentage of total sediment coarser than -0.5 phi (1.44 mm).

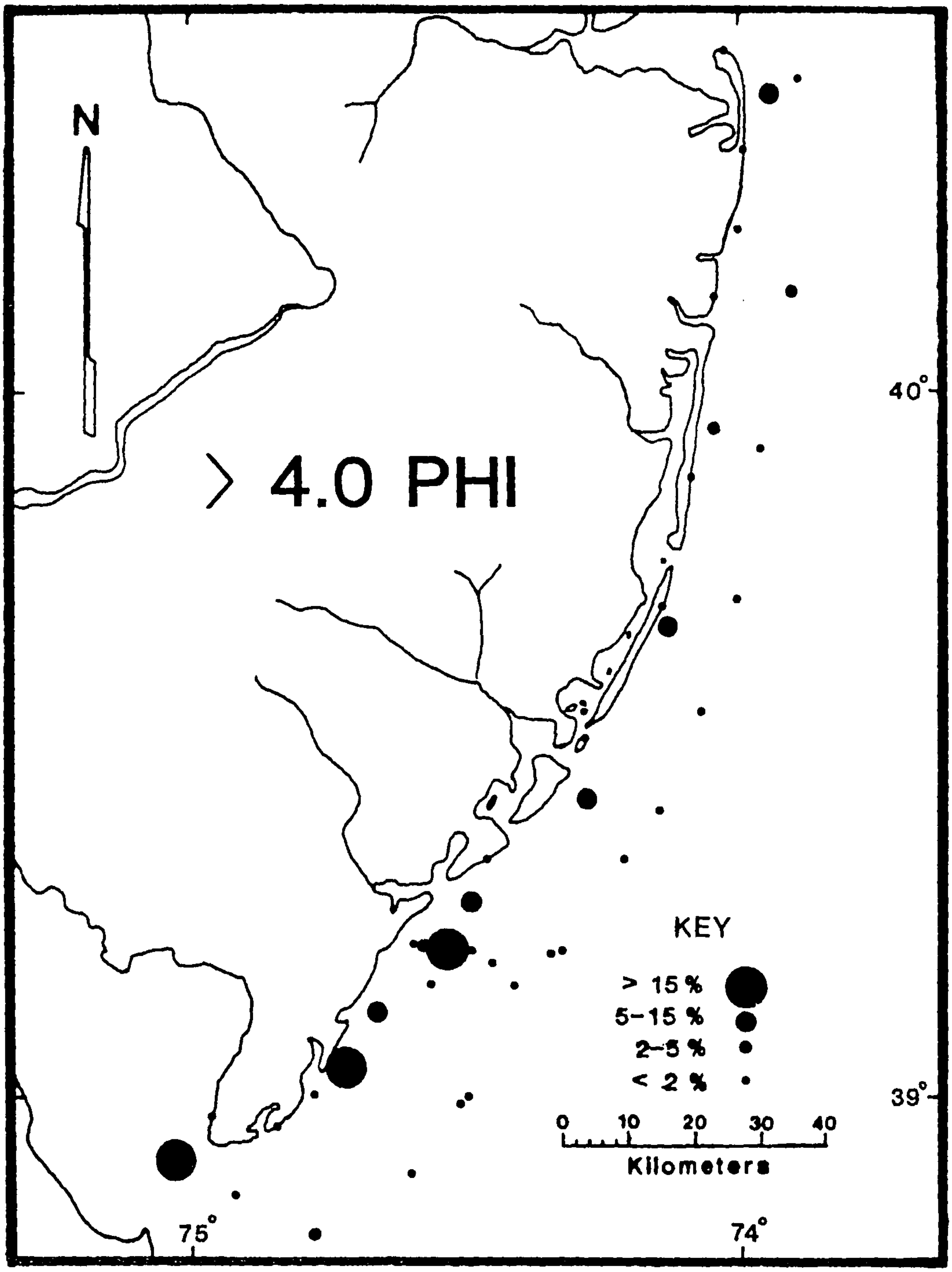

Figure 17. Percentage of total sediment finer than 5.0 phi (64 um). than 64 microns).

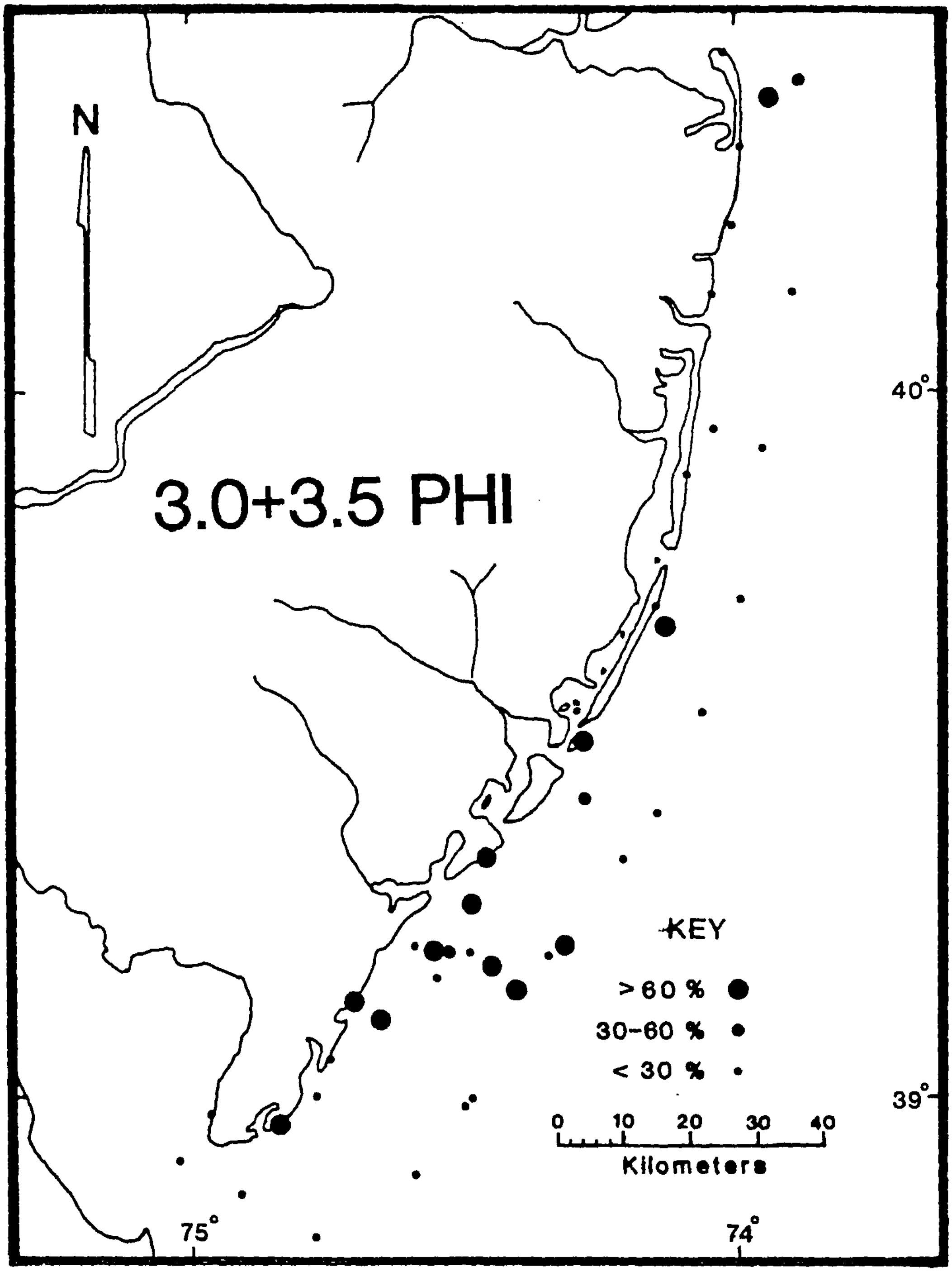

Figure 18. Percentage of total sediment in the 3.0 and 3.5 phi size classes (0.18 to 0.09 mm).

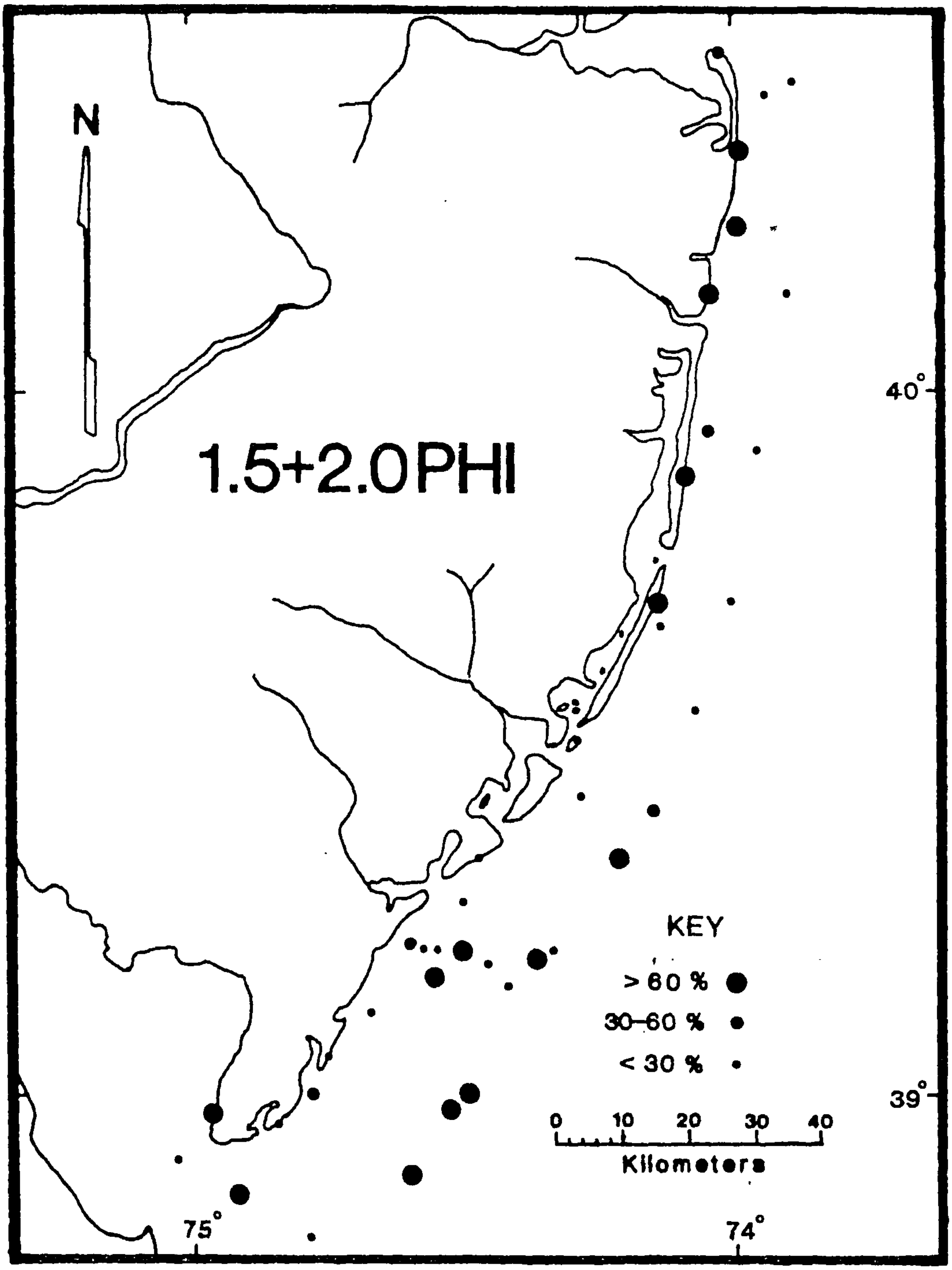

Figure 19. Percentage of total sediment in the 1.5 and 2.0 phi size classes (0.50 to 0.25 mm).

RELATIONSHIP BETWEEN BATHYMETRY AND TEXTURE

Despite the observed grouping of samples with similar textural distributions in the New Jersey nearshore region (figures 16-19), there is local variability in sediment texture. This is particularly true, for example, near Great Egg Harbor, where adjacent samples (figures 18 and 19) often are comprised of distinctly different sediment types. Shelf topography was examined to determine if some correlation existed between it and the marked textural variations.

There appears to be bathymetric control of sediment textures in some but not all samples. Most of the samples collected from ridge crests consist of medium sand (0.28-0.55 mm), while swale samples contain predominantly fine sand (0.06-0.19 mm) (table 2). This relationship between texture and bathymetry is illustrated in a sample traverse taken by Hall (1981) (figure 20).

SEDIMENT COLOR

Color determinations for beach, inner shelf, and river sediments are listed in appendix 1. Gravel and medium sand are generally light yellowish brown (10YR6/4 to 10YR5/3), to brown to light olive grey (5Y7/2 to 5Y6/2, 2.5Y6/3 to 2.5Y5/3). Fine sand and muddy samples range from black to dark olives and greys (2.5Y3/0, 5Y4/1, 5Y3/3 to 5Y3/1). There is however some overlap, and a number of medium and fine sand samples (B3, B18, B23, A4, A9,

	SAMPLE ID	MEAN PHI SIZE	TEXTURAL CLASS	COLOR
RIDGE SAMPLES	A8	1.66	MEDIUM SAND	2.5Y6/4
	A10	1.82	MEDIUM SAND	5Y6/2
	A14	0.86	MEDIUM SAND	10YR6/4
	A47	1.28	MEDIUM SAND	5Y4/3
	MJ22	1.51	MEDIUM SAND	10YR6/3
	MJ25	1.43	MEDIUM SAND	5Y7/2
	MJ27	1.34	MEDIUM SAND	2.5Y6/3
SWALE SAMPLES	A11	2.54	FINE SAND	5Y4/2
	A42	2.46	FINE SAND	5Y4/2
	MJ23	2.68	FINE SAND	5Y4/1
	MJ24	4.13	MUD	5Y3/2
	MJ26	2.71	FINE SAND	5Y4/3

Table 2. Texture (classification of Folk (1976)) and color (Munsell Color Chart) of ridge and swale samples.

	SAMPLE ID	MEAN PHI SIZE	TEXTURAL CLASS	COLOR
RIDGE SAMPLES	A8	1.66	MEDIUM SAND	2.5Y6/4
	A10	1.82	MEDIUM SAND	5Y6/2
	A14	0.86	MEDIUM SAND	10YR6/4
	A47	1.28	MEDIUM SAND	5Y4/3
	MJ22	1.51	MEDIUM SAND	10YR6/3
	MJ25	1.43	MEDIUM SAND	5Y7/2
	MJ27	1.34	MEDIUM SAND	2.5Y6/3
SWALE SAMPLES	A11	2.54	FINE SAND	5Y4/2.
	A42	2.46	FINE SAND	5Y4/2
	MJ23	2.68	FINE SAND	5Y4/1
	MJ24	4.13	MUD	5Y3/2
	MJ26	2.71	FINE SAND	5Y4/3

Table 2. Texture (classification of Folk (1976)) and color (Munsell Color Chart) of ridge and swale samples.

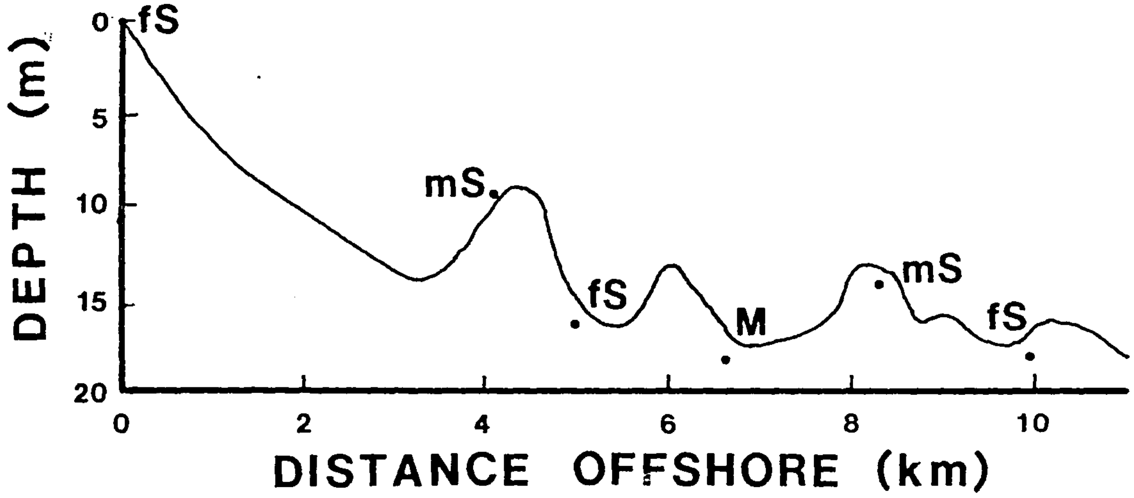

Figure 20. Cross-section of an inner shelf traverse, showing the texture of collected samples. Traverse consists of sample B23 from this study, and samples MJ22-MJ26 from the study of Hall (1981). Vertical exaggeration is 200x. Medium sand (mS) is found on the ridges, while fine sand (fS) and mud (M) are prevalent in the troughs. The cross-section is taken from NOAA Navagation Chart 12318 (32nd edition, 1979), while dots mark the water depths at each sample site recorded by Hall (1981).

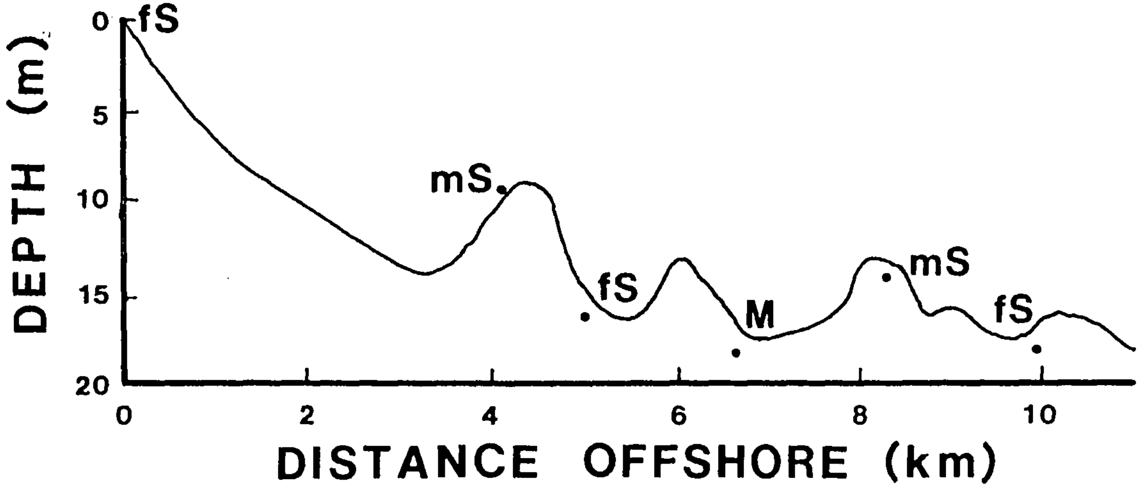

Figure 20. Cross-section of an inner shelf traverse, showing the texture of collected samples. Traverse consists of sample B23 from this study, and samples MJ22-MJ26 from the study of Hall (1981). Vertical exaggeration is 200x. Medium sand (mS) is found on the ridges, while fine sand (fS) and mud (M) are prevalent in the troughs. The cross-section is taken from NOAA Navagation Chart 12318 (32nd edition, 1979), while dots mark the water depths at each sample site recorded by Hall (1981).

A11, A24, A36, A42, A47, MJ26) are classified as olive and olive grey (5Y5/2, 5Y4/2, 5Y4/3).

Mud content is often a good indicator of sediment color. All of the samples with mud contents above 5 percent are black to dark olive grey (2.5Y3/0, 5Y3/2). However, several samples with low mud contents (<2 percent) are also black or dark olive grey. Thus, dark color does not always imply a high clay content.

Ridge sands are mostly lightish brown to brownish grey, but include two olive colored sands. Swale sediments range from dark grey to olive and olive grey (table 2). Beach samples consist of very light colored sediment; white to pale brown to olive grey (10YR8/1 to 10YR7/3, 5Y6/1 to 5Y5/2).

SEDIMENT COMPOSITION

CLAY-SIZED MINERALOGY

Thirty three beach, shelf, and river samples were analyzed for clay mineral content. The methods used for qualitative and semi-quantitative analysis are described in appendix 5.

Many authors have discussed the problems inherent in dealing with clay minerals. Variations in composition, crystallite size, and lattice perfection produce variations in peak position, height, and area within an individual clay species. Anderson (1961), Douglas and Fressinger (1971), Kelley (1980) and others have noted that pretreatments can degrade clays in varying amounts, which can alter relative estimates of clay percentages. Pierce and Siegel (1969) and Stokke and Carson (1973) observed wide variation in semi-quantitative results, depending upon the mounting technique used. Stokke (1976), Gibbs (1977), Arcaro (1978), and Kelley (1980) showed that clay mineralogy varies with grain size, and Towe (1974) argues against the use of the traditional <2um fraction in clay mineral studies.

Whenever possible, attempts were made to address and account for the problems associated with clay mineral quantification. Three samples were selected for an investigation of the effect of size on mineralogy. Samples A49, A37, and A31 were separated into one phi-size fractions, from 5 phi (32 um) to 14 phi (0.06 um). Figures 21, 22, and 23 contain representative diffractograms from the three

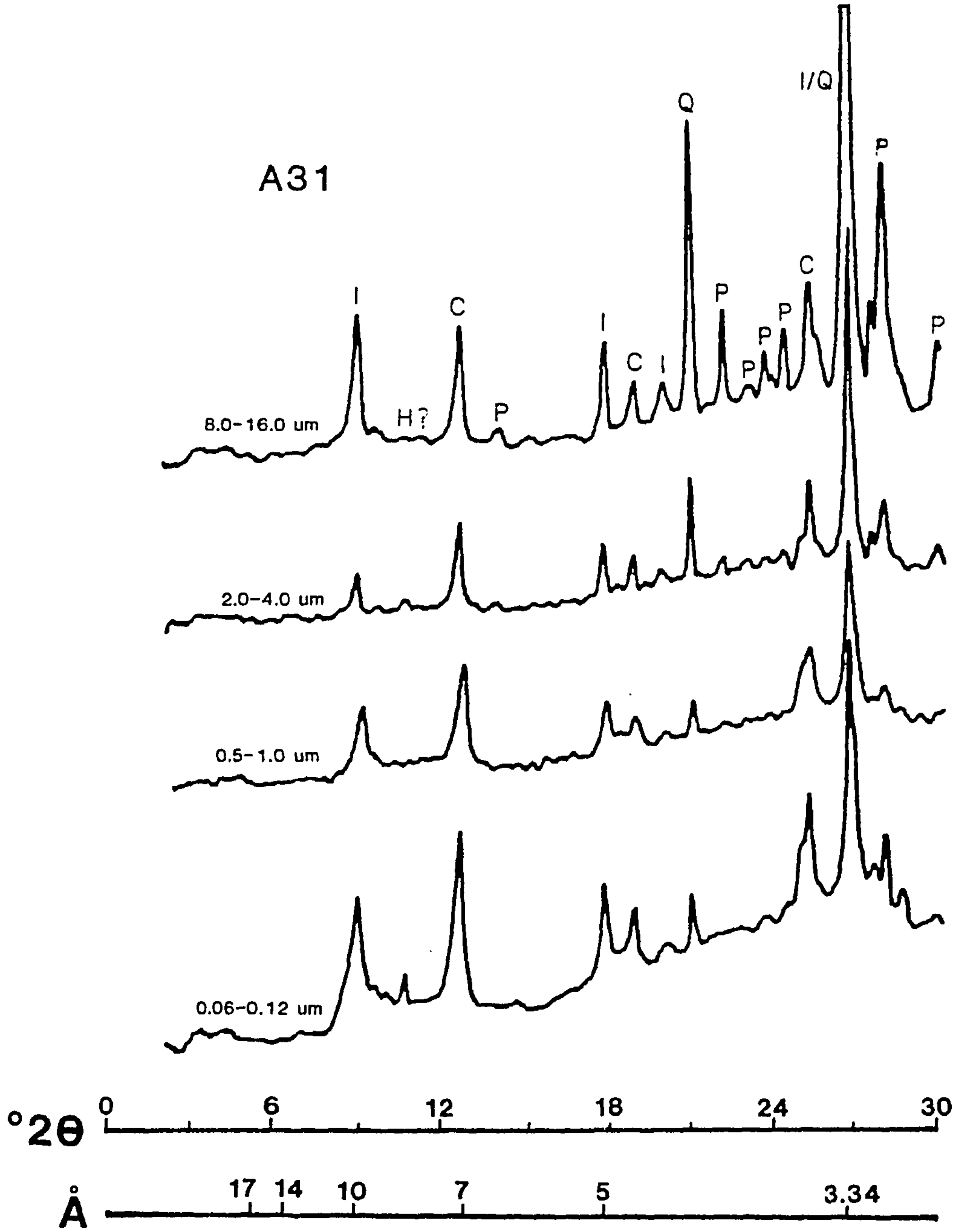

Figure 21. X-ray diffraction patterns of representative size fractions of sample A31. Phases identified include: 10 angstrom clay (I) (illite), 7/14 angstrom clay (C) (kaolinite/chlorite), plagioclase (P), quartz (Q), and hornblende (H).

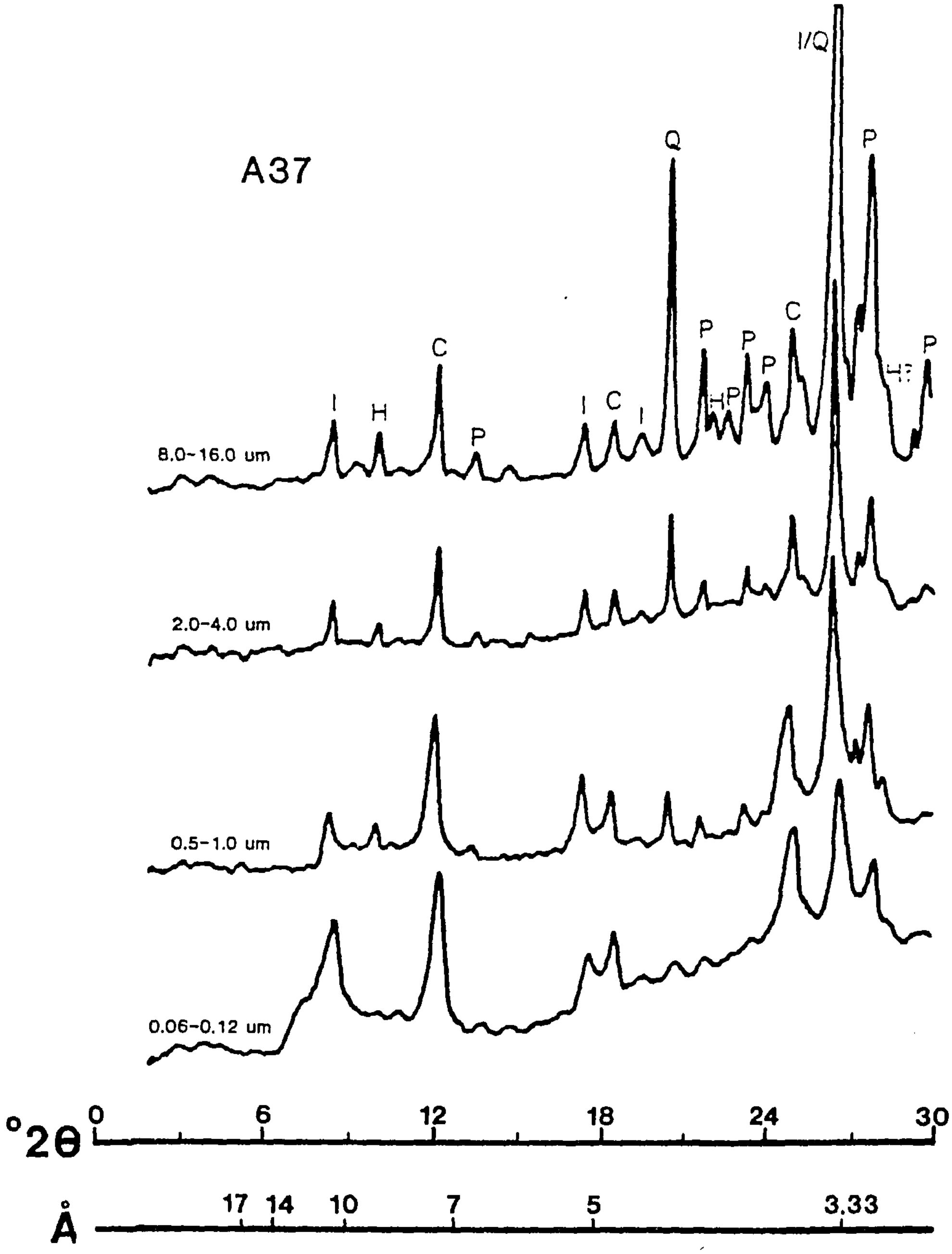

Figure 22. X-ray diffraction patterns of representative size fractions of sample A37. Phases identified include: 10 angstrom clay (I) (illite), 7/14 angstrom clay (C) (kaolinite/chlorite), plagioclase (P), quartz (Q), and hornblende (H).

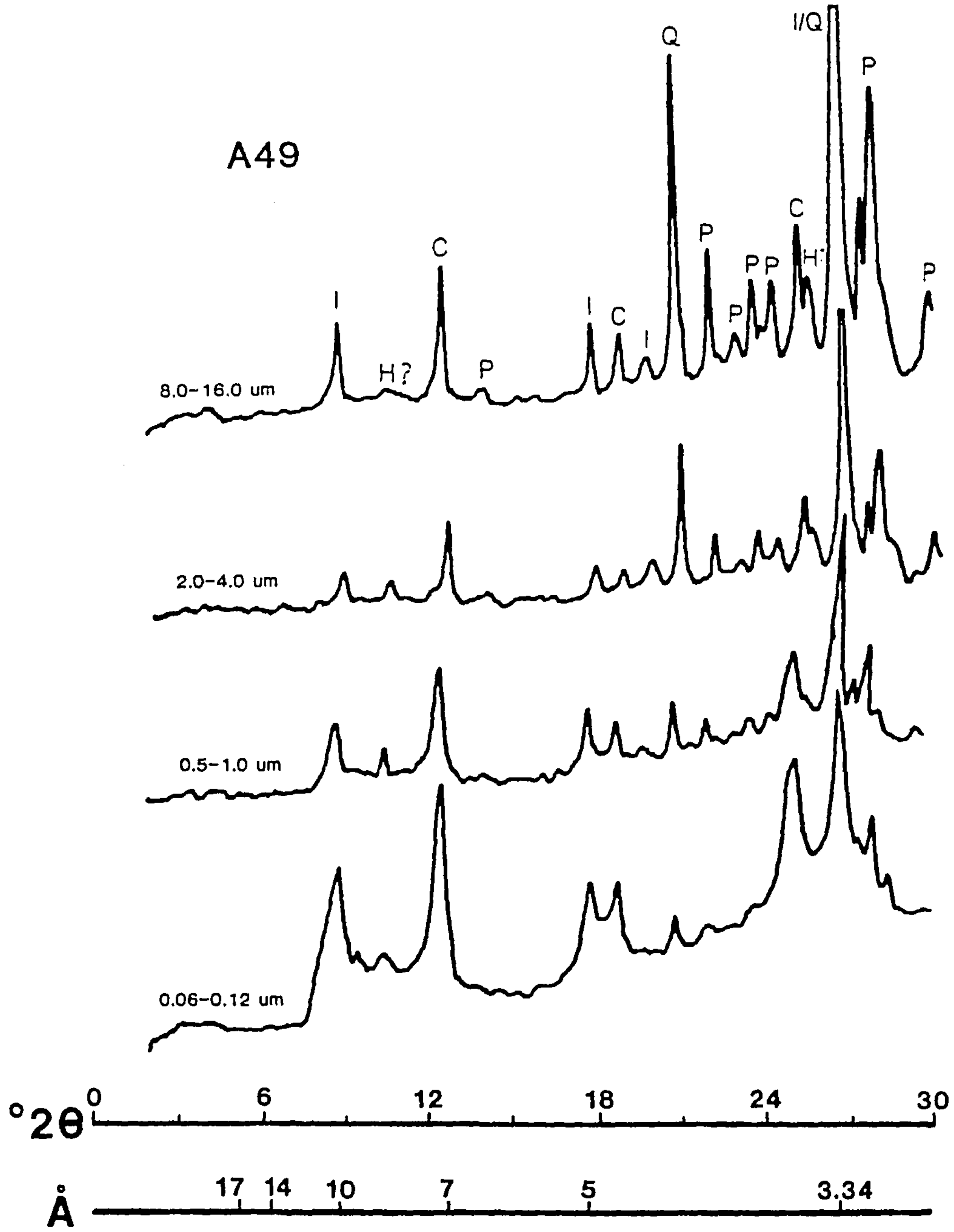

Figure 23. X-ray diffraction patterns of representative size fractions of sample A49. Phases identified include: 10 angstrom clay (I) (illite), 7/14 angstrom clay (C) (kaolinite/chlorite), plagioclase (P), quartz (Q), and hornblende (H).

samples. A similar pattern is observed in each sample: a 10 angstrom clay (illite) and 7/14 angstrom clay (kaolinite/chlorite) are the most abundant phases in the fine fraction (>9 phi, <2 um), while quartz and feldspar dominate the coarser sizes (<9 phi, >2 um). In addition, hornblende is a significant component of the coarse fraction (<7 phi, >8 um) of sample A37.

Glycolated versions of the same samples were compared to determine differences in clay mineralogy between size fractions (figure 24). A ten angstrom clay (illite) and 7/14 angstrom clay (kaolinite/chlorite) are significant components in all fractions. In the finer sizes (<1.0 um), a broad swelling in the 4.0-5.2 degree range (17-24 angstroms) indicates the presence of smectites, and possibly, mixed-layer clays (see discussion in appendix 5). Gibbs (1965), Stokke (1976), Arcaro (1978), and Kelley (1980) found that 17 angstrom clays (smectites), are concentrated in the finer size fractions; X-rays of the bulk <2 um (>9 phi) fraction will often not detect it. Since the presence of smectites may be useful in differentiating between samples, it was decided to use the >11 phi fraction (<0.5 um) for clay mineral quantification.

Ten angstrom (illite) and 7/14 angstrom (kaolinite/chlorite) clays are the major components in the <0.5 um fraction of all the samples studied. Quartz, plagioclase, microcline, and amphibole are present in minor amounts in most samples. Seventeen angstrom clays (smectites) are present in significant amounts (up to 25 percent) in some samples, but are absent from most.

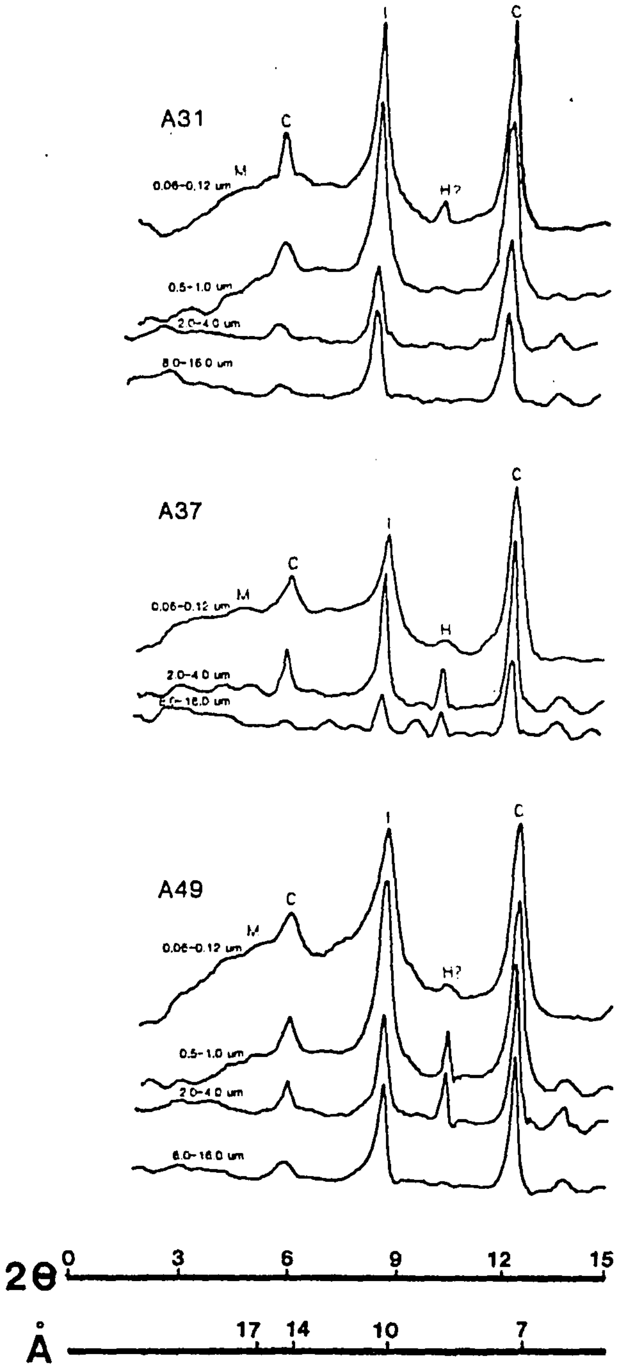

Figure 24. Glycolated X-ray diffraction patterns of samples A31, A37, and A49. Smectites (M) and possible mixed layer clays, are seen as a broad swelling in the finer size fractions. Other minerals identified include: 10 angstrom clay (I) (illite) , 7/14 angstrom clay (C) (kaolinite/chlorite), plagioclase (P), quartz (Q), and hornblende (H).

The normalized relative percentages of 10 angstrom clay (illite), 7/14 angstrom clay (kaolinite/chlorite), quartz, and 17 angstrom clay (smectites) are listed in appendix 5, table 4. In beach and shelf samples; 10 angstrom clay (illite) ranges from 26 to 81 percent (average = 44.2 percent, S.D. =13 percent), 7/14 angstrom clay (kaolinite/chlorite) from 18 to 68 percent (average = 44.6 percent, S.D. = 10 percent), quartz from 2 to 17 percent (average = 7.7 percent, S.D. = 4.7 percent), and 17 angstrom clays (smectites) from 0 to 28 percent (average = 3.8 percent, S.D. = 6.9 percent).

Ternary diagrams of mineral percentages are shown in figures 25 and 26. For illite, kaolinite/chlorite, and quartz (figure 25), each data point is the average of three intensity (peak area) measurements. A 90 percent confidence interval for each value is found in appendix 5, table 4. For 10 angstrom and 7/14 angstrom clays, a confidence interval of +- 2 to 7 percent is typical, although confidence intervals for several samples exceed +- 10 percent.

Although most of the samples in figure 25 exhibit a grossly similar mineralogy, several samples can be clearly distinguished from the rest. Samples B1 and B3 are distinguished by a high percentage of 10 angstrom clay, while sample R6 has a high percentage of 7/14 angstrom clays. Figure 26 renormalizes the samples without quartz, and separates samples containing detectable amounts of 17 angstrom clay.

Despite the error associated with clay mineral quantification,

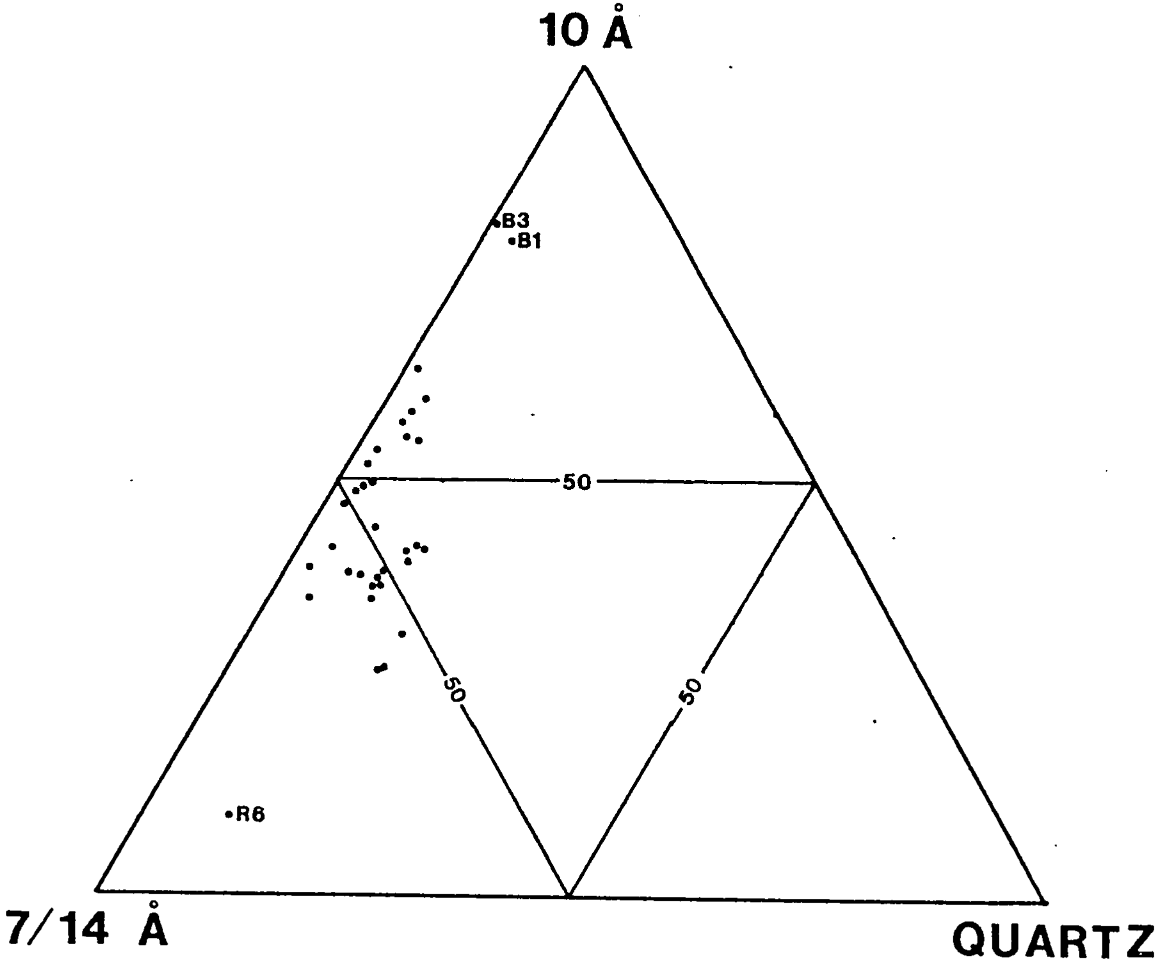

Figure 25. Percentages of 10 angstrom clay, 7/14 angstrom clay (kaolinite/chlorite, smectites), and quartz in the less than 0.5 micron unglycolated fraction.

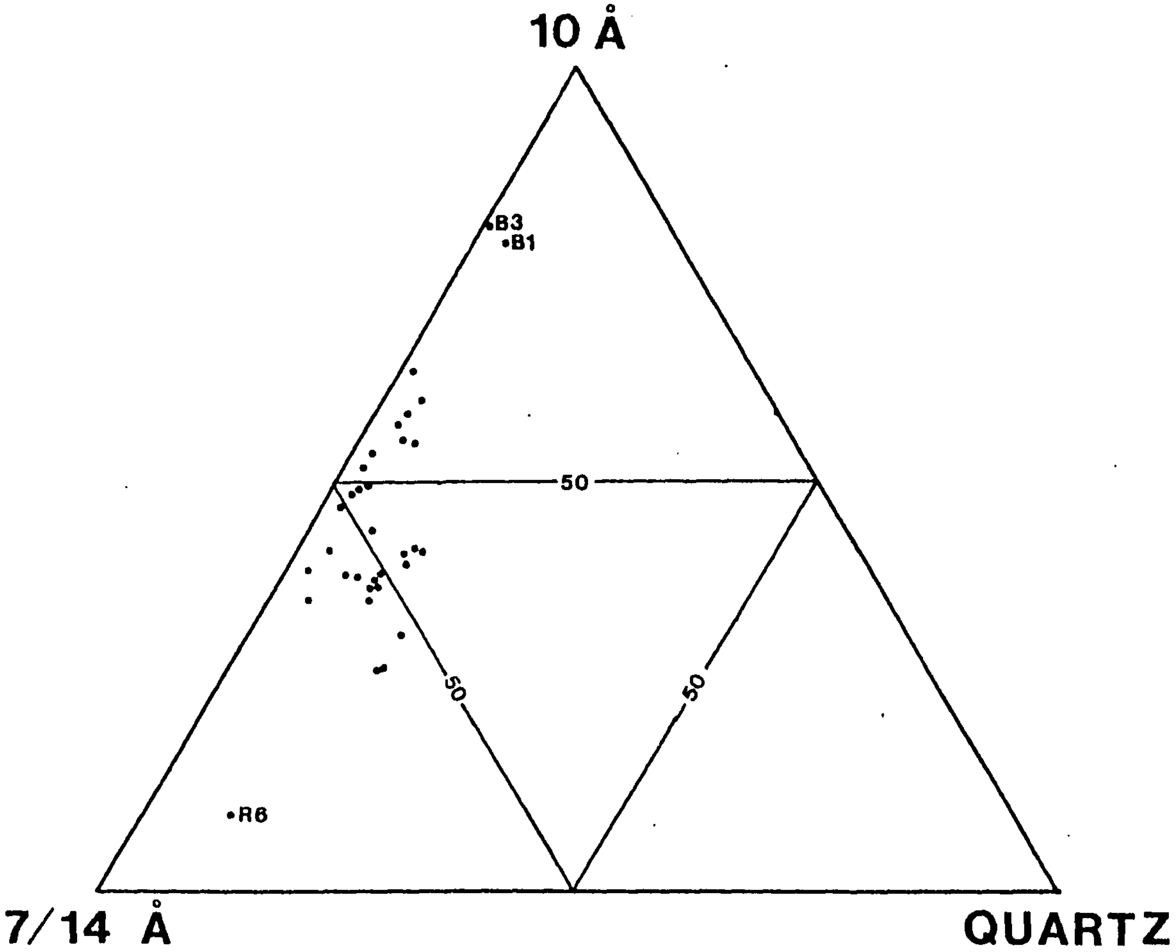

Figure 25. Percentages of 10 angstrom clay, 7/14 angstrom clay (kaolinite/chlorite, smectites), and quartz in the less than 0.5 micron unglycolated fraction.

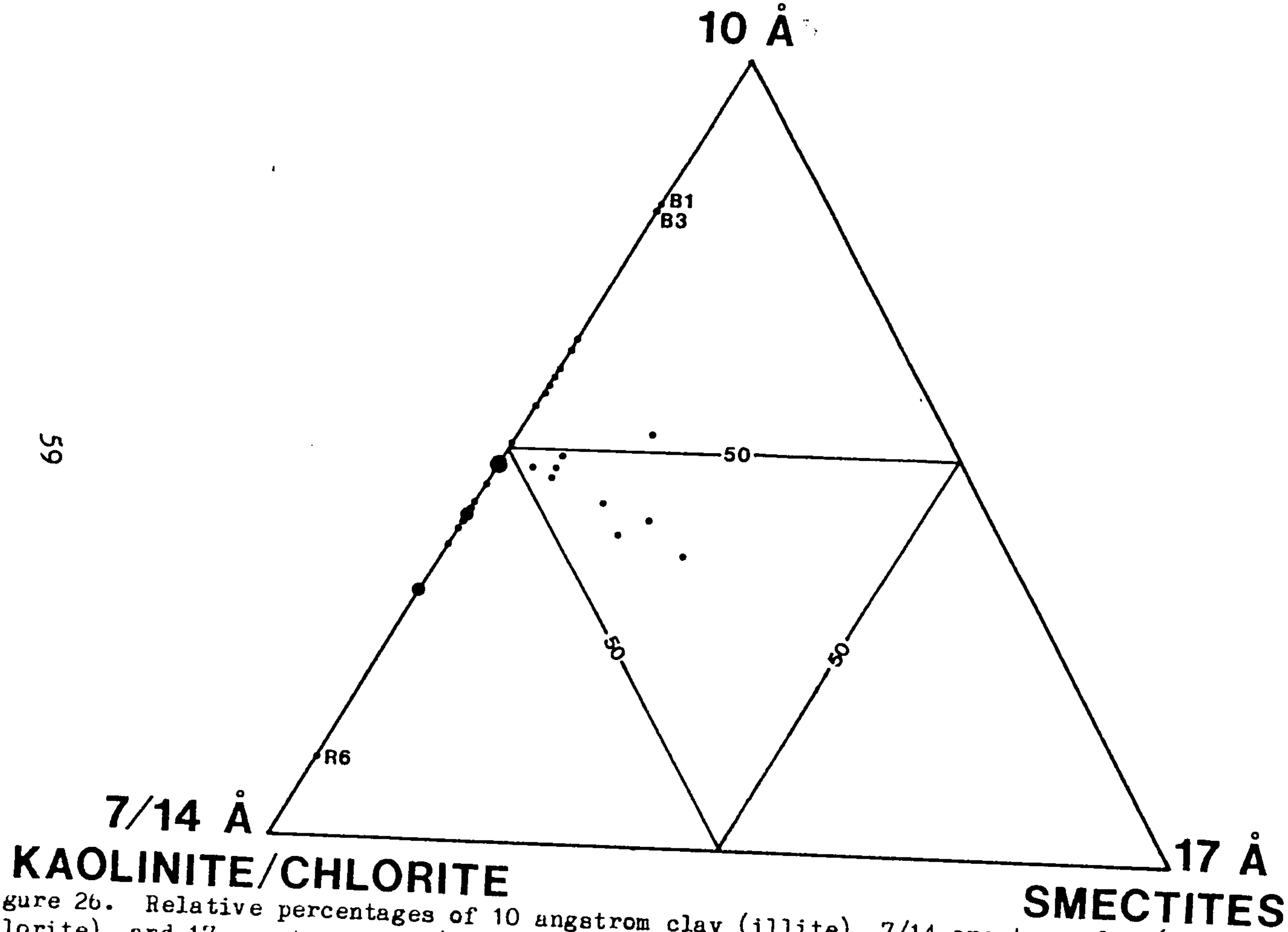

Figure 26. Relative percentages of 10 angstrom clay (illite), 7/14 angstrom clay (kaolinite/ chlorite), and 17 angstrom clay (smectites, and mixed-layered clays) in the less than 0.5 um fraction of glycolated samples. Larger dots represent two ● or three ● samples with similar mineralogy.

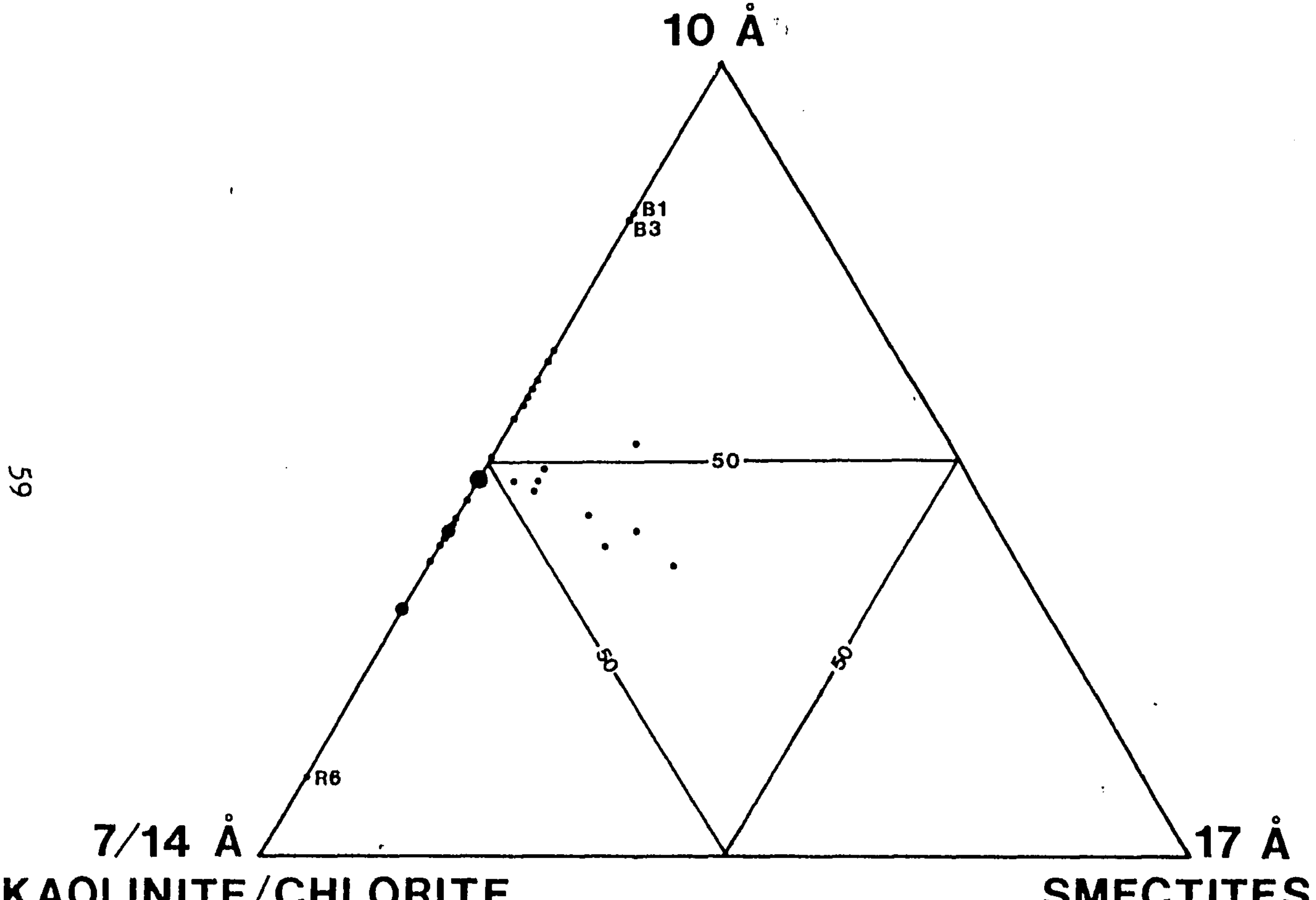

Figure 26. Relative percentages of 10 angstrom clay (illite), 7/14 angstrom clay (kaolinite/ chlorite), and 17 angstrom clay (smectites, and mixed-layered clays) in the less than 0.5 um fraction of glycolated samples. Larger dots represent two ● or three ● samples with similar mineralogy.

some samples with similar mineralogy exhibit a definite areal grouping. Relatively low (<0.75) ratios of 10 to 7/14 angstrom clays (figure 27) are found on the central New Jersey beaches and inner shelf. Other samples either have intermediate ratios (0.75-2.00), or have too much error (>10 percent) associated with their quantification to allow classification.

The majority of the smectite-bearing (17 angstrom) samples occur on the beaches and shelf in the southern part of the sampling area, and in the mudball sample (figure 28). Except for two isolated samples (A22, A42), no other part of the shelf has detectable amounts of smectite.

SILT-SIZE MINERALOGY

Twenty six silt samples were analyzed for mineralogy. Separation and identification techniques are discussed in appendix 5. The 5 to 7 phi (32 to 8 um) fraction was used, as it contained the greatest amount of silt-sized material.

Quartz (4.26, 3.34 angstroms) is the most abundant mineral in the coarse silt fraction of most samples. Chlorite (14 angstroms), a 10 angstrom phase, hornblende (8.5 angstroms), and plagioclase (3.18 angstroms) are clearly present (figure 29, UN). In order to identify the minor phases which could be used to differentiate between samples, the heavy mineral fraction of each sample was separated, using heavy liquid with a specific gravity of 2.90.

After one separation (figure 29, S1), the 10 angstrom peak,

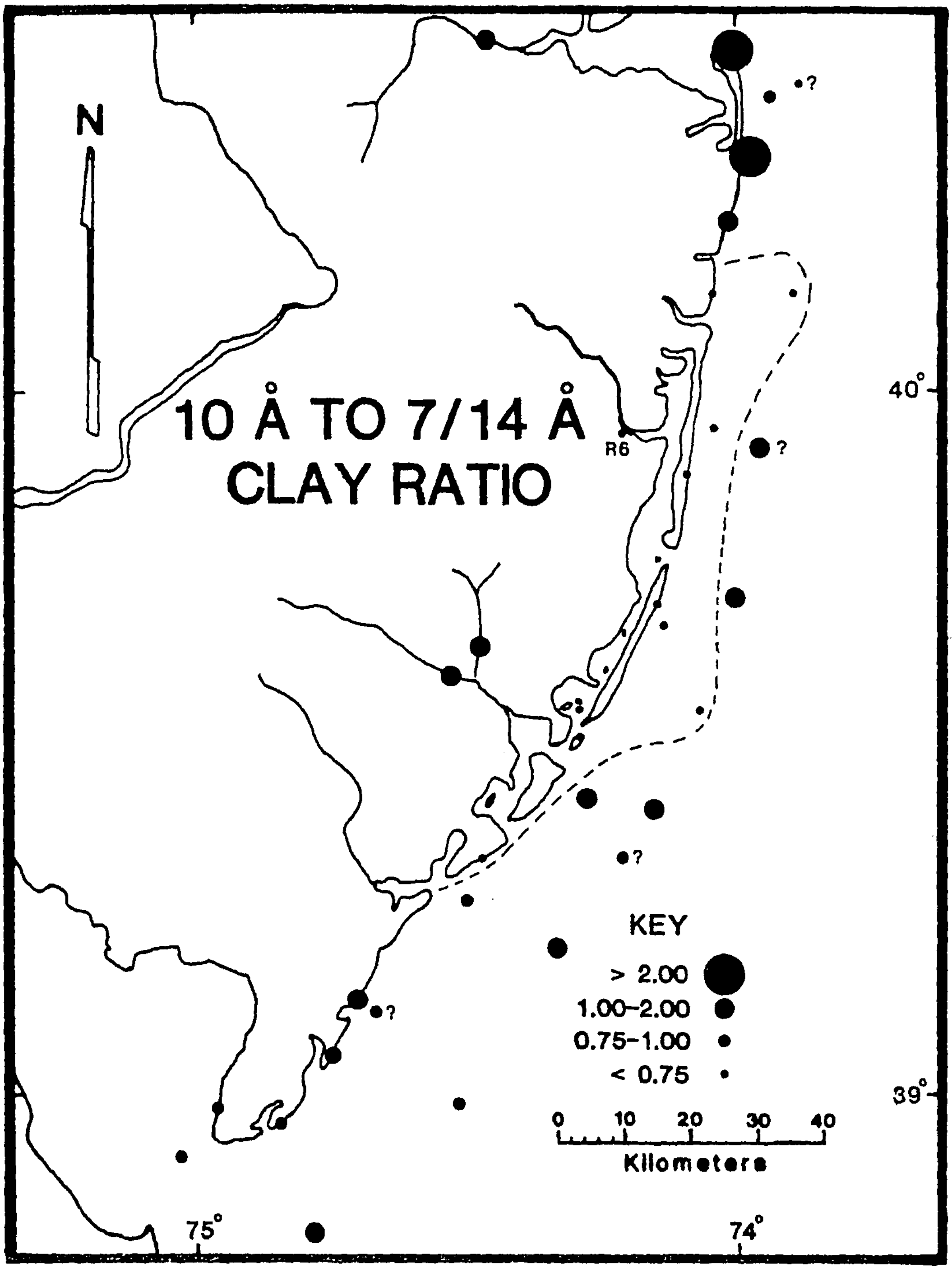

Figure 27. Ratio of 10 angstrom (illite, glauconite) to 7/14 angstrom (Kaolinite/chlorite) phases for the fine clay fraction (<0.5 um) of each sample. Ratio values followed by a question mark indicate samples with large (<10 percent) reproducability errors. Dashed line separates samples with the lowest (<0.75) 10 angstrom to 7/14 angstrom ratio.

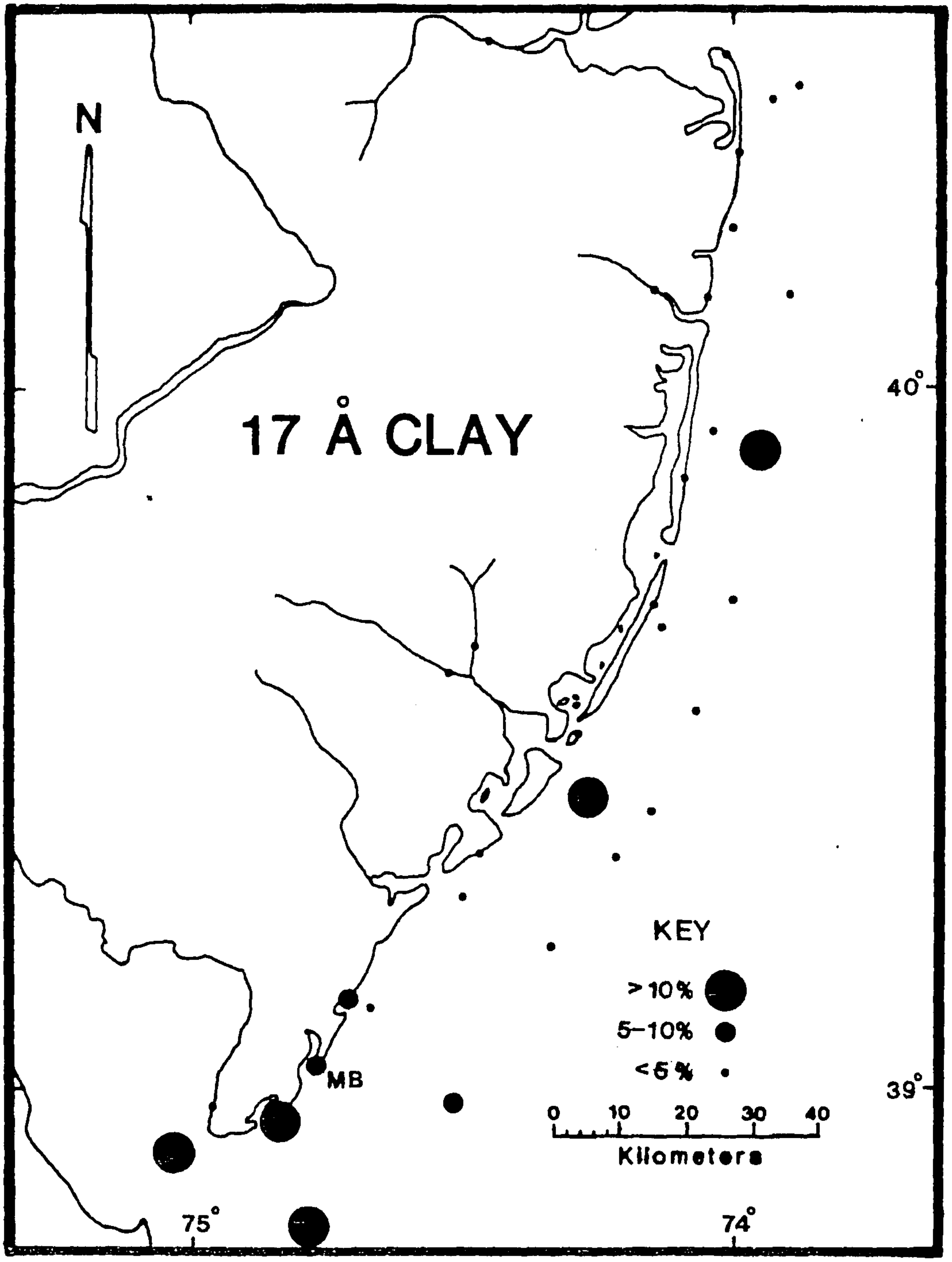

Figure 28. Percentage of 17 angstrom clay (glycolated smectites) in in the fine clay fraction (<0.5 um) of each glycolated sample.

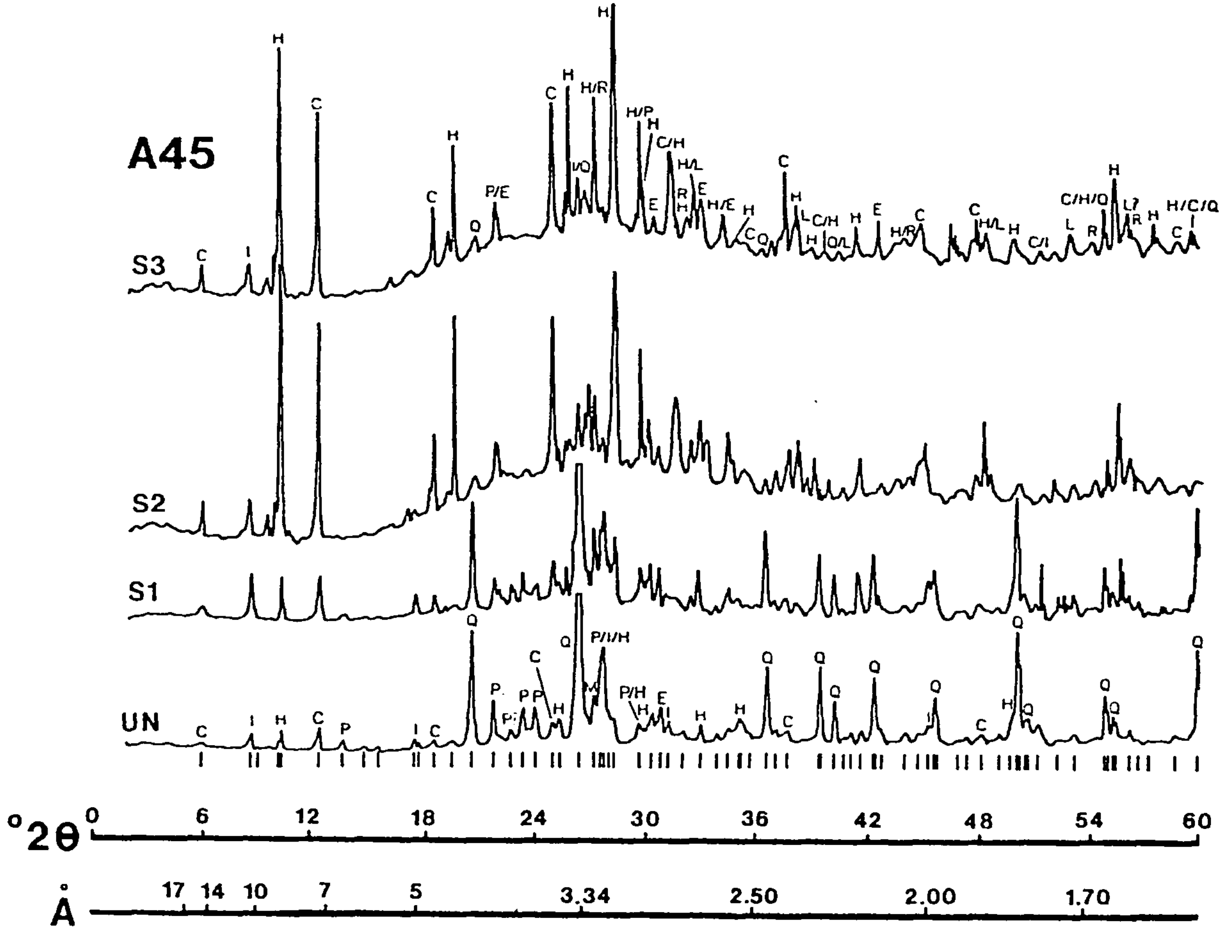

Figure 29. X-ray diffraction patterns of the silt-sized (5-7 phi, 8-32 um) fraction of sample A45 unseparated (UN), and after repeated heavy liquid separations (S1, S2, S3). The large quartz peaks in patterns UN and S1 have been shortened for graphical convenience. Phases identified include: quartz (Q), kaolinite/chlorite (C), 10 angstrom phases (I; illite/muscovite, glauconite), plagioclase (P), microcline (M), hornblende (H), ilmenite (L), and rutile/pseudorutile (R).

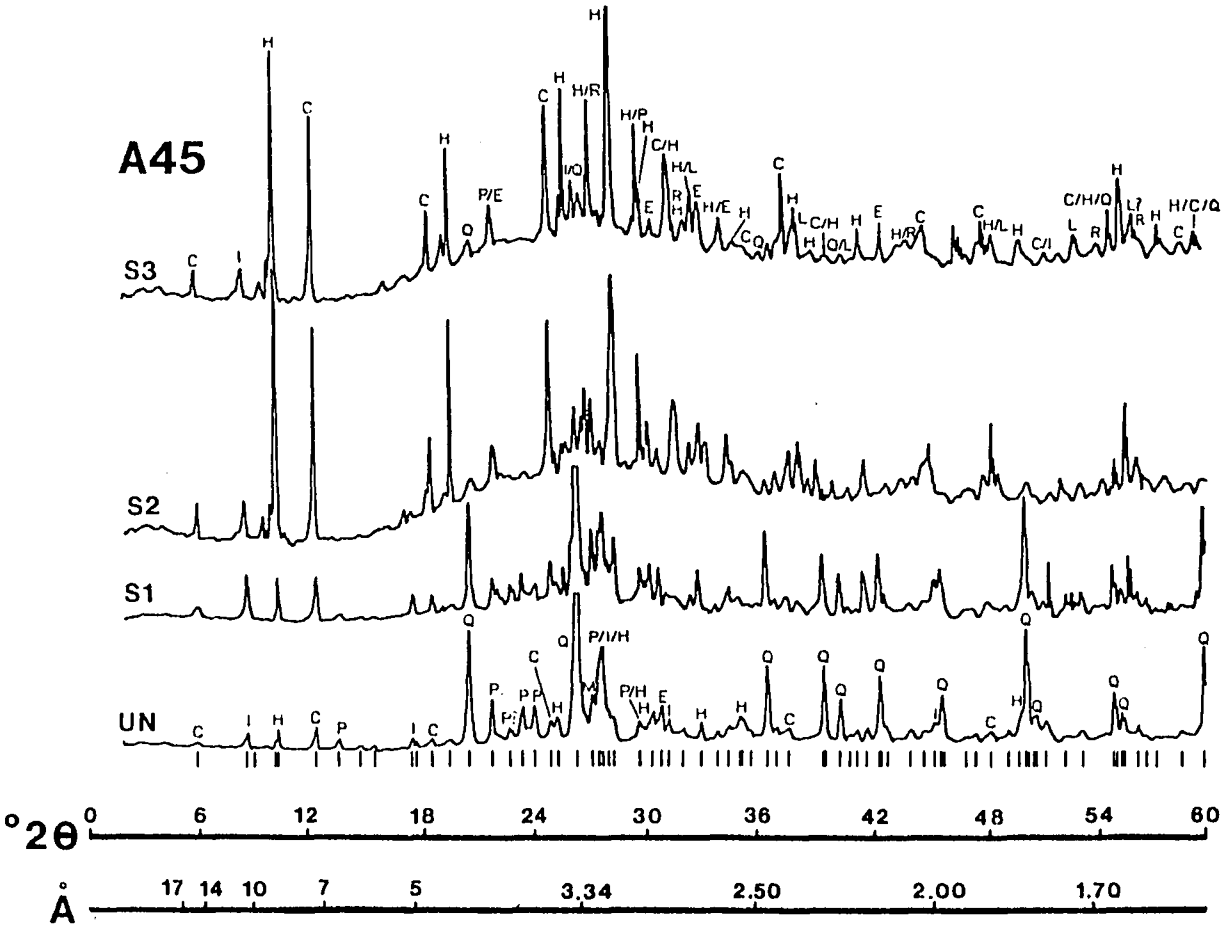

Figure 29. X-ray diffraction patterns of the silt-sized (5-7 phi, 8-32 um) fraction of sample A45 unseparated (UN), and after repeated heavy liquid separations (S1, S2, S3). The large quartz peaks in patterns UN and S1 have been shortened for graphical convenience. Phases identified include: quartz (Q), kaolinite/chlorite (C), 10 angstrom phases (I; illite/muscovite, glauconite), plagioclase (P), microcline (M), hornblende (H), ilmenite (L), and rutile/pseudorutile (R).

chlorite (14 angstroms), and hornblende (8.52 angstroms) increase slightly in relation to the quartz (4.26 angstroms) peak, although quartz is still the major component. After the second separation (S2), quartz (4.26 angstroms) and plagioclase (3.18 angstroms) decrease considerably, while hornblende(8.52 angstroms) and chlorite (14 angstroms) become the major phases. The 10 angstrom peak is diminished with respect to chlorite and hornblende, but is enhanced with respect to quartz.

Other minor phases were resolved after the second separation (figure 29, S2). Major peaks of epidote (2.68 angstroms), ilmenite (1.73 angstroms), and rutile or pseudorutile (1.64 angstroms) are present as individual diffraction maxima, while the smaller peaks of these minor phases generally interfere with peaks of quartz, chlorite, and hornblende.

The third separation (figure 29, S3) does little to further enhance the heavy mineral fraction with respect to quartz (4.26 angstroms) and plagioclase (3.18 angstroms). Since each separation results in some sample loss, two heavy liquid separations were considered adequate for each subsequent sample.

Several samples contained too little silt-sized material to permit separation. These samples were x-rayed without heavy liquid separation, and thus had high intensity quartz peaks. The problems associated with analysis of these samples will be discussed later.

McMaster (1954) and Schroeder (1982) found a variety of heavy minerals present in minor amounts in New Jersey beach and shelf sands. Because of the limited resolution of the x-ray diffraction method, it was impossible to confidently determine whether minerals other than those identified were present in the silt fraction. Slowing the scan speed from 0.5 degrees 2 theta/minute to 0.25 or 0.125 degrees 2 theta/minute failed to define minor phases in several samples.

The presence of quartz, plagioclase, and possibly minor amounts of unidentified minerals in variable quantities produced absorption effects which hindered quantification of the silt-sized heavy minerals. Rather than attempting to precisely quantify the silt composition, the relative intensities of a major peak for each mineral were computed. This method permited gross comparison between samples, in order to determine whether different heavy mineral zones are recognizable within the silt fraction. The relative intensity ratios for each sample are listed in appendix 6, table 6.

Because of the limited resolution of the x-ray diffraction method, trace occurrences of epidote, ilmenite, and rutile-pseudorutile may have been present, but were undetected in some samples. This is particularly likely for samples B10, B12, B16, B18, B25, and A22, for which little sample was available for x-ray analysis.

Diffraction intensities from separated silts were subjected to R-mode factor analysis in order to determine which minerals could be used to differentiate between samples. Four factors were generated, which account for over 97 percent of the variability in silt mineralogy (figure 30). Factor one is characterized primarily by ilmenite and rutile-pseudorutile. Factor two is enhanced in hornblende, and depleted in chlorite. Factor three is dominated by ten angstrom minerals, while factor four is depleted in epidote.

Rather than plotting factor scores produced by R-mode factor analysis, measured intensities of mineral combinations were compared for each sample. Chlorite and hornblende have the highest relative peak intensities in most samples. The highest values for a hornblende/chlorite intensity ratio (>0.7; figure 31) occur along the southern two thirds of the beaches and inner shelf, and the southern one third of the offshore traverse. A high hornblende to chlorite intensity ratio (>0.8) is also observed for a sample from Great Egg Harbor River (R2).

Factor one suggests that ilmenite and rutile-pseudorutile have a strong positive correlation. The highest values for combined relative intensity ratios of ilmenite and rutile-pseudorutile (20 to 30 percent; figure 32) are found in two northern rivers (Toms River (R6), and Raritan River (R7)), the two northernmost shelf samples (A31, A28), and in sample R4 (Wading River). Other significant occurrences (intensity ratio >10 percent) of these minerals are found in southern shelf samples (A4, A36, A42, A46, and MJ3).

The ten angstrom peak was artificially enhanced in samples that did not undergo heavy liquid separation, and could not therefore be used for comparison purposes. Because of the trace accumulation of

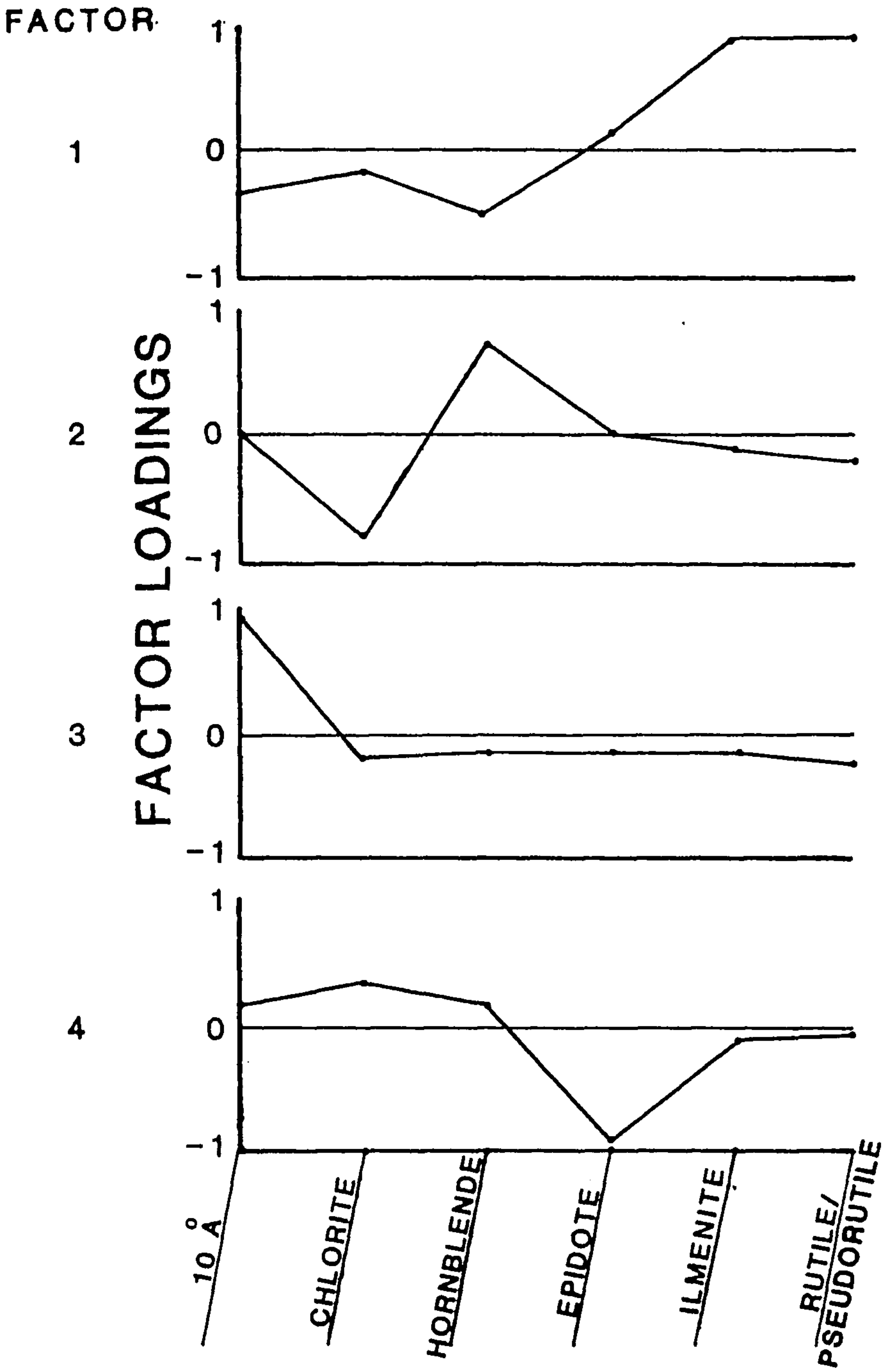

Figure 30. Factor loadings plotted against silt (5-7 phi, 8-32 um), mineralogy for R-mode factor analysis.

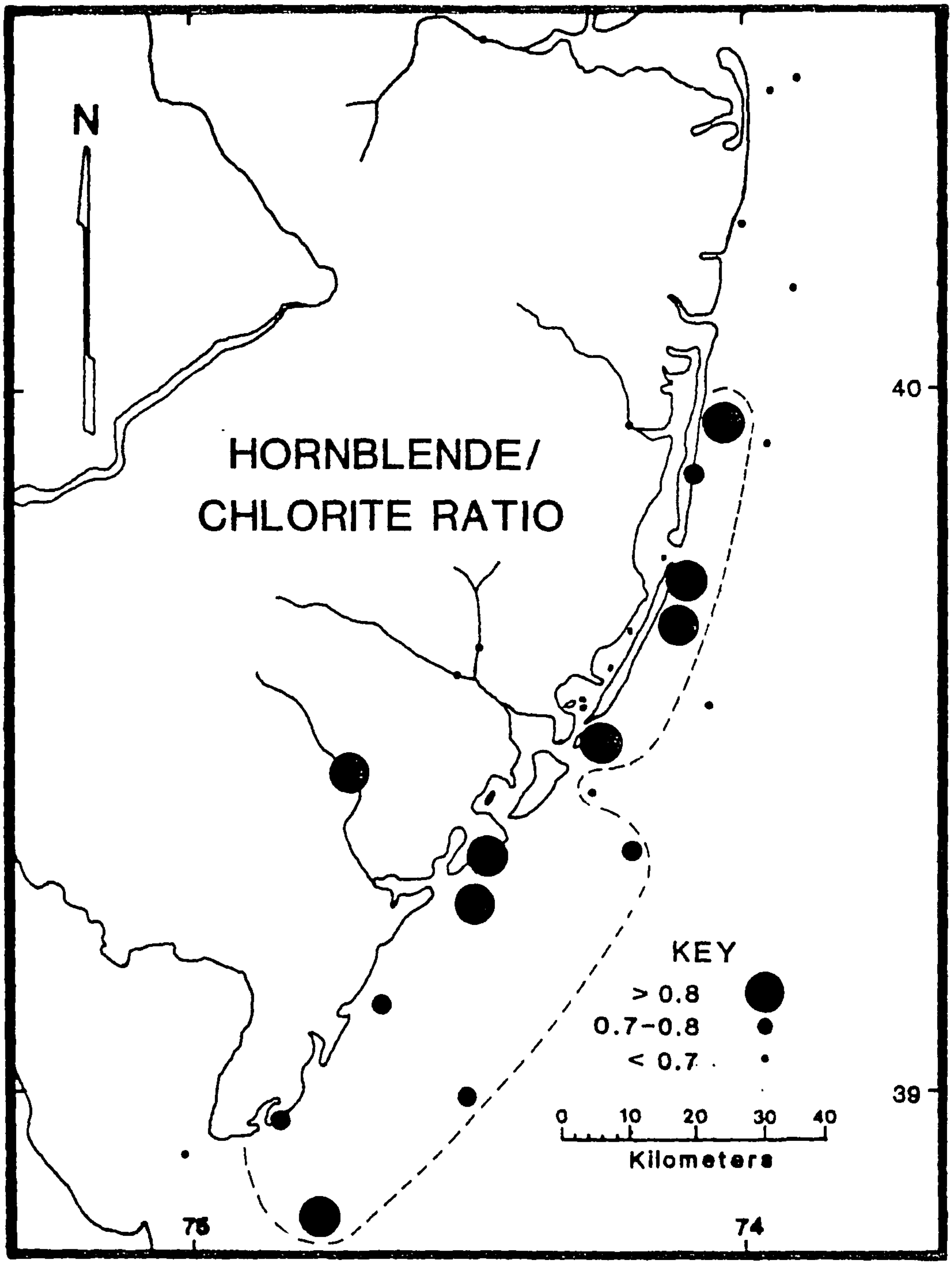

Figure 31. Ratio of relative intensities of silt-sized (5-7 phi, 8-32 um) hornblende to chlorite.

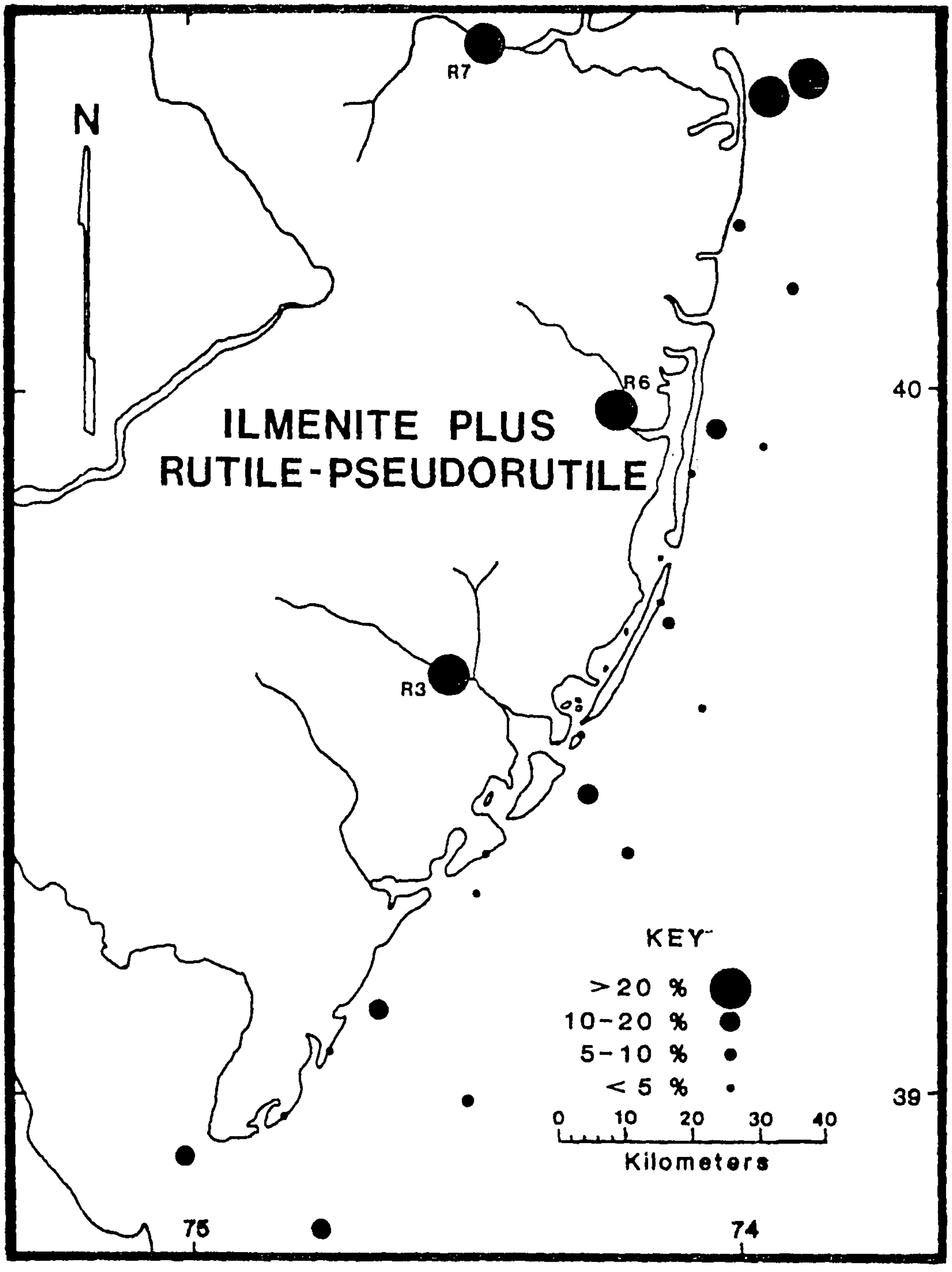

Figure 32. Combined relative intensity ratios of silt-sized (5-7 phi, 8-32 um) ilmenite plus rutile-pseudorutile.

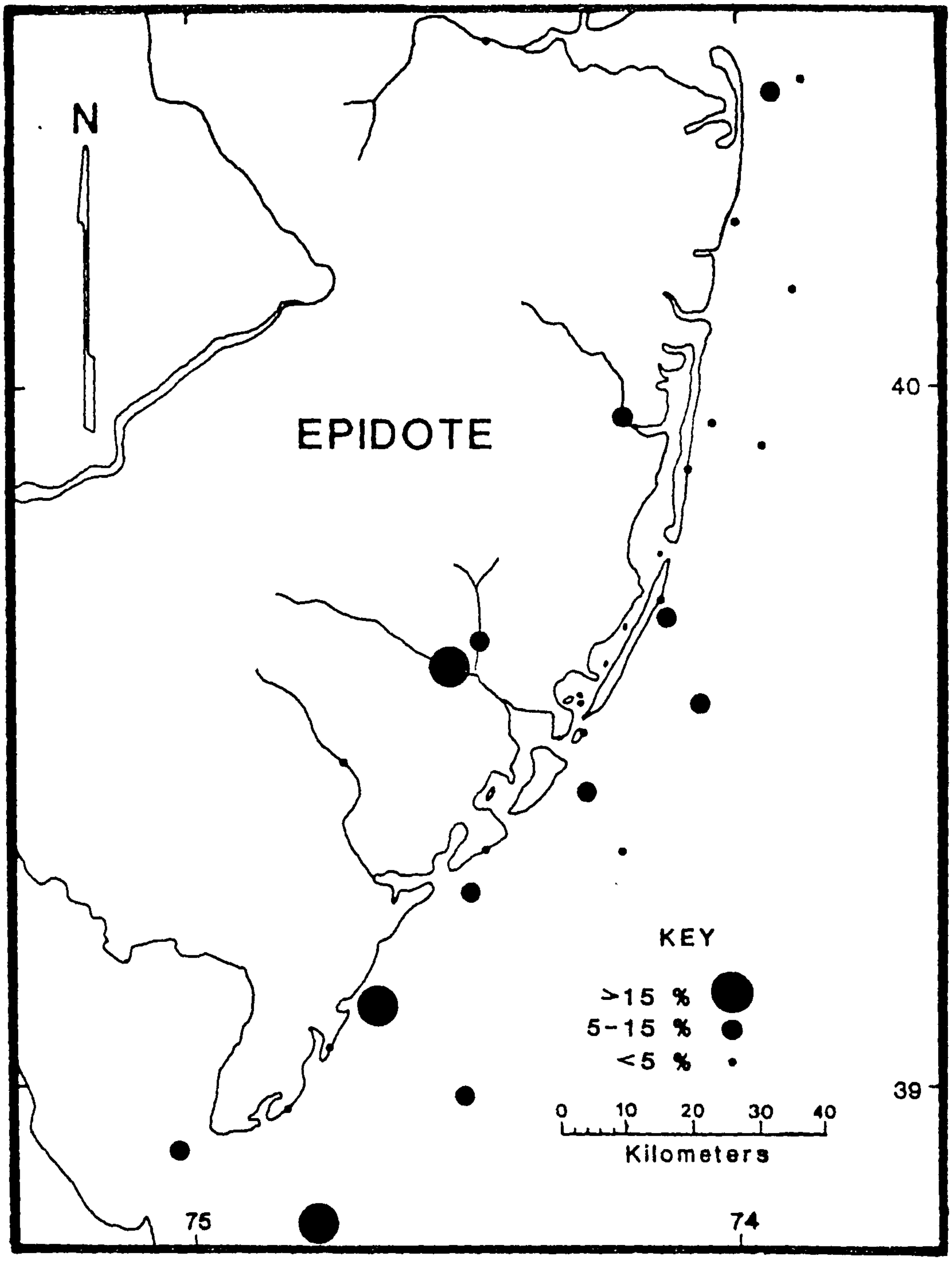

Figure 33. Relative intensities of silt-sized (5-7 phi, 8-32 um) epidote.

epidote in some samples, this mineral is also of uncertain value as a significant tracer in the silt fraction. Nevertheless, the epidote percentages of shelf samples which underwent heavy liquid separation are clearly concentrated on the southern two thirds of the inner shelf (figure 33), somewhat mimicing the pattern observed for hornblende (figure 31).

Comparison of silt and clay composition, and size data, revealed no regular interrelationships between any samples. Sample R6, which contained the highest amount of chlorite/kaolinite in the clay fraction, possessed a very high chlorite intensity ratio in the silt fraction. However, no other samples exhibited a noticeable correlation of chlorite in the two size classes.

ORIGIN OF NEW JERSEY NEARSHORE SEDIMENT

Textural and clay and silt data from this study, combined with the sand-sized heavy mineral data of McMaster (1954) and Schroeder (1982), and other studies (Hathaway, 1972; Kelley, 1980) indicate that New Jersey nearshore sediment has both local and regional sources.

LOCAL SEDIMENT SOURCES

Sandy Hook to Shrewsbury Rocks

Several samples taken north of Shrewsbury Rocks are texturally or mineralogically anomalous, when compared to nearby beach and shelf samples. Shelf samples A28 and A31 contain greater amounts of fine sand (>30 percent sediment in the 3.0 and 3.5 phi size classes) than nearby shelf and beach samples (figure 18), and smaller amounts of gravel (<3 percent sediment coarser than -0.5 phi) than nearby shelf sediments (figure 16). Beach samples B1 and B3 have the highest 10 angstrom to 7/14 angstrom (illite to kaolinite/chlorite) ratios (>2.0) of any beach, shelf, or river sample (figure 27).

Although there is no direct evidence from this study, Pleistocene glaciofluvial sediment appears to be an important source of northern New Jersey inner shelf material. In this region, Pleistocene lower sea levels resulted in deep subaerial erosion of Coastal Plain strata by the Hudson and Raritan Rivers. The area is now covered by up to 30 meters of Pleistocene sediment (Williams and Duane, 1974). Shepard and Cohee (1936) found that the heavy mineral assemblages and pebble lithologies of northern New Jersey shelf sediments more closely resemble Long Island shelf sediments than New Jersey shelf sediment south of Shrewsbury Rocks.

A second source of sediment north of Shrewsbury Rocks, which is perhaps the most volumetrically important, is dumping of waste solids in New York Harbor, and on the adjacent inner shelf (Gross, 1972; Williams and Duane, 1974) (figure 34). A study of non-floatable sediments dumped in the New York Bight between 1964 and 1968 revealed an annual discharge of about 4.6 million metric tons per year. The amount of solid waste is particularly significant when compared to the estimated suspended sediment load

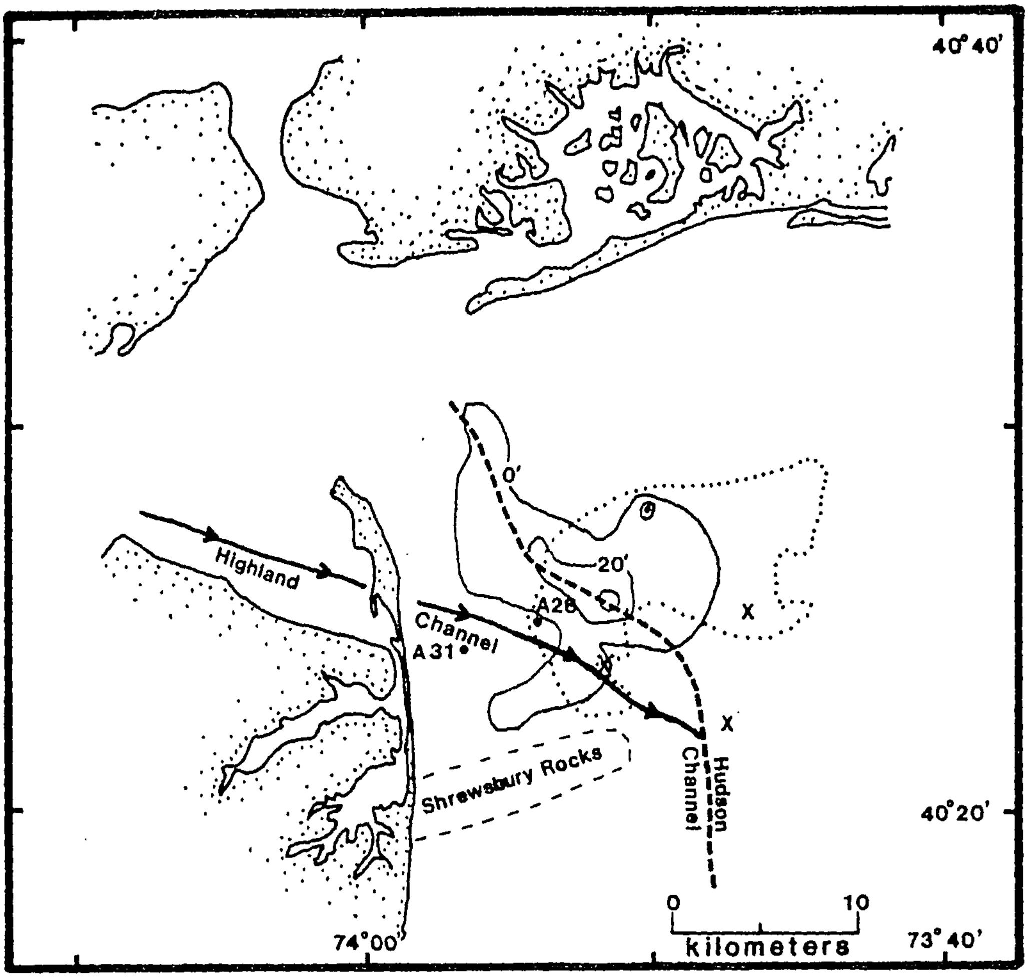

Figure 34. Map showing the effect of marine dumping on the northern New Jersey inner shelf. Contours display the differences between an 1845 and a 1934 bathymetric survey, indicating the extent and thickness of disposed waste products. Crosses indicate contemporary waste disposal sites. The dotted line delineates an area of abnormally high carbon and lead concentration. Locations of shelf samples A28 and A31 from the present study are plotted. Arrows trace a subsurface channel, which is a proposed path of the Pleistocene Raritan River. Data from Gross (1972) and Williams and Duane (1974).

(6.1 million metric tons per year) carried by all Atlantic coastal rivers between Maine and Cape Hatteras. Gross (1972) indicates that there is no definite evidence of movement of wastes from the disposal site toward the New Jersey shore, and there is no direct evidence of dredge spoil contamination in samples A28 and A31 (figure 34). Nevertheless, input of such large amounts of artificially derived material undoubtedly influences the sedimentological character of the shelf north of Shrewsbury Rocks, and may account for the unusually high amounts of fine sand in this region.

The clay mineralogy of the two northern most beach samples (B1 and B3) exhibits a clear dependence on the mineralogy of underlying coastal plain formations (figure 3). Late Cretaceous to early Tertiary sediments north of Long Branch contain high concentrations of glauconite (Owens and Sohl, 1969). Burst (1958) noted that most of the "glauconite" described in the literature is a combination of micaceous, chloritic, and smectitic clay minerals. X-ray diffraction patterns of some sand-sized "glauconite" pellets from northern New Jersey closely match JCPDS pattern 9-439 for glauconite; no trace of any 14 angstrom minerals was found. Glauconite was also observed in silt-sized (8-32 um) heavy mineral grains from samples B1 and B3.

The relatively high percentage of 10 angstrom "illite" in samples B1 and B3 (figure 27) is almost certainly due to the addition of 10 angstrom glauconite in the fine clay fraction.

Shoreface and shoreline erosion of glauconite rich sediment, and northern longshore transport of this material continually provides both sand and clay sized glauconite to northern beaches. The fact that an enhanced 10 angstrom peak was not found in the clay sized fraction of shelf samples A28 and A31 (figure 27), implies that most of the fine sediment eroded from the New Jersey shoreface (north of the Manasquan region) is transported northward, parallel to the shoreline, with little material being deposited offshore.

Shrewsbury Rocks to Little Egg Inlet

The sediments between Shrewsbury Rocks and Little Egg Inlet consist predominantly of medium to coarse sand, and gravel (figures 16 and 19). The high percentage of gravel in this region appears to be a lag deposit, which remains after shoreface retreat and longshore drift eroded and transported the finer material during the Holocene transgression.

The Kirkwood and Cohansey Formations are the prominent surficial deposits along the New Jersey shore from about Asbury Park south to approximately Little Egg Inlet (figures 3 and 4). Samples with the highest amount of 7/14 angstrom clay (kaolinite/chlorite ; low 10 angstrom to 7/14 angstrom ratios, figure 27) are concentrated along the beaches in several inner shelf samples in the same region.

Coastal Plain formations were not sampled directly in this study, but river sediments were assumed to be representative of the formations they drain. Toms River (R6) contains an abnormally high percentage of kaolinite/chlorite (82 percent, 10 angstrom to 7/14 angstrom ratio = 0.11). This river and its tributaries drain portions of the Kirkwood and Cohansey Formations. Although no quantitative clay mineral studies could be found for these formations, kaolinite has been recognized as the major constituent of these formations and their overlying soils (Groot and Glass, 1958; Owens and others, 1961; Douglas and Trela, 1979; and Rhodehamel, 1979).

It seems probable that shoreface erosion of the central New Jersey shoreline releases clay-sized material from subaqueous Cohansey and Kirkwood strata, which contain larger amounts of kaolinite/chlorite relative to other New Jersey beach and inner shelf clays. The "new" clays released by shoreface erosion then mixes with continental shelf clays released by winnowing of continental shelf sediment, since relatively high amounts of kaolinite/chlorite (low 10 angstrom to 7/14 angstrom ratios) are not found seaward of this area (figure 27).

Based on the topography of the region, it appears that little glacial-derived Pleistocene sediment reached the upland subprovince of the coastal plain (figure 2), or the adjacent beaches and inner continental shelf between Little Egg Inlet and Long Branch (Williams and Duane, 1974). Pleistocene drainage patterns channeled glacial meltwater north and south of this region, and then outward over the subaerially exposed continental shelf. Williams and Duane (1974) infer that the Pleistocene Raritan River channeled meltwater eastward along the Atlantic Highlands, followed the Highland Channel across the inner shelf, and finally connected with the Hudson Channel (figure 34).

Shrewsbury Rocks form a topographic high that extends from the shoreface seaward for about 12 kilometers, where they are truncated by the Hudson Channel (figure 34). This ridge-like feature apparently was a Pleistocene subaerial drainage divide, which prevented glaciofluvial sediments of the Pleistocene Raritan and Hudson Rivers from being deposited on the present day southern New Jersey inner shelf. This conclusion is supported by seismic (McClennan, 1981; Williams and Duane, 1974), and petrographic (McMaster, 1954; Williams and Duane, 1974) evidence, which show distinctly different sediment thicknesses and composition north and south of Shrewsbury Rocks.

Little Egg Inlet to Cape May

The beaches and nearshore zone between Cape May and Little Egg Inlet are dominated by fine sand (>30 percent sediment in the 3.0 and 3.5 phi size classes; figure 18). Hornblende is enhanced with respect to chlorite in the silt fraction of the beaches and inner shelf of the same region (figure 31), and in some beach and nearshore sediments as far north as Point Pleasant. The beaches and inner shelf near Cape May peninsula contain a significant grouping of samples with measurable amounts (>5 percent) of smectite (figure 28).

The dominance of fine sand on the beaches between Cape May and Little Egg Inlet was also noted by McMaster (1954) and Schroeder (1982). Drawing from recent work on the New Jersey Coastal Plain formations (Owens and Minard, 1979), Schroeder (1982) proposed an origin for beach sands from Cape May to Little Egg Inlet. The Bridgeton Formation consists of alluvial sands and gravels with a "full (immature)" suite of heavy minerals (Owens and Minard, 1979; figure 4). The extent of deposition from this formation along the New Jersey shore closely matches the zone of hornblende-rich beach sands noted by McMaster (1954), and Schroeder (1982) (figure 5). Thus the Bridgeton Formation is thought to be the source of the hornblende-rich, fine grained beach sand between Cape May and Little Egg Inlet.

During Pleistocene low stands in sea level, the Great Egg River extended across the continental shelf, and possibly carried the discharge of the Pleistocene Schuykill River (Swift and others, 1980). Hornblende-zone sands extend offshore parallel to the path of the Pleistocene Great Egg River (figure 5). Unlike beach sands, the texture of shelf sediments in this zone is variable, with both fine and medium grained sand present (figures 18 and 19).

The hydraulic regime on the inner shelf is probably responsible for the diversity in sediment texture. The concentration of medium sand on ridges, and fine sand in swales was noted in the present study, by Hall (1980) for the inner New Jersey shelf from Little Egg Inlet to Cape May, and by other studies on the middle and outer New

Jersey continental shelf (Stubblefield and others, 1975; Frank and Friedman, 1973). Apparently, the processes which form ridge and swale topography on the southern New Jersey shelf effectively segregate the sediment into finer and coarser fractions.

The relatively large amounts of hornblende in the silt fraction of central and southern New Jersey beaches and shelf (figure 31) appear to be derived from the same source as the Hornblende zone of McMaster (1954) and Schroeder (1982). The silt-sized hornblende is derived either directly from the Bridgeton Formation, or from erosion of reworked, Bridgeton-derived beach and shelf sediments. Epidote, which is a common heavy mineral in the sand-sized fraction of the hornblende zone (McMaster, 1954), is also observed in significant amounts in the silt-sized fraction between Cape May and Barnegat Inlet (figure 34).

The occurrence of enhanced hornblende on the beaches and inner shelf (figure 31) north of its probable source area (figure 4) implies northern longshore transport of silt-sized material. This contradicts the heavy mineral data of Schroeder (1982) which suggests southern longshore transport of sand-sized sediment. Perhaps the late summer-early autumn shore parallel northerly drift noted by Bumpus and Lauzier (1965) (figure 7) is competent to transport silt-sized material northward, but not sand-sized material.

The grouping of smectite-bearing samples near the Cape May peninsula (figure 28) implies a discrete local source foe this clay mineral suite. The mudball samples collected by Meza and Paola (1977) are dated as Pleistocene in age, contain detectable amounts of smectite (figure 28), and may in fact be clay fragments from the Cape May Formation. Kelley postulated that outcropping Cape May Formation clay on the inner shelf and in Delaware Bay is the source of the fine sediment that is rapidly accumulating in southern New Jersey salt marshes. As evidence Kelley cites: the general similarity of shelf bottom, beach, and suspended sediment; the noticeable present day erosion of northeast Delaware Bay (Oostdam, 1971); and Landsat imagery, which reveals northeasterly-trending sediment plumes moving out of Delaware Bay during ebb tides (Kelley, in press).

Hall (1981) also supports the notion of movement of clay-sized sediment out of Delaware Bay, and northeastward transport along the New Jersey coast. Trace metal concentrations in the clay-sized fraction have high values in upper Delaware Bay, with increasing concentrations found with increasing distance north, west, and east of Cape May peninsula. While it is possible that metal-rich clays may be derived from a source south of Delaware Bay, the combination of Hall's (1981) and Kelley's (1980, in press) data appears to indicate a Delaware Bay and/or inner shelf source for at least some of the clays present on the inner shelf, and in the tidal marshes of southern New Jersey. Thus, the northward movement of silt-sized sediment noted in this study agrees with the proposed northward movement of clay-sized sediment noted by Kelley (1980, in press), and Hall (1981).

The Mullica and Wading Rivers (samples R3 and R4) were sampled near the upstream limit of estuarine influence. Because of the similarity of these samples with typical shelf clay mineralogy, and the probable low sediment discharge of these rivers, no input of clay-sized material to the nearshore zone could be recognized.

Sediment color on the southern New Jersey shelf seems to be best ascribed to the micro-environment of the depositional site (Swift and Boehmer, 1972) rather than to a recent or relict origin (Emery, 1968; Stanley, 1969). The good correlation of color with texture noted by Hall (1981) for southern New Jersey inner shelf sediments (medium to coarse sand-yellows and browns; fine sands-olive and grey), was observed in many shelf samples in this study south of Little Egg Inlet (table 2). Recent studies have noted the occasional movement of inner shelf sands in the present hydraulic environment (McClennan, 1973; Butman and others; 1976, 1979; and others), and exposure of pre-Holocene grey silty clays in troughs (Stubblefield and Swift, 1975). Since shelf sands are subject to movement, but maintain a good coarse/brown, fine/grey relationship, it appears that these sands can come to a fairly rapid equilibrium with their environment. The lighter color of beach sands may be due to the constant abrasion experienced by sand grains in this environment, which could effectively erode any surficial coatings.

REGIONAL SEDIMENT SOURCES

The previous section outlined the evidence for local sources for New Jersey beach and inner shelf sediment. Because of the relatively uniform mineralogy of the fine fraction (figure 25), it seems possible that much of this fine sediment was derived from a single regional source.

There is a strong similarity between the "northern assemblage" clay mineral suite defined by Hathaway (1972) from the continental shelf and slope, and the mineralogy of the fine clay fraction (<0.5 um) off New Jersey. Table 3 compares the average mineralogy on New Jersey beach and inner shelf fines with other regional and local studies. The papers chosen described their quantification method in sufficient detail that raw diffraction intensities for each mineral could be back calculated, and applied to the calibration curves produced for this study. Despite differences in pretreatments, size, and mounting techniques, table 3 shows the general similarity between typical beach and inner shelf clays, and clays from other Middle Atlantic studies.

Hathaway (1972) described the origin of the clay mineralogy of northern Atlantic Ocean. The fine-grained sediments produced during the Pleistocene glaciations consist mostly of unweathered, mechanically eroded materials from Paleozoic and older rocks of the northern Appalachian region. Hathaway (1972, p. 303) states:

> "The fine-grained minerals of these rocks tend to be

STUDY	SAMPLE ID	SIZE (in ums)	ORIGINALLY[1] REPORTED				RECALCULATED			
			I	C/K	Q	M	I	C/K	Q	M
		2.0-0.5	59	32	4	4	40	53	4	3
KELLEY (1980)	S3	0.5-0.25	51	34	--	15	34	56	--	10
CAPE MAY INNER		<0.25	65	18	--	18	50	36	--	14
SHELF AND BEACH		2.0-0.5	56	30	11	3	38	50	10	2
SEDIMENT	S4	0.5-0.25	71	20	4	5	53	40	2	4
		<0.25	72	21	--	7	54	40	--	5
HATHAWAY (1972)[2]										
DELAWARE BAY AND NEW		<2.0	61	36	--	3	42	56	--	2
JERSEY CONTINENTAL SLOPE										
MEZA AND PAOLA (1976)	M7	<2.0	50	40	--	10	32	61	--	6
PLEISTOCENE MUDBALLS	MS5	<2.0	72	20	--	7	54	41	--	5
STONE HARBOR N.J.										
BISCAYE (1965)	S[3]	<2.0	61	24	--	15	43	43	--	14
SEA BOTTOM CLAY	N	<2.0	67	27	--	5	47	48	--	4
NORTHWESTERN ATLANTIC OCEAN										

			I	C/K	Q	M
PRESENT STUDY:	MEAN	<0.5	44 + 5	45 + 4	8 + 2	4 + 2
NEW JERSEY INNER SHELF	RANGE	<0.5	26-81	18-68	2-17	0-28
AND BEACH CLAYS						

Table 3. Relative clay mineral intensities from the present study, and several contiguous studies. 1 in some cases other minerals were originally identified; 2 original percentages are approximate; 3 average of deep sea clays south (S) and north (N) of the New Jersey shoreline. I = illite, C/K = chlorite/kaolinite, Q = quartz, M = smectite

			ORIGINALLY[1] REPORTED				RECALCULATED			
STUDY	SAMPLE ID	SIZE (in ums)	I	C/K	Q	M	I	C/K	Q	M
		2.0-0.5	59	32	4	4	40	53	4	3
KELLEY (1980)	S3	0.5-0.25	51	34	--	15	34	56	--	10
CAPE MAY INNER		<0.25	65	18	--	18	50	36	--	14
SHELF AND BEACH		2.0-0.5	56	30	11	3	38	50	10	2
SEDIMENT	S4	0.5-0.25	71	20	4	5	53	40	2	4
		<0.25	72	21	--	7	54	40	--	5
HATHAWAY (1972)[2]										
DELAWARE BAY AND NEW		<2.0	61	36	--	3	42	56	--	2
JERSEY CONTINENTAL SLOPE										
MEZA AND PAOLA (1976)	M7	<2.0	50	40	--	10	32	61	--	6
PLEISTOCENE MUDBALLS	MS5	<2.0	72	20	--	7	54	41	--	5
STONE HARBOR N.J.										
BISCAYE (1965)	S[3]	<2.0	61	24	--	15	43	43	--	14
SEA BOTTOM CLAY	N	<2.0	67	27	--	5	47	48	--	4
NORTHWESTERN ATLANTIC OCEAN										

			I	C/K	Q	M
PRESENT STUDY:	MEAN	<0.5	44 + 5	45 + 4	8 + 2	4 + 2
NEW JERSEY INNER SHELF	RANGE	<0.5	26-81	18-68	2-17	0-28
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Table 3. Relative clay mineral intensities from the present study, and several contiguous studies. 1 in some cases other minerals were originally identified; 2 original percentages are approximate; 3 average of deep sea clays south (S) and north (N) of the New Jersey shoreline. I = illite, C/K = chlorite/kaolinite, Q = quartz, M = smectite

> mostly mica, or illite, and chlorite. The rock flour produced by glacial erosion would have contained these minerals and finely divided quartz, and accessory minerals such as hornblende. Little kaolinite or montmorillonite would have been available except where the ice front crossed sedimentary formations of the coastal plain."

New England soil clays developed during Pleistocene interglacial stages and during the Holocene would likewise be fairly fresh and only slightly weathered (Jackson and others, 1948). Quaternary clay samples from New England (Allen and Johns, 1960), and southern Quebec (Jackson and others, 1948) are dominated by illite and quartz, with smaller amounts of chlorite, plagioclase, and amphibole.

During the Pleistocene low stages of sea level, most glacial meltwater was carried directly to the shelf edge over the exposed continental shelf. Pleistocene oceanic drainage patterns, which were probably similar to present day patterns, carried the "northen assemblage" minerals as far south as Cape Hatteras (Hathaway, 1972). As sea level rose during the Holocene, fine sediments were winnowed from shelf deposits, and transported seaward past the shelf edge, or landward into coastal estuaries. This process accounts for the similarity of Middle Atlantic Bight estuary, and continental shelf and slope clay mineralogy, and for the lack of fines on the continental shelf.

Like the fine clay size fraction, silt-sized material may have regional sources. Chlorite and hornblende are common minerals of the silt fraction of fresh glacially derived sediments which contain a chlorite - illite dominated fine clay fraction (Jackson and others, 1948). Thus the silt fraction in the study area may be partially derived from the same "northern assemblage" minerals noted by Hathaway (1972) for the clay fraction.

LOCAL VERSUS REGIONAL SOURCES OF NEW JERSEY NEARSHORE FINES

The presence of an illite plus kaolinite/chlorite dominated clay fraction implies a uniform regional source for New Jersey fine nearshore sediments. Nevertheless, the occurrence of trace minerals in distinct areal groupings (smectites, figure 28), and the enhancement of certain phases with respect to the regional average (illite to kaolinite/chlorite ratio, figure 27; hornblende to chlorite ratio, figure 31), implies a local input of mineralogically distinguishable fine sediment.

The clay mineralogy of New Jersey nearshore sediment is of limited use as an indicator of sediment transport. The enhanced occurrence of a particular tracer (illite to kaolinite/chlorite ratio, figure 27; smectite abundance, figure 31), is recognized only in close proximity to the source of that tracer. Apparently, the small size and mobility of clays allows sediments from different sources to mix readily under the influence of variable direction tidal, and (seasonal) wind-induced currents. Since the mineralogy of local and regional sources is not radically different, mixing quickly obliterates the mineralogic "signature" of a local source. Thus, while local sources for clay-sized sediment in the New Jersey nearshore zone can be determined, the mineral assemblages from these sources are not useful as tracers.

In the silt fraction, hornblende is a major component of an individual source (Bridgeton Formation; figure 4), and is a useful indicator of nearshore sediment transport direction both northward and southward (figure 31). alongshore, figure 36). While other silt-sized material was identified (chlorite, epidote, ilmenite, and rutile-pseudorutile), the patchy distribution of these minerals prevented their use in recognition of a particular source area. There was no apparent correlation between these minerals and sand-sized heavy mineral zones observed by McMaster (1954) and Schroeder (1982).

SUMMARY AND CONCLUSIONS

SUMMARY OF BEACH AND NEARSHORE SEDIMENTOLOGY

Beach and inner shelf sediment on the New Jersey coast (water depth of less than 20 meters) consists mainly of fine to medium sand. Medium sand (250 to 500 um) is found on beaches north of Little Egg Inlet, on beaches of Delaware Bay, and in occasional inner shelf samples south of Little Egg Inlet. Fine sand (90 to 180 um) is found on the beaches and nearshore sediments between Cape May and Little Egg Inlet, and on the inner shelf north of Shrewsbury Rocks. South of Little Egg Inlet, a ridge and swale topography exists on the shelf. The sediments consist predominately of find sand in the swales, and medium to coarse sands on the ridges.

Sand is apparently released to the nearshore environment by shoreface erosion. North of Shrewsbury Rocks, anomalously fine shelf sand may be at least partially derived from Pleistocene glacial outwash, and/or from dumped waste solids in the New York Bight. Between Shrewsbury Rocks and Little Egg Inlet, sand is derived from underlying Tertiary (Kirkwood and Cohansey Formations), and older coastal plain formations. South of Little Egg Inlet, sand is derived from the Bridgeton Formation of possible Miocene age.

Most of the sand with significant gravel content (>20 percent) is found on the shelf surface north of Little Egg Inlet. This gravel probably represents a lag deposit left when shoreface erosion and longshore transport removed finer sediment.

CONCLUSIONS

1. Most New Jersey beach and inner shelf sediments contain very little (<2 percent) fine fraction (<64 um). The mineralogy of most fine samples displays a strong similarity to the clay minerals of the "northern assemblage" (illite - chlorite dominated; Hathaway, 1972) found in the estuaries and outer continental shelf and rise of the Middle Atlantic Bight. This mineral suite was derived from Pleistocene glacial erosion of Northern Appalachian igneous and metamorphic rocks, and transported to the nearshore zone by glacial meltwater. Despite the general similarity of New Jersey nearshore clay mineralogy, the fine fraction of several samples appears to be at least partially derived from local sources.

2. Clay-size sediment from beaches north of Long Beach is at least partially derived from erosion of glauconite-rich late Cretaceous to early Tertiary Coastal Plain sediments, which outcrop along the northern New Jersey shore. Beach and nearshore sediments between Point Pleasant and Little Egg Inlet may receive fine sediment input from shoreface and subaqueous erosion of the Kirkwood and Cohansey formations, which appear to have greater amounts of kaolinite/chlorite than surrounding shelf and beach samples.

3. The presence of smectite clay indicates a southern New Jersey inner shelf/northeastern Delaware Bay source for the fine fraction near the Cape May peninsula. Fine sediment is probably derived from subaqueous erosion of seafloor-outcropping Cape May

Formation clay.

4. Silt-sized sediment, like the clay-sized fraction, may be derived from regional input of Pleistocene glacial outwash. However, silt enriched in hornblende, and possibly epidote, is derived from the Bridgeton Formation, and is found on the beaches from Cape May to Point Pleasant, and the inner shelf from Cape May to Little Egg Inlet. Hornblende content in the silt fraction is aerially more extensive than in the sands, probably due to the greater mobility of silt in the nearshore environment.

5. The occurrence of significant (>5 percent) clay-sized sediment in some samples north of a probable Cape May peninsula source, and northward transport of silt-sized hornblende, imply that northern nearshore transport of fine-grained sediment may occur from Cape May to Point Pleasant. This transport, which is probably seasonal and may be induced by summer and winter circulation, is in the opposite direction (NE) to the previously observed net sand transport (SW).

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APPENDIX (1)

SAMPLE LOCATION AND DESCRIPTION

(A) Beach Samples - Collected 8/25/79-8/27/79

SAMPLE	LOCATION	MACROSCOPIC DESCRIPTION (from Folk, 1954)	COLOR	
B1	Sandy Hook- North Beach	Sand	5Y6/1	Grey
B3	Galilee - North of Monmouth Beach	Sand	5Y5/2	Olive grey
B6	Sea Girt	Sand	10YR7/2	Light grey
B10	Island Beach State Park	Sand	10YR8/2	White
B12	Harvey Cedars	Sand	10YR8/1	White
B16	Pullen Island	Sand	5Y5/1	Grey
B18	Atlantic City	Sand	5Y5/2	Olive grey
B23	Stone Harbor	Sand	5Y5/2	Olive grey
B25	Wildwood Crest	Sand	5Y5/1	Grey
B27	Town Bank - Delaware Bay	Sand	10YR7/3	Very pale brown
MB	Stone Harbor	Slightly gravelly sandy mud	2.5Y3/0	Very dark grey

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B12	Harvey Cedars	Sand	10YR8/1	White
B16	Pullen Island	Sand	5Y5/1	Grey
B18	Atlantic City	Sand	5Y5/2	Olive grey
B23	Stone Harbor	Sand	5Y5/2	Olive grey
B25	Wildwood Crest	Sand	5Y5/1	Grey
B27	Town Bank - Delaware Bay	Sand	10YR7/3	Very pale brown
MB	Stone Harbor	Slightly gravelly sandy mud	2.5Y3/0	Very dark grey

(B) SHELF SAMPLES - COLLECTED 7/18/79, 3/30/80, 5/23/80-6/11/80

SAMPLE	LOCATION		DEPTH (m)	DESCRIPTION	COLOR	
	LORAN C (3H4/3H5)	LAT / LONG (N) (W)				
A2	3445/3181	38 51.6'/74 51.8'	9.4	Sand	2.5Y5/3	Greyish brown to light olive brown
A4	3451/3155	38 48.1'/74 46.1'	17.7	Muddy sandy gravel	5Y4/2	Olive grey
A6	3548/3143	38 53.4'/74 36.7	20.1	Sand	5Y6/2	Light olive grey
A7	3634/3143	38 59.5'/74 31.2'	19.2	Sand	2.5Y6/2	Light brownish grey
A8	3644/3144	39 00.3'/74 30.8'	12.8	Sand	2.5Y6/3	Light brownish grey
A9	3752/3151	39 08.9'/74 25.4'	20.4	Sand	5Y4/2	Olive grey
A10	3801/3145	39 11.7'/74 21.0'	18.0	Sand	5Y6/2	Light olive grey
A11	3808/3143	39 12.0'/74 20.2'	19.2	Sand	5Y4/2	Olive grey
A13	3911/3143	39 19.8'/74 13.4'	19.5	Slightly gravelly sand	5Y6/2	Light olive grey
A14	3976/3141	39 24.6'/74 09.4'	17.4	Slightly gravelly sand	10YR6/4	Light yellowish brown
A16	4083/3147	39 32.6'/74 04.0'	18.3	Sandy gravel	10YR5/5	Yellowish brown
A19	4196/3163	39 42.3'/74 00.1'	20.4	Sandy gravel	10YR5/4	Yellowish brown
A22	4338/3205	39 57.9'/73 57.8'	21.3	Gravelly sand	10YR5/3	Brown
A24	4446/3227	40 08.4'/73 54.5'	21.9	Sandy gravel	5Y4/3	Olive
A28	4588/3281	40 25.9'/73 53.9'	20.7	Sand	5Y3/2	Dark olive grey
A31	4562/3298	40 24.3'/73 56.5'	11.6	Slightly gravelly sand	5Y3/3	Dark olive

(B) SHELF SAMPLES - COLLECTED 7/18/79, 3/30/80, 5/23/80-6/11/80

SAMPLE	LOCATION LORAN C (3H4/3H5)	LAT / LONG (N) (W)	DEPTH (m)	DESCRIPTION	COLOR	
A2	3445/3181	38 51.6'/74 51.8'	9.4	Sand	2.5Y5/3	Greyish brown to light olive brown
A4	3451/3155	38 48.1'/74 46.1'	17.7	Muddy sandy gravel	5Y4/2	Olive grey
A6	3548/3143	38 53.4'/74 36.7	20.1	Sand	5Y6/2	Light olive grey
A7	3634/3143	38 59.5'/74 31.2'	19.2	Sand	2.5Y6/2	Light brownish grey
A8	3644/3144	39 00.3'/74 30.8'	12.8	Sand	2.5Y6/3	Light brownish grey
A9	3752/3151	39 08.9'/74 25.4'	20.4	Sand	5Y4/2	Olive grey
A10	3801/3145	39 11.7'/74 21.0'	18.0	Sand	5Y6/2	Light olive grey
A11	3808/3143	39 12.0'/74 20.2'	19.2	Sand	5Y4/2	Olive grey
A13	3911/3143	39 19.8'/74 13.4'	19.5	Slightly gravelly sand	5Y6/2	Light olive grey
A14	3976/3141	39 24.6'/74 09.4'	17.4	Slightly gravelly sand	10YR6/4	Light yellowish brown
A16	4083/3147	39 32.6'/74 04.0'	18.3	Sandy gravel	10YR5/5	Yellowish brown
A19	4196/3163	39 42.3'/74 00.1'	20.4	Sandy gravel	10YR5/4	Yellowish brown
A22	4338/3205	39 57.9'/73 57.8'	21.3	Gravelly sand	10YR5/3	Brown
A24	4446/3227	40 08.4'/73 54.5'	21.9	Sandy gravel	5Y4/3	Olive
A28	4588/3281	40 25.9'/73 53.9'	20.7	Sand	5Y3/2	Dark olive grey
A31	4562/3298	40 24.3'/73 56.5'	11.6	Slightly gravelly sand	5Y3/3	Dark olive

	LOCATION					
SAMPLE	LORAN C (3H4/3H5)	LAT / LONG (N) (W)	DEPTH (m)	DESCRIPTION	COLOR	
A33b	4463/3270	40 13.6'/73 58.8'	13.4	Slightly gravelly	5Y2.5/2	Black
A36	4299/3222	39 56.5'/74 02.9'	15.2	Sand	5Y5/2	Olive grey
A37	4246/3210	39 51.4'/74 04.4'	13.1	------	----------------	
A39	4121/3185	39 39.5'/74 08.4'	11.3	Sand	5Y3/2	Dark olive grey
A42	3946/3171	39 25.2'/74 17.1'	9.4	Sand	5Y4/2	Olive grey
A45	3801/3183	39 16.6'/74 29.6'	10.1	Muddy sand	5Y3/1	Very dark grey
A46	3653/3186	39 06.7'/74 40.8'	8.8	Sand	5Y3/2	Dark olive grey
A47	3582/3181	39 01.0'/74 44.6'	10.7	Slightly gravelly sand	5Y4/3	Olive
A49	3533/3180	38 01.0'/74 44.6'	10.4	------	----------------	
MJ3	3166/3539	38 54.6'/75 00.6'	11.9	Slightly gravelly sandy mud	5Y3/2	Dark olive grey
MJ22	----	39 12.6'/74 35.6'	9.1	Sand	10YR6/3	Pale brown
MJ23	-----	39 12.5'/74 34.7'	16.5	Sand	5Y4/1	Dark grey
MJ24	-- --	39 12.3'/74 33.8'	18.6	Muddy sand	5Y3/2	Dark olive grey
MJ25	-----	39 10.9'/74 32.7'	14.6	Slightly gravelly sand	5Y7/2	Light grey
MJ26	-----	39 11.8'/74 31.7'	19.2	Sand	5Y4/3	Olive
MJ27	-----	39 08.4'/74 35.4'	10.7	Slightly gravelly sand	2.5Y6/3	Light yellowish grey to light yellowish brown

	LOCATION					
SAMPLE	LORAN C (3H4/3H5)	LAT / LONG (N) (W)	DEPTH (m)	DESCRIPTION	COLOR	
A33b	4463/3270	40 13.6'/73 58.8'	13.4	Slightly gravelly	5Y2.5/2	Black
A36	4299/3222	39 56.5'/74 02.9'	15.2	Sand	5Y5/2	Olive grey
A37	4246/3210	39 51.4'/74 04.4'	13.1	------	----------------	
A39	4121/3185	39 39.5'/74 08.4'	11.3	Sand	5Y3/2	Dark olive grey
A42	3946/3171	39 25.2'/74 17.1'	9.4	Sand	5Y4/2	Olive grey
A45	3801/3183	39 16.6'/74 29.6'	10.1	Muddy sand	5Y3/1	Very dark grey
A46	3653/3186	39 06.7'/74 40.8'	8.8	Sand	5Y3/2	Dark olive grey
A47	3582/3181	39 01.0'/74 44.6'	10.7	Slightly gravelly sand	5Y4/3	Olive
A49	3533/3180	38 01.0'/74 44.6'	10.4	------	----------------	
MJ3	3166/3539	38 54.6'/75 00.6'	11.9	Slightly gravelly sandy mud	5Y3/2	Dark olive grey
MJ22	-----	39 12.6'/74 35.6'	9.1	Sand	10YR6/3	Pale brown
MJ23	------	39 12.5'/74 34.7'	16.5	Sand	5Y4/1	Dark grey
MJ24	-- --	39 12.3'/74 33.8'	18.6	Muddy sand	5Y3/2	Dark olive grey
MJ25	-----	39 10.9'/74 32.7'	14.6	Slightly gravelly sand	5Y7/2	Light grey
MJ26	------	39 11.8'/74 31.7'	19.2	Sand	5Y4/3	Olive
MJ27	-----	39 08.4'/74 35.4'	10.7	Slightly gravelly sand	2.5Y6/3	Light yellowish grey to light yellowish brown

(C) RIVER SAMPLES - COLLECTED 6/10/80

SAMPLE	LOCATION	COLOR	
R2	Great Egg Harbor River at U.S. Route 40	2.5YR3/1	Very dark grey to dusk red
R3b	Mullica River at N.J. Route 563	5YR2/1	Black
R4	Wading River at N.J. Route 542	10YR2/1	Black
R6	Toms River at Garden State Parkway	7.5YR3/2	Dark Brown
R7	Raritan River at U.S. Route 1	5YR3/4	Dark reddish brown

(C) RIVER SAMPLES - COLLECTED 6/10/80

SAMPLE	LOCATION	COLOR	
R2	Great Egg Harbor River at U.S. Route 40	2.5YR3/1	Very dark grey to dusk red
R3b	Mullica River at N.J. Route 563	5YR2/1	Black
R4	Wading River at N.J. Route 542	10YR2/1	Black
R6	Toms River at Garden State Parkway	7.5YR3/2	Dark Brown
R7	Raritan River at U.S. Route 1	5YR3/4	Dark reddish brown

APPENDIX 2

SIZE ANALYSIS TECHNIQUE

A 25 to 100 gram subsample was separated from each grab sample. The sediment was placed in an 8 ounce jar, along with distilled water, and 20 mls of a 50 g/l solution of sodium metaphosphate (a dispersant), and shaken by a Burrell wrist action shaker for 30 minutes. The sample was then wet sieved through a 4 phi (62 um) sieve, and the fine fraction washed into a 1000 ml settling tube and saved for pipette analysis.

The coarse material (<4 phi, >62 um) was dried in an oven at 60 degrees centigrade. Some samples contained small amounts of plant debris which was removed manually, while others contained whole shells and shell fragments. It is usually not easy to tell whether a shell is an allochthonous or autochthonous part of the sediment, so only shell fragments larger than the largest clastic particles were removed (see discussion in Frank and Friedman, 1973).

The dried sample was sieved through a series of 11 sieves from -1.0 phi (2 mm) to 4.0 phi (62 um), at half phi intervals. The 11 sieves were divided into two stacks, and each stack was vibrated on a sieve shaker for 10 minutes. The weight of each size fraction was recorded to the nearest 0.001 gram. Each reported phi size consists of material between that size, and the preceeding half size (ex: 3.0 phi fraction consists of material between 2.5 and 3.0 phi (177 to 125 um).

Any dry material that passed through the 4 phi sieve (pan fraction) was added to the fine fraction. Distilled water was added to the settling tubes to increase the volume to 1000 mls, and the tubes were stored in a constant temperature bath at 25 degrees centigrade. No flocculation of clays was observed in the settling tubes, so no additional dispersant was added prior to pipetting.

A series of eight 20 ml aliquots taken from each settling tube were dried and weighed, to provide values for the 5 to 11 phi size fractions at 1 phi intervals. The settling times and pipette depths were calculated using Stoke's law.

APPENDIX (3)

SIZE ANALYSIS

Weight Percent in Phi Sizes

SAMPLE	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	MEAN (Folk,	SD 1966)
B1	0.00	0.16	0.59	7.39	33.31	46.52	11.02	0.45	0.10	0.02	0.02	0.43	1.06	0.38
B3	0.00	0.00	0.27	0.75	6.06	33.05	46.80	10.72	1.25	0.10	0.05	0.94	1.58	0.37
B6	0.00	0.00	0.15	4.18	27.13	46.01	19.59	2.30	0.17	0.01	0.01	0.45	1.19	0.40
B10	0.00	0.00	0.00	0.00	3.11	28.33	50.59	16.32	0.73	0.02	0.01	0.89	1.67	0.37
B12	0.00	0.00	0.00	0.16	0.58	11.79	55.41	24.68	6.02	0.70	0.06	0.61	1.88	0.35
B16	0.00	0.00	0.00	0.00	0.01	0.10	2.67	26.48	57.65	11.27	1.16	0.67	2.65	0.31
B18	0.00	0.00	0.00	0.04	0.03	0.05	0.47	5.33	43.65	47.08	2.00	1.35	3.00	0.27
B23	0.00	0.00	0.00	0.00	0.01	0.22	4.10	17.02	57.14	19.89	1.00	0.62	2.75	0.34
B25	0.00	0.00	0.00	0.01	0.01	0.01	0.13	3.97	54.08	38.92	0.89	1.98	2.97	0.27
B27	0.00	0.00	0.00	0.09	1.03	15.87	65.73	16.19	0.50	0.02	0.00	0.58	1.75	0.28
A2	0.00	0.00	0.00	0.00	5.01	21.09	42.86	18.78	8.24	2.38	0.65	0.99	1.81	0.55
A4	75.63	0.78	0.86	2.23	3.16	3.26	2.42	1.58	3.05	3.21	1.15	2.67	----	----
A6	0.00	0.00	0.00	0.82	2.86	25.27	45.36	19.22	3.76	1.36	0.28	1.08	1.74	0.43
A7	0.00	0.05	0.16	0.72	4.35	19.25	44.59	22.59	6.31	0.98	0.17	0.83	1.80	0.47
A8	0.00	0.05	0.21	1.18	5.52	25.97	47.94	15.05	3.15	0.27	0.03	0.64	1.66	0.43
A9	0.00	0.00	0.00	0.11	0.31	0.82	2.95	13.29	47.71	29.99	2.89	1.93	2.82	0.37
A10	0.00	0.00	0.11	0.32	4.52	26.19	37.19	16.12	10.50	3.63	0.60	0.82	1.82	0.60
A11	0.00	0.00	0.00	0.00	1.83	7.96	7.82	17.54	49.13	13.14	1.31	1.26	2.54	0.57
A13	1.88	1.08	1.16	7.91	9.59	35.89	26.49	12.26	2.95	0.31	0.06	0.43	1.39	0.65
A14	2.94	5.22	6.80	17.40	19.31	27.95	17.27	2.50	0.30	0.04	0.02	0.25	0.86	0.79
A16	61.85	14.39	2.95	3.86	5.99	6.98	3.00	0.51	0.10	0.02	0.01	0.34	-1.13	1.46
A19	46.22	3.55	4.63	16.25	16.65	9.06	2.70	0.36	0.11	0.02	0.01	0.43	-1.61	2.78
A22	22.71	0.93	5.62	20.28	26.34	16.50	5.98	0.89	0.32	0.03	0.01	0.38	-0.96	3.28
A24	50.35	2.64	4.41	3.10	4.39	7.06	6.17	6.34	8.86	1.95	0.84	3.88	-2.04	4.46

APPENDIX (3)

SIZE ANALYSIS

Weight Percent in Phi Sizes

SAMPLE	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	MEAN (Folk,	SD 1966)
B1	0.00	0.16	0.59	7.39	33.31	46.52	11.02	0.45	0.10	0.02	0.02	0.43	1.06	0.38
B3	0.00	0.00	0.27	0.75	6.06	33.05	46.80	10.72	1.25	0.10	0.05	0.94	1.58	0.37
B6	0.00	0.00	0.15	4.18	27.13	46.01	19.59	2.30	0.17	0.01	0.01	0.45	1.19	0.40
B10	0.00	0.00	0.00	0.00	3.11	28.33	50.59	16.32	0.73	0.02	0.01	0.89	1.67	0.37
B12	0.00	0.00	0.00	0.16	0.58	11.79	55.41	24.68	6.02	0.70	0.06	0.61	1.88	0.35
B16	0.00	0.00	0.00	0.00	0.01	0.10	2.67	26.48	57.65	11.27	1.16	0.67	2.65	0.31
B18	0.00	0.00	0.00	0.04	0.03	0.05	0.47	5.33	43.65	47.08	2.00	1.35	3.00	0.27
B23	0.00	0.00	0.00	0.00	0.01	0.22	4.10	17.02	57.14	19.89	1.00	0.62	2.75	0.34
B25	0.00	0.00	0.00	0.01	0.01	0.01	0.13	3.97	54.08	38.92	0.89	1.98	2.97	0.27
B27	0.00	0.00	0.00	0.09	1.03	15.87	65.73	16.19	0.50	0.02	0.00	0.58	1.75	0.28
A2	0.00	0.00	0.00	0.00	5.01	21.09	42.86	18.78	8.24	2.38	0.65	0.99	1.81	0.55
A4	75.63	0.78	0.86	2.23	3.16	3.26	2.42	1.58	3.05	3.21	1.15	2.67	----	----
A6	0.00	0.00	0.00	0.82	2.86	25.27	45.36	19.22	3.76	1.36	0.28	1.08	1.74	0.43
A7	0.00	0.05	0.16	0.72	4.35	19.25	44.59	22.59	6.31	0.98	0.17	0.83	1.80	0.47
A8	0.00	0.05	0.21	1.18	5.52	25.97	47.94	15.05	3.15	0.27	0.03	0.64	1.66	0.43
A9	0.00	0.00	0.00	0.11	0.31	0.82	2.95	13.29	47.71	29.99	2.89	1.93	2.82	0.37
A10	0.00	0.00	0.11	0.32	4.52	26.19	37.19	16.12	10.50	3.63	0.60	0.82	1.82	0.60
A11	0.00	0.00	0.00	0.00	1.83	7.96	7.82	17.54	49.13	13.14	1.31	1.26	2.54	0.57
A13	1.88	1.08	1.16	7.91	9.59	35.89	26.49	12.26	2.95	0.31	0.06	0.43	1.39	0.65
A14	2.94	5.22	6.80	17.40	19.31	27.95	17.27	2.50	0.30	0.04	0.02	0.25	0.86	0.79
A16	61.85	14.39	2.95	3.86	5.99	6.98	3.00	0.51	0.10	0.02	0.01	0.34	-1.13	1.46
A19	46.22	3.55	4.63	16.25	16.65	9.06	2.70	0.36	0.11	0.02	0.01	0.43	-1.61	2.78
A22	22.71	0.93	5.62	20.28	26.34	16.50	5.98	0.89	0.32	0.03	0.01	0.38	-0.96	3.28
A24	50.35	2.64	4.41	3.10	4.39	7.06	6.17	6.34	8.86	1.95	0.84	3.88	-2.04	4.46

Weight Percent in Phi Sizes

SAMPLE	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	MEAN (Folk,	SD 1966)
A28	0.83	0.01	0.69	1.41	2.65	5.34	13.96	30.70	32.00	7.33	2.73	2.35	2.35	0.68
A31	1.22	0.00	0.10	0.41	0.72	1.25	4.46	18.34	43.40	17.37	3.48	9.25	2.77	1.12
A33b	2.63	0.62	2.85	5.51	12.81	42.81	28.70	2.93	0.20	0.06	0.06	0.82	1.25	0.55
A36	0.25	0.20	0.24	3.65	5.26	17.42	38.96	23.31	5.53	0.53	0.21	4.44	1.79	0.63
A39	0.00	0.00	0.00	0.00	0.61	1.24	4.68	6.36	41.68	26.59	11.14	7.69	3.05	0.63
A42	0.00	0.20	0.71	1.42	2.40	4.77	14.39	27.09	30.34	9.17	3.78	5.72	2.46	0.89
A45	0.00	0.00	0.00	0.00	0.00	0.82	1.67	4.52	25.67	36.83	17.86	12.64	3.29	0.97
A46	0.00	0.00	0.00	0.17	0.35	0.38	0.44	0.78	10.03	55.67	23.95	6.23	3.39	0.40
A47	1.05	1.67	1.76	12.57	15.83	33.83	15.79	6.34	4.32	4.70	0.66	1.49	1.28	0.86
MJ3	0.17	0.31	0.52	0.97	1.42	1.82	1.34	1.37	4.86	7.61	10.11	69.48	5.92	----
MJ22	0.11	0.17	0.14	1.79	4.87	50.00	35.72	6.26	0.45	0.04	0.03	0.42	1.51	0.33
MJ23	0.09	0.35	0.25	1.13	1.95	7.85	7.97	9.70	30.33	30.72	7.18	2.48	2.68	0.79
MJ24	0.00	0.13	0.12	0.71	1.39	7.07	7.68	10.74	18.38	14.67	4.31	34.81	4.13	2.74
MJ25	0.05	0.85	1.18	7.48	10.39	34.93	29.09	11.54	3.18	0.59	0.05	0.68	1.43	0.62
MJ26	0.00	0.00	0.00	0.00	0.22	1.29	4.51	17.16	54.38	19.48	1.62	1.34	2.71	0.36
MJ27	1.26	1.64	1.15	5.95	9.10	46.54	28.14	5.10	0.40	0.09	0.03	0.60	1.34	0.50
MB	1.52	0.05	0.37	0.83	0.69	0.54	0.38	0.35	0.63	4.18	8.00	82.48	----	----

Weight Percent in Phi Sizes

SAMPLE	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	MEAN (Folk,	SD 1966)
A28	0.83	0.01	0.69	1.41	2.65	5.34	13.96	30.70	32.00	7.33	2.73	2.35	2.35	0.68
A31	1.22	0.00	0.10	0.41	0.72	1.25	4.46	18.34	43.40	17.37	3.48	9.25	2.77	1.12
A33b	2.63	0.62	2.85	5.51	12.81	42.81	28.70	2.93	0.20	0.06	0.06	0.82	1.25	0.55
A36	0.25	0.20	0.24	3.65	5.26	17.42	38.96	23.31	5.53	0.53	0.21	4.44	1.79	0.63
A39	0.00	0.00	0.00	0.00	0.61	1.24	4.68	6.36	41.68	26.59	11.14	7.69	3.05	0.63
A42	0.00	0.20	0.71	1.42	2.40	4.77	14.39	27.09	30.34	9.17	3.78	5.72	2.46	0.89
A45	0.00	0.00	0.00	0.00	0.00	0.82	1.67	4.52	25.67	36.83	17.86	12.64	3.29	0.97
A46	0.00	0.00	0.00	0.17	0.35	0.38	0.44	0.78	10.03	55.67	23.95	6.23	3.39	0.40
A47	1.05	1.67	1.76	12.57	15.83	33.83	15.79	6.34	4.32	4.70	0.66	1.49	1.28	0.86
MJ3	0.17	0.31	0.52	0.97	1.42	1.82	1.34	1.37	4.86	7.61	10.11	69.48	5.92	----
MJ22	0.11	0.17	0.14	1.79	4.87	50.00	35.72	6.26	0.45	0.04	0.03	0.42	1.51	0.33
MJ23	0.09	0.35	0.25	1.13	1.95	7.85	7.97	9.70	30.33	30.72	7.18	2.48	2.68	0.79
MJ24	0.00	0.13	0.12	0.71	1.39	7.07	7.68	10.74	18.38	14.67	4.31	34.81	4.13	2.74
MJ25	0.05	0.85	1.18	7.48	10.39	34.93	29.09	11.54	3.18	0.59	0.05	0.68	1.43	0.62
MJ26	0.00	0.00	0.00	0.00	0.22	1.29	4.51	17.16	54.38	19.48	1.62	1.34	2.71	0.36
MJ27	1.26	1.64	1.15	5.95	9.10	46.54	28.14	5.10	0.40	0.09	0.03	0.60	1.34	0.50
MB	1.52	0.05	0.37	0.83	0.69	0.54	0.38	0.35	0.63	4.18	8.00	82.48	----	----

SIZE ANALYSIS - FINE FRACTION

SAMPLE	5.0	6.0	7.0	8.0	9.0	10.0	11.0	>11.0	TOTAL
A4	0.47	0.50	0.22	0.24	0.26	0.15	0.01	0.81	2.66
A24	0.58	0.39	0.51	0.20	0.13	0.38	0.03	1.66	3.88
A31	1.77	0.99	0.82	1.19	0.99	0.24	0.19	3.05	9.24
A39	4.75	0.49	0.05	0.05	0.12	0.02	0.16	2.05	7.69
A42	0.91	1.97	1.29	0.46	0.31	0.11	0.07	0.60	5.72
A45	4.49	2.00	1.17	0.48	0.72	0.45	0.48	2.83	12.62
A46	3.79	0.57	0.06	0.13	0.07	0.15	0.03	1.43	6.23
MJ3	18.06	13.97	9.29	4.10	5.23	5.93	1.09	11.82	69.49
MJ24	5.35	5.31	5.67	5.83	4.64	2.56	1.16	4.28	34.80
MB	4.04	17.71	14.67	2.46	7.79	2.42	9.28	24.10	82.47

SIZE ANALYSIS - FINE FRACTION

SAMPLE	5.0	6.0	7.0	8.0	9.0	10.0	11.0	>11.0	TOTAL
A4	0.47	0.50	0.22	0.24	0.26	0.15	0.01	0.81	2.66
A24	0.58	0.39	0.51	0.20	0.13	0.38	0.03	1.66	3.88
A31	1.77	0.99	0.82	1.19	0.99	0.24	0.19	3.05	9.24
A39	4.75	0.49	0.05	0.05	0.12	0.02	0.16	2.05	7.69
A42	0.91	1.97	1.29	0.46	0.31	0.11	0.07	0.60	5.72
A45	4.49	2.00	1.17	0.48	0.72	0.45	0.48	2.83	12.62
A46	3.79	0.57	0.06	0.13	0.07	0.15	0.03	1.43	6.23
MJ3	18.06	13.97	9.29	4.10	5.23	5.93	1.09	11.82	69.49
MJ24	5.35	5.31	5.67	5.83	4.64	2.56	1.16	4.28	34.80
MB	4.04	17.71	14.67	2.46	7.79	2.42	9.28	24.10	82.47

APPENDIX (4)

NORMALIZED FACTOR MEASUREMENTS FOR R-MODE FACTOR ANALYSIS

(A) Size Analysis

SAMPLE	FACTORS 1	2	3	4	5
A2	.15081	.20766	.76688	.24217	.10546
A4	1.00000	.45402	.63172	.15278	.18439
A6	.15962	.13632	.75726	.20544	.10615
A7	.15981	.20321	.81846	.21110	.11490
A8	.15939	.09921	.72493	.23721	.09950
A9	.07264	.91231	.67766	.55484	.05738
A10	.13215	.22938	.72383	.31092	.09274
A11	.05865	.83582	.84770	.55947	.08701
A13	.12846	.19003	.66581	.55332	.10338
A14	.17579	.27830	.60941	.87852	.13092
A16	.98653	.39979	.62043	.23439	.15682
A19	.65737	.44427	.64111	.66566	.17538
A22	.33007	.41025	.62735	.96363	.16422
A24	.72837	.48548	.70999	.31877	.19088
A28	.10372	.70687	.95163	.43969	.14340
A31	.08752	.85714	.82165	.53347	.17718
A33b	.13177	.08825	.55059	.59508	.09089
A36	.15219	.25209	.84283	.29384	.16475
A39	.09187	.80839	.55247	.53254	.13009
A42	.10224	.68591	.89895	.44169	.17217
A45	.12049	.70623	.34060	.47943	.16971
A46	.15826	.60305	0.00000	.40995	.06486
A47	.09329	.28374	.58455	.78435	.11166
B1	0.00000	.17247	.48558	1.00000	.08885
B3	.14937	.03932	.65632	.27287	.09084
B6	.02993	.11727	.50747	.81504	.08156
B10	.16922	.05030	.72339	.16789	.09891
B12	.19879	.17681	.87018	.05346	.11858
B16	.05016	1.00000	1.00000	.55717	.10216
B18	.08112	.91277	.46246	.56935	0.00000
B23	.05775	.97624	.84557	.56980	.06776
B25	.06249	.97881	.56771	.61911	.02058
B27	.21820	.02410	.75411	0.00000	.09724
MJ3	.11261	.50283	.69678	.56885	.85206
MJ22	.11180	0.00000	.55529	.40484	.06558
MJ23	.10357	.69182	.51288	.50941	.06217
MJ24	.10836	.58539	.70904	.50812	.40125
MJ25	.10926	.17891	.66175	.54946	.10332
MJ26	.06070	.94470	.83202	.56176	.07726
MJ27	.12274	.07508	.55693	.55289	.08205
MB	.12447	.47870	.75926	.56920	1.00000

(B) Fine Clay Fraction (<11 phi) Mineralogy

SAMPLE	FACTORS 1	 2	 3
A4	.31331	.56415	.67658
A7	.44258	.32778	.66690
A11	.33879	.08905	.67803
A13	.47288	.16448	.87929
A14	.36225	.07312	.54277
A16	.53789	.15100	.67753
A19	.32428	.06257	.55783
A22	.38869	.79077	.99618
A24	.57587	.11820	.41432
A28	.57919	.09066	.23969
A31	.48893	.18705	.30100
A33b	.33952	.06258	.52209
A36	.61993	.20877	.87390
A39	.54758	.20732	1.00000
A42	.45583	.56172	.50062
A45	.47541	.12690	.65722
A46	.44238	.16298	.93088
B1	0.00000	.03624	.99716
B3	.01409	0.00000	.76898
B6	.45656	.14912	.82524
B10	.54683	.15194	.67022
B12	.61243	.21385	.91823
B16	.56539	.14781	.61097
B18	.57067	.15590	.64947
B23	.44189	.31475	.48616
B25	.42559	1.00000	.80463
B27	.51909	.14496	.68386
MB	.42755	.30237	.46332
MJ3	.46187	.69518	.66289
R3b	.40108	.05912	.38299
R4	.28536	.06633	.64173
R6	1.00000	.17983	0.00000
R7	.27661	.03905	.49858

(C) Silt Size (5 to 7 phi) Mineralogy

	FACTORS			
SAMPLE	1	2	3	4
A4	.25026	.72779	.28658	.42944
A7	.13328	.48523	.18699	.58245
A13	.14592	.49831	.18944	.87599
A16	0.00000	.12462	.26116	.63561
A22	.18613	.22261	1.00000	.63833
A24	.17329	.17100	.36104	.74488
A28	.49464	.27482	.39863	.77116
A31	.42569	.30022	.30902	.39780
A33b	.19098	.43100	.57484	.78205
A36	.36876	.76555	.21066	.94526
A39	.11976	.63828	.15734	.56009
A42	.22391	.34392	.34338	.60653
A45	.07237	.75811	.12356	.74365
A46	.34792	.59984	.32735	.25437
B10	.09306	.56298	.44483	.84180
B12	.10250	.58828	.66382	0.00000
B16	.18008	.75172	.68254	.85194
B18	.11240	1.00000	.27719	1.00000
B25	.03845	.52937	.25039	.86926
MB	.03199	0.00000	.38862	.64872
MJ3	.27715	.40415	.25342	.44491
R2	.16933	.71749	.65816	.84620
R3b	1.00000	.54268	.80474	.29565
R4	.12778	.36370	.28607	.58887
R6	.22337	.25513	0.00000	.85634
R7	.47435	.26876	.34647	.78365

APPENDIX 5

MINERALOGIC ANALYSIS

Because of the dominance of sand-sized (>62 um) material in most beach and shelf sediments, large initial volumes of sediment were needed to extract sufficient fine fraction for x-ray examination. Depending upon visual examination of the clay content, from 0.5 to 3.0 kilograms of sediment were washed in small increments through a 4 phi (62 um) sieve. The fine material that passed through the screen was collected in one liter french square jars, and concentrated by candle filteration. The samples were then slaked to remove dissolved salts.

Pretreatments

Removal of Fe/Mn oxides, biogenous calcium carbonate, and organic matter are common pretreatments in clay mineral studies, since these substances often mask or decrease the size of x-ray diffraction peaks (Jackson, 1956; Arcaro, 1976; and others). Kelley (1980) found that fine-grained marine sediment from southern New Jersey contained little or no detectable calcium carbonate, and Fe/Mn oxides. Furthermore, Kelley observed that pretreatment methods produced measurable differences in x-ray diffraction patterns.

Several samples in this study were selected to assess the affect of pretreatments on clay mineralogy. Treatments tested were iron removal using the method of Mehra and Jackson (1960), and organic removal using hydrogen peroxide (Jackson, 1956). It was decided to abandon the use of these methods, after considerable variation was noticed in several samples after treatment (figure 35).

Size Separation

Size separation was achieved through repeated centrifugation or settling, and decantation. Very fine clay (>11 phi, <0.5 um) was separated into several size classes using a Sharples super centrifuge. Size classes separated were; 11-10 phi (0.50-0.25 um), 12-13 phi (0.25-0.13 um), 13-14 phi (0.13-0.06 um), and less than 14 phi (0.06 um). The centrifuge was calibrated using a stroboscope, and centrifuge times were taken from a nomograph by Jackson (1956).

The size fraction between 8 and 11 phi was separated into three (one) phi size classes using a table top centrifuge, with centrifuge times taken from Tanner and Jackson (1947). The sediment fraction between 5 and 8 phi was separated by gravity settling, using times calculated from Stoke's law. The process of centrifugation or settling and decantation was repeated 3 to 6 times to insure good separation of size classes.

Mounting Method

All samples were mounted on specially cut glass slides (approximately 14 by 18 by 1 mm) which fit into a Phillips x-ray

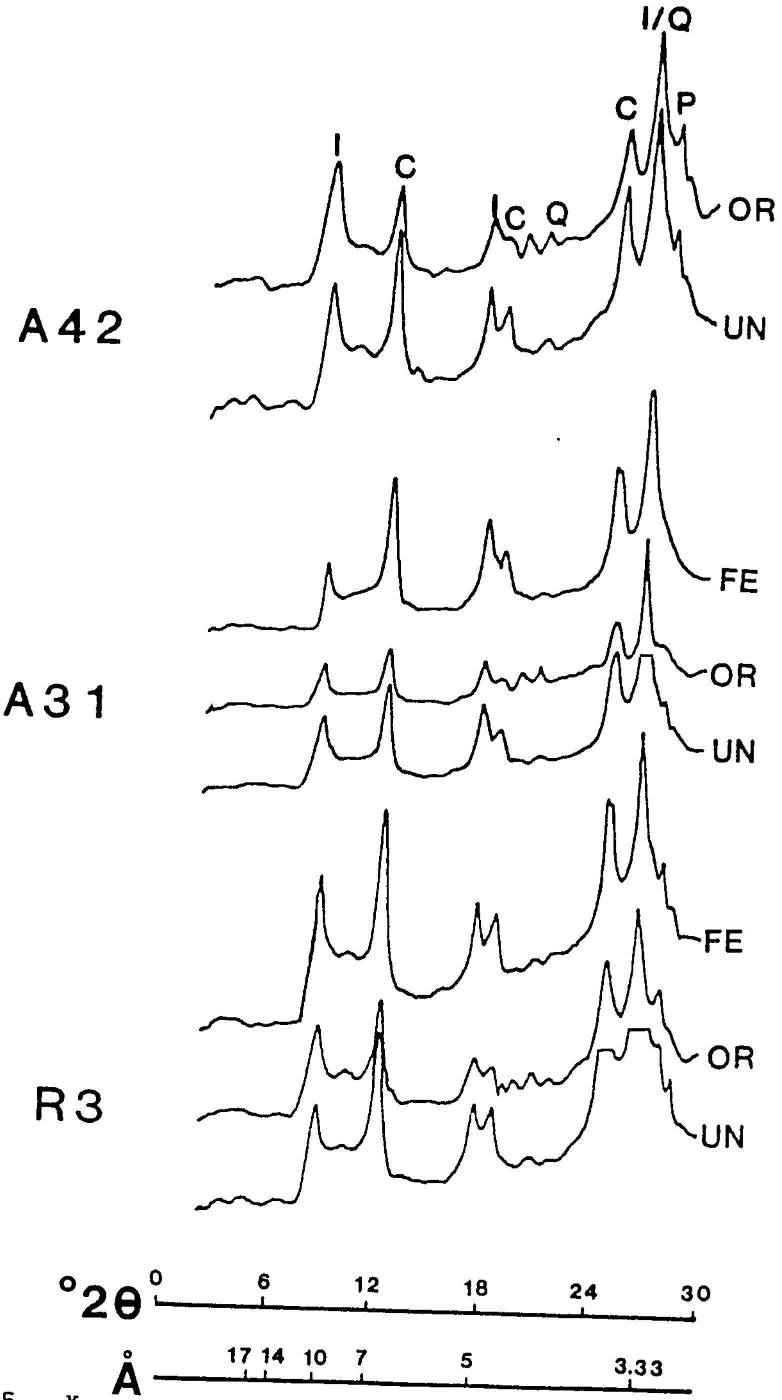

Figure 35. X-ray diffraction patterns of the less than 0.5 um fraction of untreated samples (UN), and after organic (OR) and iron (FE) pretreatments. The 10 angstrom (illite/glauconite) peak, and the 7 angstrom (kaolinite/chlorite) peak exhibit the greatest relative changes after treatment.

specimen holder. The fine clay fraction was mounted using the smear-on-glass slide technique described by Gibbs (1965). A portion of the <0.5 um fraction was dried to a paste, and spread across a glass slide with a spatula to produce a thin, even sediment layer. This method, when properly applied, is found to be accurate and reproducible, regardless of the amount of sample mounted (Stokke and Carson, 1973).

Qualitative Identification

All samples were x-rayed on a Phillips APD 3600 Automated Powder Diffractometer using CuK alpha radiation at instrument settings of 45 Kv and 30 mA. The goniometer is driven by a stepper motor, and samples were x-rayed in angle increments of .02 degrees, and a time increment of 2.4 seconds, to produce a scanning speed of one half degree/minute.

The <0.5 um fraction was x-rayed from 2 to 30 degrees two theta in the air dried, and glycolated states. The minerals were identified by their major x-ray diffraction peaks. Qualitative mineral identification agreed with other recent work on coastal New Jersey fines (Kelley, 1980; Meza and Paola, 1977; Levy, 1978).

Illite was identified by a series of basal reflections (10, 5, 3.3 angstroms) which showed little or no change on glycolation (Carroll, 1970). Additional peaks in the silt fraction indicate the presence of a 2M mineral (muscovite). The (001)/(002) peak intensity ratio was always less than 4, indicating that little or no trioctahedral phyllosilicate (biotite) was present (Bradley and Grim, 1961; Roaldset, 1972).

Glauconite is an important constituent of the sand fraction in some northern New Jersey beach sediments (McMaster, 1954; Schroeder, 1982). Because of the similarity between the x-ray diffraction patterns of illite and glauconite, no attempt was made to differentiate between glauconite, and other 10 angstrom phases.

Chlorite was identified by a series of basal reflections (14, 7.0, 4.7, and 3.5 angstroms), which showed no change with glycolation (Carroll, 1970). The technique of Biscaye (1964) was used in an attempt to differentiate the 3.57 angstrom (24.9 degree) kaolinite peak from the 3.53 angstrom (25.2 degree) chlorite peak. In no samples could two separate peaks be resolved from the 25 degree peak. Typically, this peak was slightly skewed toward the high angle side, possibly indicating a predominance of chlorite. The 7 angstrom peak is referred to as the chlorite/kaolinite peak, with no attempt made to quantitatively differentiate between the two minerals.

Smectite was recognized as a broad swelling in the 17-20 angstrom region (5.2-4.4 degrees) upon glycolation. No higher order reflections were observed. The occurrence of high angle swelling (20-28 angstroms, 4.0-3.0 degrees) may be due to the presence of regularly interstratified clays such as chlorite-smectite or illite-smectite. No attempt was made to positively identify the mineralogy of this interlayering, and its occurrence was included in the quantification of smectite.

Several other minerals which were common in the coarser fractions, were identified in the fine fraction by their most prominent diffraction peaks. These minerals include quartz (4.26 angstroms, 27.9 degrees), hornblende (8.4 angstroms, 10.5 degrees), plagioclase (3.19 angstroms, 27.9 degrees), and microcline (3.24 angstroms, 27.5 degrees).

Quantification Method

The quantitative techniques utilized in this study were arrived at after some experimentation, and a review of current methods cited in the literature. Pierce and Siegel (1969) found a wide variability in clay mineral percentages, as determined by five common calculation methods. Although many quantification schemes provide reproducible results for a particular study area, comparison of clay percentages calculated with different methods in different regions are often unwarranted. Because of the variable results obtained with different quantification schemes, calibration curves were generated for the major phases in this study.

Gibbs (1965) and Halma (1969) discuss the use of calibration standards extracted from study samples, as a way to overcome the problems of compositional and crystalinity differences in clay minerals. Gibbs' extraction methods are based on density differences between minerals, and the preferential occurrence of each mineral in a different size fraction.

Although separation of standards from sample material is theoretically sound, there would be difficulty in applying separation techniques to the samples in this study. The three test samples exhibited no consistent differences in the relative abundance of illite and chlorite in each size fraction. Kelley (1980) found that the overall crystallinity of New Jersey shelf clay minerals decreases from coarse to fine sizes, which implies that standards should be extracted from the size fraction to be analyzed. Separation of minerals in the <0.5 um fraction would require knowledge of clay mineral specific gravities, which can be variable for different minerals in different areas. After considering the time consuming nature and uncertainty of success of standard separation from collected samples, laboratory standards with similar properties and sizes (<0.5 um) were judged to be acceptable substitutes.

Calibration curves were prepared for illite, chlorite, and quartz. Illite no. 35 from Fithian, Illinois (distributed by Ward's Natural Science Establishment, Inc., Rochester, N. Y.) was chosen as the illite standard. The >11 phi (<0.5 um) fraction contained only traces of the 20.8 degree quartz peak, and a 12.4 degree (7 angstrom) clay peak.

The chlorite standard used was from Calaveras County, California (Wards' Scientific). It contained no noticeable clay or quartz impurities in the >11 phi fraction.

The quartz standard was prepared by grinding pure crystals in an aluminum oxide mortar. This standard contained no noticeable impurities, and appeared to have similar peak properties as sample quartz.

Several feldspars were ground and x-rayed to determine if suitable standards for plagioclase and microcline could be found. None of the standards tested proved to be comparable to the plagioclase and microcline peaks found in the coarser sample fractions. Choosing one or two feldspar standards to represent what is probably a combination of feldspars in the study area is an inaccurate and simplistic approach. Since the sample feldspars cannot be accurately characterized by standards, and since they do not appear to be volumetrically important, no attempt was made to quantify the feldspar content of each sample. Similarly, hornblende, which was present at the threshold level of x-ray detection in some samples, was not quantified in the clay fraction.

Mineral percentages in the fine fraction were calculated using a modification of a Phillips quantification method (LaChance and Traill, 1966). A series of 18 standard mixtures were prepared by mixing three standard phases (illite, chlorite, and quartz) in varying relative weight percents. Ten percent corundum was added to each mixture as an internal standard. The areas of a major quartz (20.7 degree), illite (8.6 degree), chlorite/kaolinite (12.4 degree) and corundum (43.4 degree) peak were measured for each phase with a quantitative collection program. The peak areas were presented as relative ratios, with the alumina peak set at one. The areas of the illite, chlorite/kaolinite, and quartz peaks were then normalized to 100%.

Three repetitions of the 18 standard mixtures were averaged, to produce a mean intensity value for each mineral phase. The normalized intensities and known concentrations (weight) percentages were then plugged into an empirical correction equation:

$$C_i = (a_i I_i + b_i) *$$

$$(I + (K_i)(I_j))$$

where: I_i = intensity of phase i

a_i = slope

b_i = y intercept

K_i = correction coefficent of phase j

I_j = intensity of phase j

This equation is modified from a quantitative program developed by LaChance and Traill (1966) for x-ray spectrometry. Each phase is corrected for possible absorption effects of the other two phases. The slope (A), y intercept (B) and correction coefficents for each phase (K1,. K2) are presented below:

	A	B	K-ILL	K-CHL	K-QTZ
ILLITE	0.915	1.349	---	-0.146E-4	0.594E-2
CHLORITE	1.057	-1.450	-0.551E-2	---	0.128E-2
QUARTZ	0.9927	5.420	-0.654E-2	-0.604E-2	---

Each of the 33 samples was X-rayed 3 times for the same 4 phases as the standard slides. The intensities were normalized, and quartz, illite, and chlorite concentrations were computed using the empirical correction coefficents determined for each phase. The sum of the computed concentrations deviated slightly from 100%, and required an additional normalization. The resulting calculations yield the relative percentages of chlorite, illite, and quartz in each sample. The average concentration of each phase is listed in table 4, along with a 90% confidence interval for each value.

Due to the nature of the smectite peak - a broad swelling in the low angle range - it was impossible for the computer program to accurately measure its peak area. Glycolated and unglycolated samples were compared manually, and the area of the smectite swelling was measured using a polar planimeter. Following Biscaye's (1965) method, the smectite area was multiplied by a factor of 4, and assigned a percentage relative to illite. All of the phases were then renormalized to 100%. No error calculations were performed on the reported smectite values.

TABLE 4

AVERAGED NORMALIZED MINERAL PERCENTAGES IN THE >11 PHI (<0.5 um) SIZE FRACTION WITH A 90% CONFIDENCE INTERVAL

SAMPLE	10 ANGSTROM (ILLITE/ GLAUCONITE)	7/14 ANGSTROM (KAOLINITE/ CHLORITE)	QUARTZ	17 ANGSTROM (SMECTITES/ MIXED-LAYER CLAYS)
B1	78.0 + 0.6	18.4 + 1.9	3.6 + 2.3	---
B3	80.8 + 4.8	19.6 + 4.5	0.0	---
B6	41.7 + 4.2	47.0 + 1.3	11.4 + 2.8	---
B10	36.5 + 3.0	52.7 + 0.7	10.8 + 2.4	---
B12	26.7 + 2.7	56.6 + 3.2	16.7 + 2.0	---
B16	35.9 + 2.0	53.9 + 2.0	10.2 + 1.2	---
B18	34.8 + 1.8	54.2 + 1.4	11.0 + 1.8	---
B23	46.1 + 4.5	43.8 + 3.7	3.6 + 0.9	---
B25	35.1 + 2.8	35.5 + 2.6	4.6 + 2.1	24.8
B27	38.7 + 1.9	51.0 + 1.2	10.4 + 0.6	---
A4	51.1 + 2.4	32.8 + 2.4	2.2 + 0.7	13.9
A7	43.2 + 1.2	43.9 + 0.7	6.9 + 1.8	6.0
A11	54.2 + 7.3	39.7 + 5.7	6.0 + 1.9	---
A13	39.3 + 11.3	47.9 + 9.2	12.7 + 3.7	---
A14	54.5 + 3.8	41.3 + 3.8	4.2 + 0.3	---
A16	37.1 + 6.4	52.1 + 6.2	10.7 + 1.6	---
A19	57.6 + 1.8	39.0 + 1.8	3.6 + 0.5	---
A22	37.6 + 15.1	35.6 + 11.1	8.6 + 7.5	18.2
A24	38.3 + 2.4	54.7 + 2.3	7.0 + 2.2	---
A28	40.9 + 10.4	55.0 + 8.7	4.0 + 2.2	---
A31	46.4 + 1.1	48.1 + 0.8	2.2 + 0.5	3.3
A33b	56.8 + 2.6	39.9 + 2.4	3.3 + 0.8	---
A36	26.8 + 6.6	57.1 + 4.8	16.1 + 3.0	---
A39	30.9 + 5.5	52.5 + 5.7	16.6 + 1.8	---
A42	42.0 + 2.9	42.0 + 2.1	2.6 + 0.9	13.4
A45	42.9 + 5.4	48.3 + 1.9	8.9 + 3.8	---
A46	41.1 + 9.0	46.0 + 6.5	12.9 + 4.2	---
MJ3	37.6 + 3.6	41.1 + 3.7	4.9 + 1.8	16.4
MB	47.8 + 4.5	43.0 + 3.8	2.9 + 1.2	6.4
R3	53.8 + 2.6	43.8 + 2.7	2.3 + 0.2	---
R4	59.4 + 3.2	36.4 + 2.8	4.1 + 0.8	---
R6	8.9 + 3.2	81.5 + 3.1	9.8 + 1.5	---
R7	62.6 + 7.1	36.0 + 6.6	1.4 + 0.9	---

Silt Fraction Identification

The heavy mineral fraction of the 5 to 7 phi (32 to 8 um) split was separated using a mixture of tetrabromoethane (specific gravity = 2.955) and dimethylformide (specific gravity = 0.965), producing a liquid with a density of 2.90. Fifty ml of heavy liquid were added to a 50 ml centrifuge tube, along with 0.2-0.5 gms of silt-size material. The sample was then centrifuged for approximately 20 minutes at 1500 RPM. The heavy fraction was then carefully extracted from the bottom of the tube with a pipette. After repeating the separation, the heavy fraction was ground to a powder using a mortar and pestle. Water was added to the dry powder to make a slurry, and this mixture was then mounted using the smear slide technique (Gibbs, 1965).

Identification of silt-sized minerals was accomplished through identification of major and minor x-ray peaks, along with optical examination, and comparison with previous studies. For the major phases (quartz, chlorite, hornblende, and illite), all of the major, and many of the minor diffraction peaks are resolvable. Only the highest intensity peaks of the minor phases (epidote, ilmenite, rutile-pseudorutile) were observed. In addition, a number of peaks represent the overlapping of peaks from two or more phases.

The x-ray method permits accurate identification of only the most abundant phases in each sample. In most samples, there are a small number of minor peaks that cannot be ascribed to any of the recognized phases. These peaks may be generated from some of the trace heavy minerals observed in the sand size by McMaster (1954) and Schroeder (1982). It was impossible, however, to identify any other phases with certainty.

Chlorite and hornblende are easily indexed using patterns 16-351 and 29-1257A respectively, from the JCPDS powder diffraction file. As in the clay fraction, the chlorite peaks may possibly enhanced by the presence of kaolinite. The 10.0, 5.0, 3.3 angstrom reflection series belong to combination of 10 angstrom phases, possibly including illite, muscovite, and glauconite. These minerals have densities of from 2.4 to 2.95, so the heavy mineral separation probably removed a significant proportion of these phases.

Epidote was identified in many samples by the presence of two 100 intensity peaks (2.90 and 2.68 angstroms), and several other smaller peaks (JCPDS file 29-733). A number of the major ilmenite peaks interfere with peaks of other minerals, but two of the higher intensity peaks (1.73 and 1.64 angstroms) are present in many samples (JCPDS file 29-733). Rutile and Pseudorutile (JCPDS files 21-1276 and 19-635 respectively) exhibit a number of similar diffraction peaks, and could not be clearly differentiated in this study.

For each of the silt phases identified in the heavy mineral fraction, the highest intensity, non interfering peak was chosen for comparison of relative intensities (table 5). The intensity values

TABLE 5

PEAKS CHOSEN FOR RELATIVE INTENSITY COMPARISON IN THE 5 - 7 PHI (8 - 32 um) SIZE FRACTION

MINERAL(S)	PEAK 2θ°	 Å	INTENSITY (I/I100)	JCPDS File No.
HORNBLENDE	10.4	8.52	100	29-1257A
CHLORITE	25.0	3.55	80-100	16-352 29-1487
ILLITE/ MUSCOVITE/ GLAUCONITE	8.6	10.0	80-100	2-462 7-25 9-439
EPIDOTE	33.4	2.68	100	17-514
ILMENITE	52.9	1.73	55	29-733A
RUTILE/ PSEUDORUTILE	54.2	1.69	60-100	21-1276 19-635

TABLE 5

PEAKS CHOSEN FOR RELATIVE INTENSITY COMPARISON IN THE 5 - 7 PHI (8 - 32 um) SIZE FRACTION

MINERAL(S)	PEAK		INTENSITY	JCPDS
	$2\theta^{\circ}$	Å	(I/I100)	File No.
HORNBLENDE	10.4	8.52	100	29-1257A
CHLORITE	25.0	3.55	80-100	16-352 29-1487
ILLITE/ MUSCOVITE/ GLAUCONITE	8.6	10.0	80-100	2-462 7-25 9-439
EPIDOTE	33.4	2.68	100	17-514
ILMENITE	52.9	1.73	55	29-733A
RUTILE/ PSEUDORUTILE	54.2	1.69	60-100	21-1276 19-635

for each peak in a given sample were normalized to 100 percent, and the value for each mineral divided by the sum to give a normalized intensity ratio for each phase (table 6).

TABLE 6

RELATIVE INTENSITIES OF MAJOR PEAKS OF THE SILT SIZE (5-7 PHI) HEAVY MINERAL FRACTION

SAMPLE	ILLITE (10 Å)	CHLORITE (3.55 Å)	HORNBLENDE (8.52 Å)	EPIDOTE (2.68 Å)	ILMENITE (1.73 Å)	PSEUDORUTILE /RUTILE (1.69 Å)
A4	4.0	27.8	41.4	14.3	4.2	8.3
A7	2.5	47.4	33.5	8.3	3.7	4.5
A13	4.8	50.7	36.8	0.0	1.0	6.8
A16	6.7	71.3	17.3	3.3	0.9	0.5
A22	31.4	56.5	12.1	0.0	0.0	0.0
A24	8.4	66.7	15.3	0.0	5.3	4.3
A28	4.9	55.3	11.8	0.0	12.3	15.4
A31	0.0	50.1	12.2	11.5	13.0	13.2
A33b	17.4	49.4	28.0	0.0	0.0	5.1
A36	2.9	32.5	45.8	0.0	10.7	8.0
A39	2.0	38.4	42.4	10.4	3.0	3.8
A42	6.5	53.5	22.2	5.6	5.4	6.8
A45	3.9	36.0	53.4	6.7	1.9	1.7
A46	1.9	31.2	29.5	18.0	10.8	8.6
B10	15.0	45.3	39.7	0.0	0.0	0.0
B12	16.8	29.0	30.9	23.4	0.0	0.0
B16	23.1	30.9	46.1	0.0	0.0	0.0
B18	11.1	22.7	66.2	0.0	0.0	0.0
B25	8.8	50.2	41.1	0.0	0.0	0.0
MJ3	1.7	47.3	23.4	11.6	4.0	13.4
MB	10.6	77.4	8.7	1.2	1.1	1.1
R2	22.2	33.2	44.6	0.0	0.0	0.0
R3b	8.7	21.0	4.7	13.9	25.4	26.4
R4	6.0	54.0	26.3	6.6	2.4	4.8
R6	0.7	73.3	30.6	3.7	10.1	14.2
R7	3.6	56.4	12.6	0.0	9.3	18.1

TABLE 6

RELATIVE INTENSITIES OF MAJOR PEAKS OF THE SILT SIZE (5-7 PHI) HEAVY MINERAL FRACTION

SAMPLE	ILLITE (10 Å)	CHLORITE (3.55 Å)	HORNBLENDE (8.52 Å)	EPIDOTE (2.68 Å)	ILMENITE (1.73 Å)	PSEUDORUTILE /RUTILE (1.69 Å)
A4	4.0	27.8	41.4	14.3	4.2	8.3
A7	2.5	47.4	33.5	8.3	3.7	4.5
A13	4.8	50.7	36.8	0.0	1.0	6.8
A16	6.7	71.3	17.3	3.3	0.9	0.5
A22	31.4	56.5	12.1	0.0	0.0	0.0
A24	8.4	66.7	15.3	0.0	5.3	4.3
A28	4.9	55.3	11.8	0.0	12.3	15.4
A31	0.0	50.1	12.2	11.5	13.0	13.2
A33b	17.4	49.4	28.0	0.0	0.0	5.1
A36	2.9	32.5	45.8	0.0	10.7	8.0
A39	2.0	38.4	42.4	10.4	3.0	3.8
A42	6.5	53.5	22.2	5.6	5.4	6.8
A45	3.9	36.0	53.4	6.7	1.9	1.7
A46	1.9	31.2	29.5	18.0	10.8	8.6
B10	15.0	45.3	39.7	0.0	0.0	0.0
B12	16.8	29.0	30.9	23.4	0.0	0.0
B16	23.1	30.9	46.1	0.0	0.0	0.0
B18	11.1	22.7	66.2	0.0	0.0	0.0
B25	8.8	50.2	41.1	0.0	0.0	0.0
MJ3	1.7	47.3	23.4	11.6	4.0	13.4
MB	10.6	77.4	8.7	1.2	1.1	1.1
R2	22.2	33.2	44.6	0.0	0.0	0.0
R3b	8.7	21.0	4.7	13.9	25.4	26.4
R4	6.0	54.0	26.3	6.6	2.4	4.8
R6	0.7	73.3	30.6	3.7	10.1	14.2
R7	3.6	56.4	12.6	0.0	9.3	18.1

VITA

Peter Louis Sudano was born Feburary 25, 1957 in Pelham, New York, to Mr. and Mrs. Joseph Sudano. The author graduated from Pelham Memorial High School in June, 1975. He entered Lehigh University in the fall of 1975, and obtained a B.S. in Geologic Sciences in 1979, and a M.S. in 1983.

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