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SCOUR AND DEPOSITION– CHANGES IN SEDIMENTATION AROUND A NUCLEAR POWER PLANT

THE UNIVERSITY OF WISCONSIN

SCOUR AND DEPOSITION —

CHANGES IN SEDIMENTATION AROUND A NUCLEAR POWER PLANT

by

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SCOUR AND DEPOSITION — CHANGES IN SEDIMENTATION AROUND A NUCLEAR POWER PLANT

Abstract

As industrial use of the coastal zone increases, the impact of water discharges upon the environment is a critical question. The sedimentary regime of Lake Michigan between Two Rivers and Two Creeks, Wisconsin was investigated because two new nuclear power plants are located along this shoreline and discharge cooling water into the lake. One of them, Point Beach Nuclear Power Plant, began operating in late 1970, discharging cooling water at the littoral zone. The problem centered on the nature of man-induced changes in patterns of natural sediment dispersal, erosion and deposition, both offshore and on the beach, because of water jetted perpendicularly into the lake at the shoreline.

Four surficial sediment types were found in the area. Desiccated red clay of Valderan age is exposed, with little or no recent sediment overlying it, along the shoreline north of Point Beach Nuclear Power Plant. This same red clay underlies the recent sediments of the area. Rocky gravel and gravelly sand are found in a lobate zone northeast of Two Creeks. Sand, predominately in the fine sand class, dominates the area south of Point Beach Nuclear Power Plant, from the shoreline to four miles offshore. Sand also extends northward in a band lakeward of the coarser sediments. Muddy sand is found about four miles offshore.

As sorting increases and grain size decreases from north to south offshore, a north to south sediment transport is indicated. The sand offshore is predominately quartz, with potash feldspar more abundant than plagioclase feldspar. Diopside, augite, enstatite, hypersthene, hornblende and magnetite are the principal minerals in the high density fraction. Pleistocene drift deposits bordering the lake are the source of the recent sediments.

Background radiation measurements revealed that the clays and muddy sands produced the highest radioactivity levels. Gravelly sand had the lowest levels with sands having intermediate values.

Natural cycles of erosion and deposition occur along the lake/land interface, but the configuration of the beaches tends toward an equilibrium state. Erosion of the land behind the beach, due to high lake levels and intense storm action, is a natural phenomenon.

Along the shoreline lakeward of Point Beach Nuclear Power Plant, an anomalous area of sand deposition has formed since the power plant began operation. Because this deposition is unnatural and not in equilibrium with the natural lake environment, it has been identified as a favorable prospect for economic exploitation. To date, no environmental degradation, as measured in the form of increased shore erosion, has been found due to the anomalous area of sand deposition associated with the power plant discharge.

One form of benthic life, the amphipod *Pontoporeia affinis* Lindström, was found during the sediment sampling.

I. INTRODUCTION

STATEMENT OF THE PROBLEM

Since the time of the early exploration by Nicolet in 1634, the great reservoir of fresh water contained in the Great Lakes has been the most singularly attractive resource of the mid- and northeastern United States. While these magnificent lakes were first used for inexpensive transportation — a use continuing to modern times — today the lakes are used for a variety of other purposes including recreation, fishing, domestic and industrial water supply, waste dilution and waste sinks, and construction aggregate in the form of sand and gravel from their shallow floors.

With the increasing need for large electrical generating plants to power the region's homes and industries, Great Lakes water has become an important resource for use in cooling the electrical generation equipment. Fossil fuel plants have been in service along the Wisconsin shore of Lake Michigan for over 50 years. Most new electrical plants are fueled by nuclear materials and large volumes of cooling water are necessary in operating these facilities. The Lake Michigan coastal zone between the ports of Kewaunee and Two Rivers, Wisconsin is an attractive location for nuclear power plants as it is near the population centers of Wisconsin and Upper Michigan and lake water is abundant.

Two nuclear power plants have been recently constructed near Two Creeks, Wisconsin. Point Beach Nuclear Power Plant is located four miles south of the Kewaunee Nuclear Power Plant, both are about 100 miles north of Milwaukee. As these plants, when running at full capacity, together discharge almost 2 million gallons per minute of cooling water at the shoreline, their effect on the offshore and beach environment becomes an important question. While to biologists and hydrodynamacists it is most significant that the water is returned to the lake somewhat warmer (8-10°C) and hence less dense than the receiving lake water, this temperature difference is of secondary importance to sedimentologists. More critical to sedimentation is that the water is returned to the lake at the littoral zone. A large volume of water jetted perpendicular to the shore can result in a sediment transport regime different from the natural system, and perhaps, act as a barrier to longshore sediment transport.

The problem, then, centers on man-induced changes in patterns of natural sediment dispersal, erosion and deposition, both offshore and on the beach, as a result of water discharged at a power plant site. Changes in patterns of sedimentation might manifest themselves in anomalous areas of erosion and deposition, as compared to the erosion/deposition patterns in the natural situation. Erosion would be of primary importance if it were concentrated at points along the water/land interface, i.e. the beach and back-beach. Deposition could become economically important if renewable sand resources were developed at sites where mining was feasible. Thus, the problem of changes in patterns of sedimentation resulting from a new sediment transport mechanism, or a barrier to natural sediment transport mechanisms, is of immediate economic and environmental significance.

OBJECTIVES

With realization that change in the sedimentary regime along the coastline of Lake Michigan could be caused by the operation of these power plants, it became apparent that a sediment study of the area would need to meet five objectives.

1. The sedimentary regime in the area had to be defined. Both the types of surficial sediments and their lateral extent had to be determined. To completely fulfill this objective, the beach material had to be studied together with the offshore sediments so that the sediments at the interface would be included in the delineation of the sediment system. Because the problem involved discovering unnatural changes which might be occurring, the natural variability in the surficial sediment patterns needed to be ascertained.

2. Sediment transport patterns had to be discovered. Patterns of sediment dispersal in the study area are important in determining the natural areas of deposition and erosion. In this regard, the source of the material in the sediment system had to be identified.

3. Short term changes due to the introduction of the cooling water at the shoreline had to be determined. Anamalous areas of erosion and deposition had to be identified both on the beach and offshore.

4. A baseline for future study of the long term effects of the water discharge on the sedimentary regime had to be established. Such a baseline would be the result of the definition of the sedimentary regime together with the identification of the dispersal patterns, the source and the natural variability of the sediments. To complete this baseline, background radiation measurements of the sediments had to be made.

5. A prediction of the long term changes in the sedimentary regime as the result of the water discharge would need to be made from a comparison of the natural sedimentary regime and the processes occurring while cooling water is being discharged. Through analysis of both the short term changes and the prediction of long term changes, the method of discharge should be evaluated.

GENERAL FEATURES OF THE PLANT

While the construction of both the Kewaunee Nuclear Power Plant and the Point Beach Nuclear Power Plant has been completed (see Figure 1-1), only the Point Beach facility has generated electricity for commercial use. The Kewaunee Plant has received its operating license from the Atomic Energy Commission and will begin operation in October 1973. The Wisconsin Public Service Corporation, Wisconsin Power and Light and Madison Gas and Electric Company are joint owners of the Kewaunee Plant.

In contrast to the Kewaunee Power Plant, the Point Beach Nuclear Power Plant has been operating commercially since 1970, and thus has been routinely discharging cooling water into Lake Michigan. Point Beach Nuclear Power Plant is owned and operated by the Wisconsin Electric Power Company and the Wisconsin Michigan Power Company. The power plant consists of two generating units, each with a capacity of 454,000 KW and each is capable of independent operation.

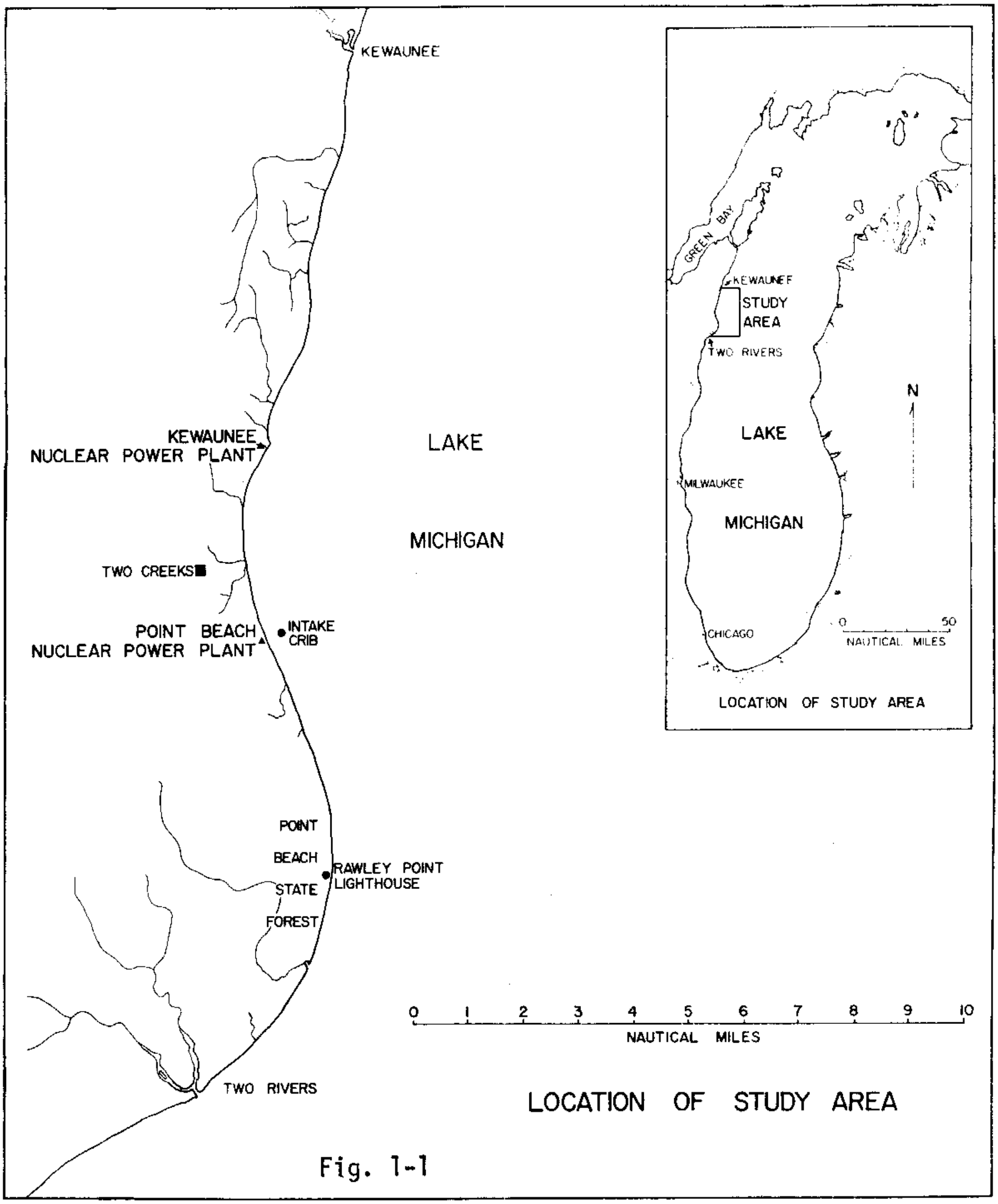

KEWAUNEE
KEWAUNEE
NUCLEAR POWER PLANT
LAKE
MICHIGAN
TWO CREEKS
POINT BEACH
NUCLEAR POWER PLANT
INTAKE
CRIB
POINT
BEACH
STATE
FOREST
RAWLEY POINT
LIGHTHOUSE
TWO RIVERS
0 1 2 3 4 5 6 7 8 9 10
NAUTICAL MILES
LOCATION OF STUDY AREA
GREEN BAY
KEWAUNEE
STUDY
AREA
TWO RIVERS
N
LAKE
MILWAUKEE
MICHIGAN
CHICAGO
0 50
NAUTICAL MILES
LOCATION OF STUDY AREA

Fig. 1-1

Cooling water for the two units is drawn from Lake Michigan through an intake crib located 1,700 feet offshore. After circulation through the plant, this somewhat warmer water is discharged at the shoreline through a corregated metal flume structure 35 feet wide and about 10 feet deep. Each generating unit has its own discharge flume structure (see Figure 1-2).

Commercial operation of Unit I was begun on December 21, 1970 and continued until October 1972 when the unit was shut down for repair and replacement of the fuel rods. Prior to December 1970, Unit I was tested periodically. Unit II at Point Beach received a 20% capacity operating license in August 1972 and continues to operate at this capacity.

GENERAL APPLICATIONS

While this study is aimed at investigating the nature of the interaction between one particular water discharge and this sedimentary regime in a part of Lake Michigan, it can serve as an example for the study of the effects of a variety of industrial uses of the coastal zone. Certainly, the discharge of large volumes of water used for any number of purposes — cooling, slurry transport and waste dilution, to name a few — can only become more common as the coastline continues as an attractive locale for industrial sites. Any industry which uses large volumes of water, whether it be for cooling, as a mechanism for the transport of particulate matter, or as part of the industrial process, faces the problem of discharge. The effects of these discharges on the natural environment of the receiving waters becomes an important question worthy of investigation.

In addition to this study serving as an example of the effects in the sedimentary regime due to a water discharge at the shoreline, it can function as an inquiry into the type of investigation necessary to delineate the effects of unnatural flow regimes on the natural sedimentary environment. Both the parameters involved in such change and some of the methods used to measure them will be defined during this study.

RELATED INVESTIGATIONS

Several workers have investigated the behavior of turbulent jets, both liquid entering liquid and gas entering gas. Pai (1954) and Abramovich (1963), in particular, reviewed the laws of fluid dynamics governing the behavior of these discharges. The behavior is generally studied in two areas: (1) the core jet, and (2) the boundary or mixing zone. Abramovich (1963, p. 3) gave a simple explanation of what happens in a turbulent jet:

> The thickening of the jet boundary layer, which consists of particles of the surrounding medium carried along with it and particles of the jet itself that have been slowed down, leads on the one hand, to an increase in the cross section of the jet, and, on the other, to a gradual "eating up" of its nonviscous core — the region between the inside boundaries of the boundary layer.

Representative studies of jet behavior, including liquid discharged into a liquid of greater density, are those of Alexander, et al. (1953), Abraham (1960),

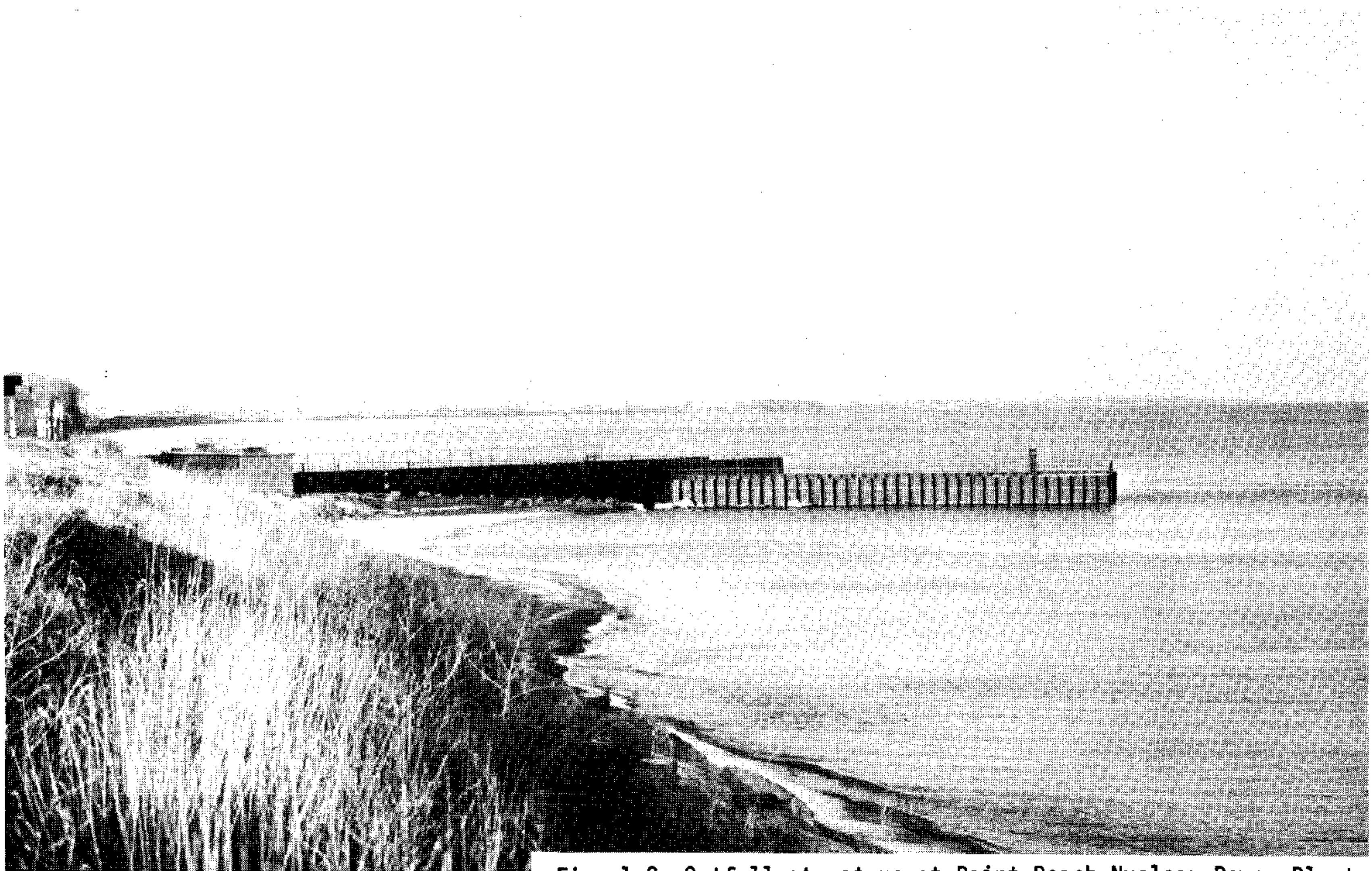


Fig. 1-2 Outfall structure at Point Beach Nuclear Power Plant

Hart (1961), and Hayashi and Shuto (1967). The problem of mixing of ocean outfalls is reviewed by Frankel and Cummings (1965) and Anwar (1969).

The thermal structure of the Point Beach plume is presently under investigation by other University of Wisconsin personnel, and the early results have been issued by Scarpace and Green (1972). Reporting only on the surface temperature structure, they found that the plume often exhibits "a series of concentric, spreading thermal fronts, across which the horizontal temperature gradients are quite large ..." (Ibid., p. 2). To our knowledge, no study of sediment movement past a power plant water discharge jet has been reported in the literature. Singamsetti (1966) undertook an investigation of the diffusion of sediment contained in a submerged jet to the receiving liquid, but this is, in a sense, the converse situation, and as such, a remote comparison.

If one conceives a plume of discharge water to be a barrier to longshore drift, a comparison can be made between the response of a sediment regime to the plume and the response of a sediment regime to a groin. Typically, after construction of a groin, sediment accretion along with advancement of the shoreline occurs on the updrift side becoming steeper and the downdrift side becoming flatter. With these alterations in the slopes, there is a resultant change in the grain size; the updrift slope is normally made up of the coarser fraction of the sediment contained in the littoral transport. These changes are local, however, in the area immediately adjacent to the groin itself and are due to the blockage of littoral transport by the groin. The magnitude of this interruption depends on the geometry of the groin structure and its permeability (Beach Erosion Board, 1966).

When the shoreline stabilizes after the construction of a groin or groin system, the littoral transport then passes over or around the groin. The Beach Erosion Board (1966, p. 223) reported: "If the groin is sufficiently high that no material may pass over it, all transport must be in depths beyond the end of the groin." If, however, such a complete damming of the littoral transport is not needed or desired, a permeable groin structure may be built.

> The primary purpose of permeability in a groin is to avoid the abrupt offset in shore alignment which normally occurs at impermeable groins by permitting a portion of the littoral forces and materials to pass through the structure and thereby induce littoral material deposition on both sides of the groin.
>
> To date insufficient empirical data have been compiled to establish quantitative relationships between the applied littoral forces, groin permeability, and resulting behavior of the shore. The present state of knowledge relating to sediment transport by waves and current does not permit conclusive findings through theoretical hydrodynamic analysis. (Ibid., p. 225).

However, several studies have investigated the effect of groins on the nearshore environment and the response of the sedimentary regime to these barriers in the littoral zone. Through the use of a tank model, Price and Tomlinson (1968) studied the effect of permeable and impermeable groins on a stable beach, a rather anomalous situation since groins would ordinarily be placed on unstable beaches. They found that, in the case of the impermeable groins, little beach build-up occurred, but that seaward of the end of the groins, a zone of deposition was established.

Furthermore, this zone of deposition extended into the area past the groin structures. In the case of the permeable groins, little effect was noticed in either the beach or offshore zones. By measuring the amount of drift, it was found that in the model situation the drift was reduced in total amount and that it was shifted seaward of the groin termination. They conclude that after stabilization, the drift is inhibited along the upper beach and "the drift along the lower beach must be correspondingly increased. The shallower depths offshore permit the increased littoral drift along these contours," (Ibid., p. 525).

In a similar model study reported by Barcelo (1968), it was found that the equilibrium situation, that of accretion and depletion on either side of the groin, was determined by the angle and energy of the incident wave, the character of the littoral drift, and the geometry of the groin structures and placement.

The placement of groins, then, interrupts and/or displaces the littoral drift. Whether or not the plume can be compared directly to a permanent coastal structure, such as a groin, remains a question.

II. REGIONAL SETTING

GENERAL FEATURES OF LAKE MICHIGAN

With a surface area of 22,400 square miles, Lake Michigan is the third largest of the North American Great Lakes. At its longest and widest points, the lake measures 307 miles and 118 miles, respectively. Geographically, the lake is elongate on a north-south axis. While the mean depth is 276 feet, a depth of 923 feet has been reported in the northern part of the lake(Hough, 1958). The drainage basin of Lake Michigan is relatively small (67,860 square miles), considering the size of the lake itself. Mean discharge from the lake is 55,000 cubic feet per second (Beeton and Chandler, 1963).

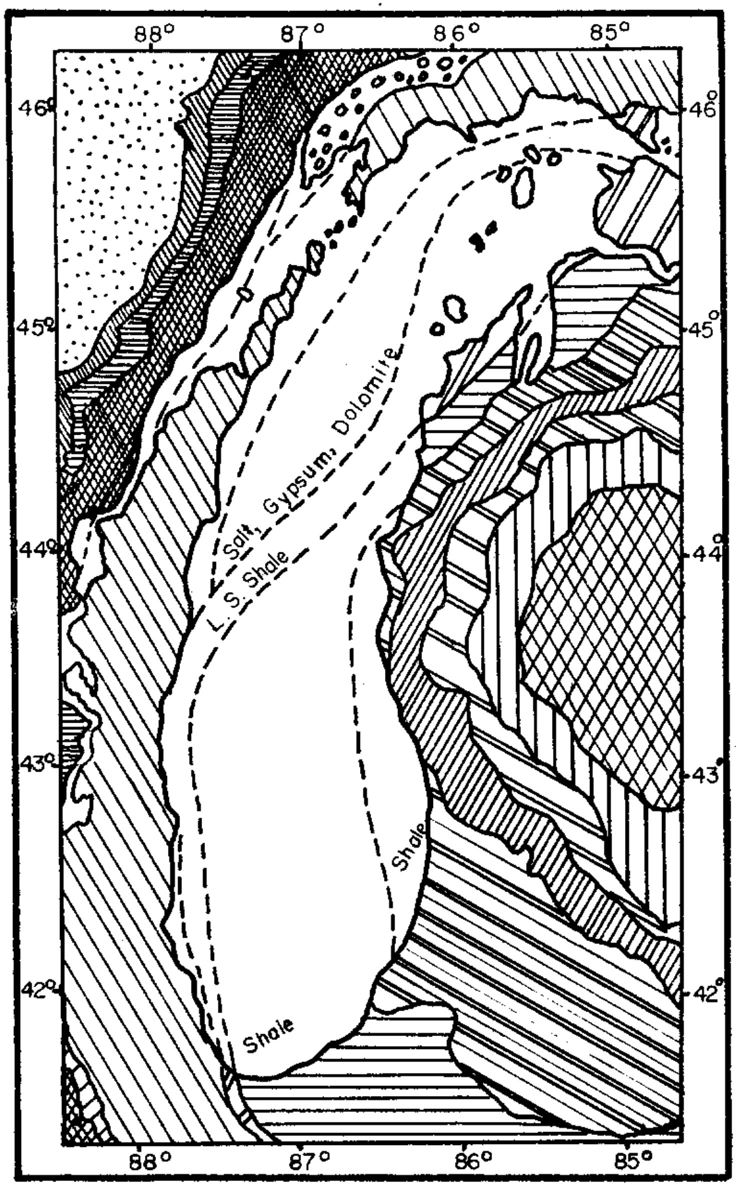
LAKE MICHIGAN BASIN GEOLOGY

The geologic history of the Lake Michigan area was important in determining the configuration of the lake basin and in determining the nature of the source material for the recent sediments of the lake. Basin morphology can play an important role in circulation patterns, environments available for biological life, and depositional/erosional surfaces for recent sediments. Further, the morphology, together with the bordering geologic formations, can determine the nature of the water/land interface. This interface can be relatively stable or can be transgressing toward the land, eroding the shoreline formations, and thus adding material to the recent sediments.

While Lake Michigan lies near the edge of the Canadian Shield,it is entirely surrounded by Paleozoic formations which overlie the Pre-Cambrian basement, as shown in Figure 2-1. These same Paleozoic deposits underlie the lake basin and provide the framework for its topographic configuration. Devonian formations outcrop along the eastern shore from the Straits of Mackinac to Frankfort, Michigan. Included in the Devonian deposits are the Bois Blanc Formation, a series of cherty dolomites, dolomitic limestones and limestones; the Transverse Group, which are primarily limestones; and the Antrim Shale. It is the Antrim Shale which is exposed along the lakeshore in southwestern Michigan and Indiana. A Mississippian sandstone, the Marshall, overlies the Antrim Shale in Lower Michigan and has topographic expressions beneath the lake itself. To the north and west of Lake Michigan, Silurian dolomite (Niagara) comprise the bedrock (Thwaites, 1947; Thwaites and Bertrand, 1957; and Hough, 1958).

Along the Wisconsin shore of Lake Michigan, the uppermost bedrock section consists of the Niagara Dolomite, about 550 feet thick, the Ordivician Richmond (Maquoketa) Shale, about 400 feet thick, and the Ordivician Galena-Platteville Dolomite. The topographic expression of the Niagara Dolomite is a large escarpment which Thwaites and Bertrand (1957, p. 836) called "The backbone of the Door Peninsula." Known as the Niagara Cuesta, this feature was formed by differential erosion of the Niagara Dolomite and the underlying strata. Glacial deposits overlie these bedrock formations along the Wisconsin shore, ranging in thickness from a few inches to 450 feet. It is exceptional, though, to find glacial drift deposits more than 20 feet thick (Ibid.)

Lake Michigan is divided into two basins, north and south, as shown in Figure 2-2. These bathymetric features are governed by the same Paleozoic formations which appear around the lake (Thwaites, 1947; Emery, 1951; and Hough, 1958). In the southern basin, the uppermost Paleozoic bedrock is the Marshall Sandstone (Middle Mississippian). Separating the southern basin from the northern



Symbol		Age	Lithology
	U.M.	Pennsylv.	Sandstone, Shale
	L.M.		Shale, Sandstone
	L.		Shale, Sandstone
	M.M.	Mississipp.	Dolomite, Shale
	L.M.		Sandstone
	L.		Shale
	U.	Devonian	Shale
	M.		Limestone, Shale
	U.	Silurian	Salt, Gypsum, Dolo.
	M.		Dolomite
	L.		Shale, Dolomite
	U.	Ordovician	Shale
	M.		Shale, Limestone
	L.		Dolomite, Shale
	U.	Cambrian	Sandstone, Shale
	U.	Huronian	Various Rocks
	M.		Various Rocks
	L.		Various Rocks
		Pre-Cambrian	Intrusives

LAKE MICHIGAN BASIN
BEDROCK GEOLOGY

Fig. 2-1 After Emery, 1951

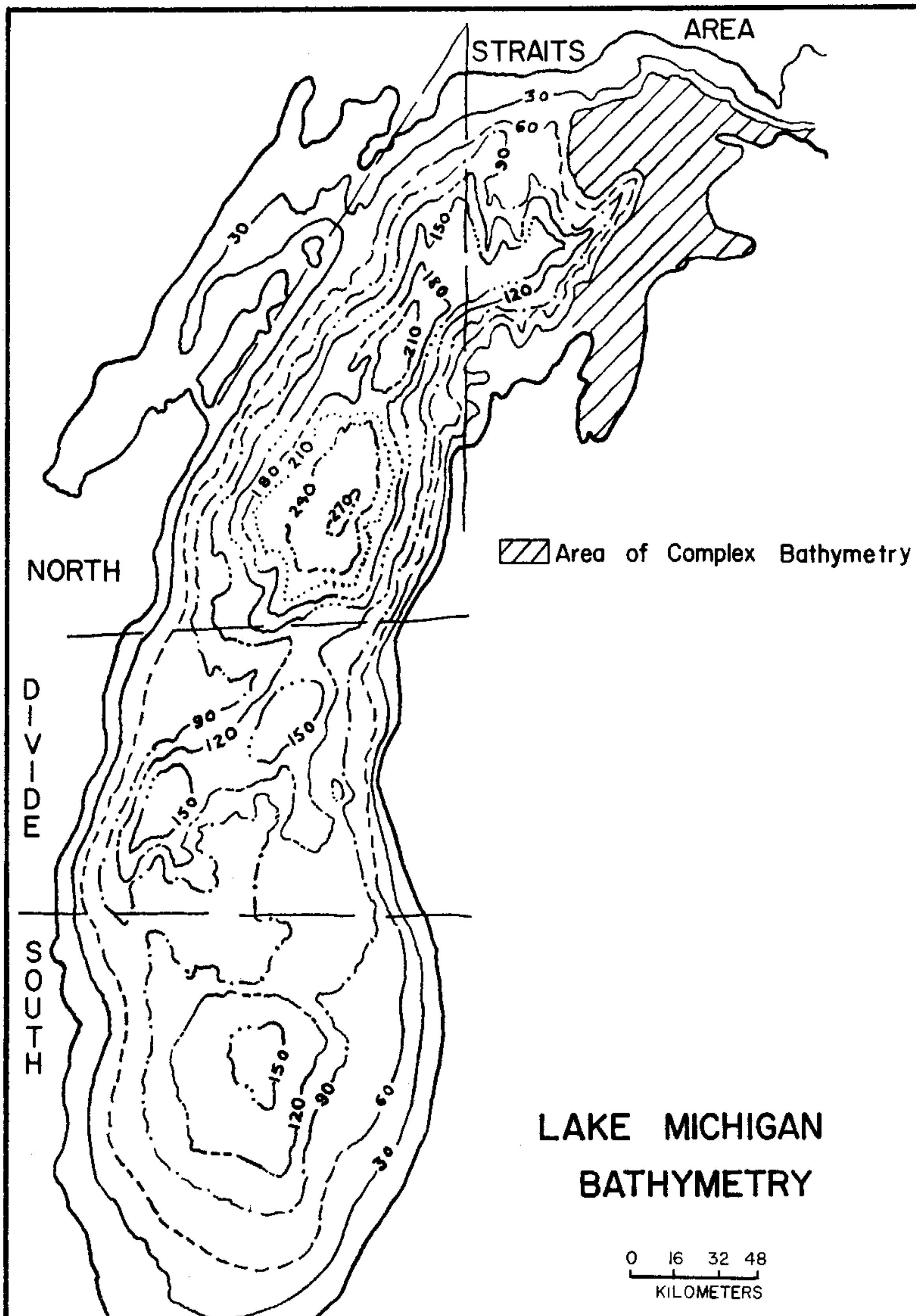


Fig. 2-2 After Emery, 1951.

part of the lake is a divide, formed by two ridge structures. The Transverse Group forms the southern ridge, while the Dundee Limestone makes up the northern one. Along the western shoreline of the northern basin, the Niagara Dolomite dips from the Niagara Cuesta underneath the lake from Sheboygan, Wisconsin, to Manistee, Michigan and continues to within 20 miles of the Straits of Mackinac. Hough (1958) ascribed the gentle smooth slope of the lake basin in the west and northwest to the dip-slope surface of the dolomites.

West of the Straits of Mackinac, the Bois Blanc Formation forms a cuesta which trends northwest past Gull Island. South of this structure, in the eastern part of the lake, but north of Frankfort, Michigan, there is a ridge and valley province made up of Silurian Evaporites and Transverse Limestones. The exact extent and depths of glacial drift overlying the Paleozoic bedrock is unknown for much of the lake. Lineback, Gross, Meyer and Unger (1971) have described the Pleistocene drift in parts of southern Lake Michigan.

It was during the Pleistocene Epoch, beginning about 500,000 years ago, that Lake Michigan attained its present form. Also during this epoch, glacial drift was deposited which today covers much of the bedrock both onshore and in the lake basin itself. The origin of the lake basin is generally ascribed (Shepard, 1937; Hough, 1958) to preglacial scour controlled, at least in part, by the topography of the preglacial geological exposures.

While there were four major glacial stages during the Pleistocene, only the last, the Wisconsin, is of special importance here. The first three had an effect on the area with their tremendous erosive and transportive powers, but their glacial deposits were modified considerably by the later Wisconsin stage, which began about 30,000 years ago. Within the Wisconsin stage, six substages have been identified, of which the last three, the Cary, Mankato and Valders (most recent) will be dealt with here.

About 14,000 years ago, the Cary substage ended. Thwaites and Bertrand (1957, p. 850) stated that, "The Cary substage of the Wisconsin stage of glaciation appears to have brought the bulk of the glacial drift of the area and caused most of the depositional land forms." Tills of Cary age are commonly found in the stratigraphic column in northeastern Wisconsin although they are sometimes buried. The Mankato substage followed, but no till of this age is found along the Wisconsin shore of Lake Michigan. A period of low water followed, allowing a fossil forest bed to become established in the geologic column. The object of considerable study, the Two Creeks Forest Bed has been dated at 11,850 ± 100 years (Broecker and Farrand, 1963). Burial of the Forest Bed came during the Valders glaciation. Often found between the forest bed and the Valders till is a layer of sand, as seen in Figure 2-3.

Following the Valders substage, the level of water in the Lake Michigan basin fluctuated several times. About 4,000 years ago, when the lake level was at 605 feet above the present sea level, a lake named Lake Nipissing filled the basin. Remnants of this lake level are prominent at Rawley Point. As the waters of Lake Nipissing lowered to their present level, a sequence of sand ridges were formed along the coast. At Rawley Point, these ridges have been preserved.

These sand ridges are visible along the shore northwards to Point Beach Power Plant, where they disappear and are replaced by a succession of drift deposits.

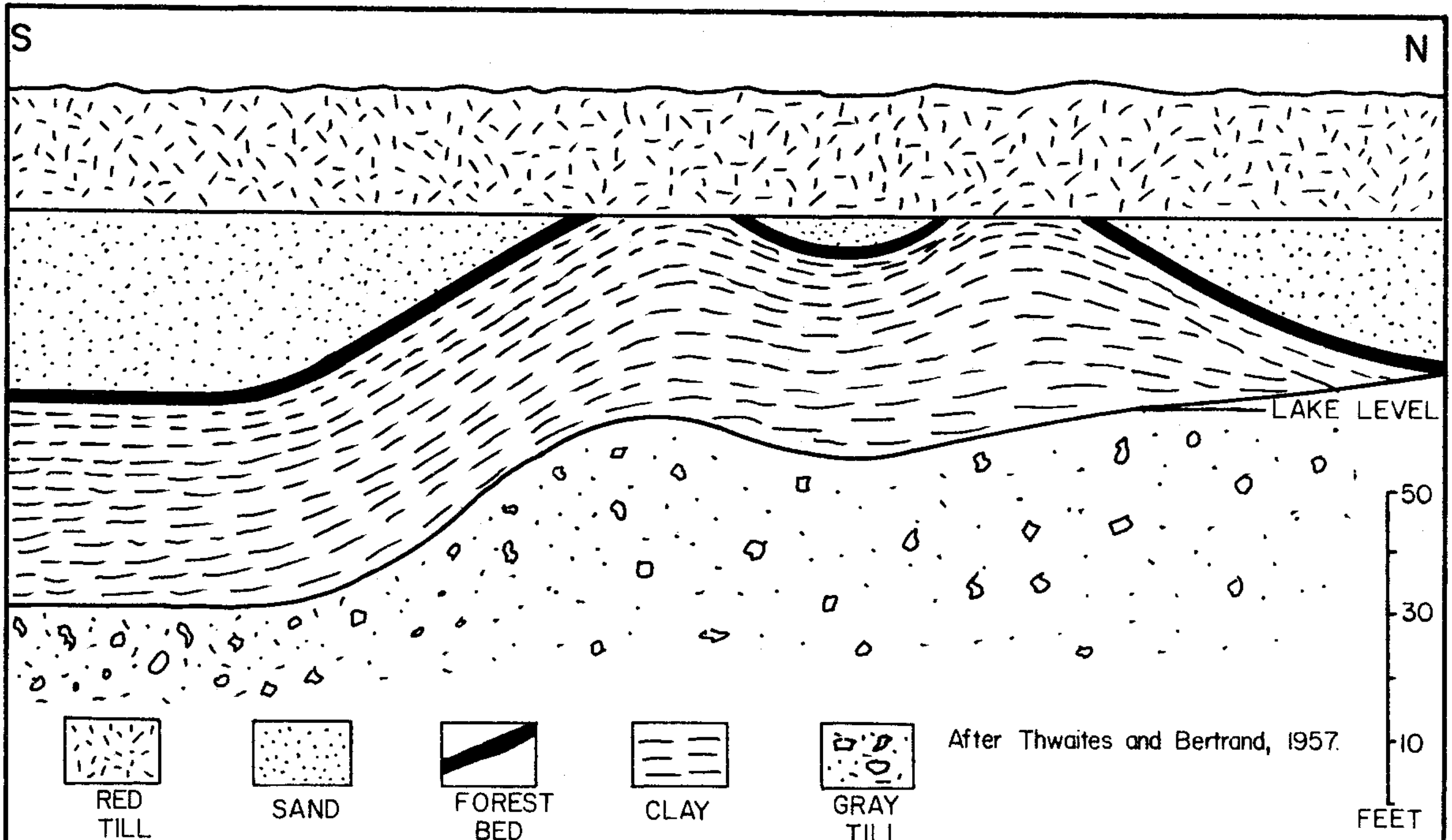


Fig. 2-3
STRATIGRAPHIC SEQUENCE EXPOSED IN SHORE BLUFF NEAR TWO CREEKS

The nature of the back edge of the beach varies from sand deposits (Fig. 2-4), to drift bluffs (Fig. 2-5) north of Point Beach Power Plant. This drift overlies the Niagara Dolomite (not exposed) and contains a number of distinct deposits. The two most prominent are the Valders till, commonly red, and the Cary till, commonly gray. Locally, other deposits can be found in the stratigraphic column. These can consist of beach (sand and gravel) and lake sediments including varved clays. The Two Creeks Forest Bed, occurring between the Valders (most recent) and the Cary tills, and containing remains of a Pleistocene forest, is an easily recognizable deposit in the area. It is this glacial drift which forms the high bluff north of the Point Beach Power Plant, continuing to Kewaunee and northwards.

The glacial drift exposed in these bluffs is primarily a red till, the Valders deposit. In Figure 2-3, a diagram of the exposed stratigraphic column in the bluffs north of Point Beach Power Plant shows that this Valders till is underlain by a sand layer, and then by the Two Creeks Forest Bed. With the lake level up considerably during the years of this present survey, the sand layer is rarely exposed. At present, only the uppermost Valders till can be seen. However, further to the north, the Two Creeks Forest Bed and associated deposits become exposed.

It should be pointed out that, while classically the Cary and Valders tills have been distinguished by their differential colors, Black (1966) reported that red clayey tills of Cary age have been found near Green Bay. Further, Murray (1953) concluded that the heavy mineral assemblages in both the Valders and Cary tills were the same and that, while the Valders was the more calcareous in the Door Peninsula, the Cary was the more calcareous to the south. Finally, Murray (1953) found that the two tills could be differentiated by their texture, with the Valders being considerably finer than the Cary.

Mineralogically, Murray (1953) identified the clay-size fraction in both the Cary and Valders tills to be predominately quartz and dolomite. Further, he identified the main heavy minerals in the fine sand fractions of both tills as opaques (predominately magnetite), hornblende, epidote, apatite, and garnet with traces of tourmaline, augite, sphene, and staurolite. Petersen, et al. (1957) have investigated the clay mineralogy of glaciolacustrine sediments associated with the Valders till and have found the principal minerals to be mica, montmorillonite, vermiculite chlorite, interstratified materials, quartz, feldspars, calcite, and dolomite. Lee, et al. (1972) compiled similar mineralogical descriptions of Valderan age deposits in the Lake Michigan basin area of eastern Wisconsin and reported that while the silt-size fraction contained quartz, feldspars, dolomite, and sometimes calcite, the clay-size fractions were composed of montmorillonite, chlorite, illite (mica), vermiculite (trace) and kaolinite (trace).

At present, a continuing effect of the Pleistocene in the Great Lakes area is the "postglacial uplift" effect. The former beach lines have been carefully surveyed and it has been found that to the north and east, they are tilted upwards (Moore, 1948). While it has not been determined whether this relative movement is the result of subsidence to the south and to the west, or uplift to the north and to the east, it is usually ascribed to isostatic recovery following removal of the heavy ice pack (Ibid.) Moore (1948) believed, however, that the present movement appears to have no connection with isostatic recovery, as he found that the areas most deeply buried beneath ice are subsiding, rather than being uplifted.

Fig. 2-4 Sand deposists at back of beach - Point Beach State Forest

Fig. 2-5 Drift bluffs north of Point Beach Nuclear Power Plant

Gauges at Two Rivers and Kewaunee show that by extrapolating the movement during the period 1914-1944 to a 100 year base, the area has subsided 1.37 and 1.34 feet respectively. Not only should this be remembered when interpreting lake levels over a long period of time, but also when reviewing erosion rates.

SEDIMENTS OF LAKE MICHIGAN

While the sediments in Lake Michigan have rot been extensively studied, several investigations have reported on their general nature, or on their distribution patterns in a small geographic area. The sediments in the southern basin have been studied in greater detail than those in the northern basin.

Hough (1935) reported the general distribution of bottom deposits in Lake Michigan south of the line from Port Washington, Wisconsin to Whitehall, Michigan. Only textural analyses were made, with no mineralogy of any sort reported. Several interesting relationships between texture, depth, and distance from shore are discussed. A major difference in the sediments found along the eastern and western shores was uncovered. Along the eastern shore, sand, silt, and clay, in order, are found at increasing distances from shore and with concomitantly increasing depths. However, within the sand zone, "the average size of the sediment first decreases with increasing distance from shore, then increases markedly becoming even greater than that of the beach material in most cases." (Ibid., p. 65). This feature is interpreted "as an indication that the bottom profile is not in adjustment with present conditions, but is more gently sloping than the theoretical profile of equilibrium." (Ibid., p. 68).

Along the western shore, glacial till characterized by a veneer of gravel is commonly found. Sand patches can be found interspersed among the gravel veneer. Hough interpreted this as "a lag concentrate of the coarser constituents of glacial till, produced by wave and current action on the bottom." (Ibid., p. 74).

East of Waukegan, 22 miles from shore, a stiff, reddish-brown, sandy clay is found which Hough (1935) related to the red tills of northeastern Wisconsin. He then deduced that, because these glacial deposits are exposed at the bottom, <u>no deposition of recent sediments is occurring in the area</u>.

When relating the recent sediments in the southern lake basin to their source, Hough (1935) pointed to the unconsolidated, easily erodable glacial tills and sand which comprise the shoreline. Riverborne material and bed rock are assigned very minor, if not negligible, roles as sediment sources.

Emery (1951) published a sediment map (Fig. 2-6) of Lake Michigan which shows a rocky bottom to occur along the coast in the study area. Further offshore, he reported sand, then mud at greater depths.

More recently, the geology of unconsolidated sediments in the southern basin has been investigated by the Illinois State Geological Survey and the University of Wisconsin Geophysical Laboratory. Several reports on this on-going research project have been issued. Gross, et al. (1970) described the uppermost layer in cores taken at four mile intervals from 12 to 32 miles due east of Waukegan as being an unconsolidated sandy-silty-clay. This material was characterized as being very soft and fluid, brownish gray to olive gray, and containing the clay minerals chlorite, illite, vermiculite, and other expandable clay materials, along with quartz and feldspar. Lineback, Ayer, and Gross (1970) assigned the

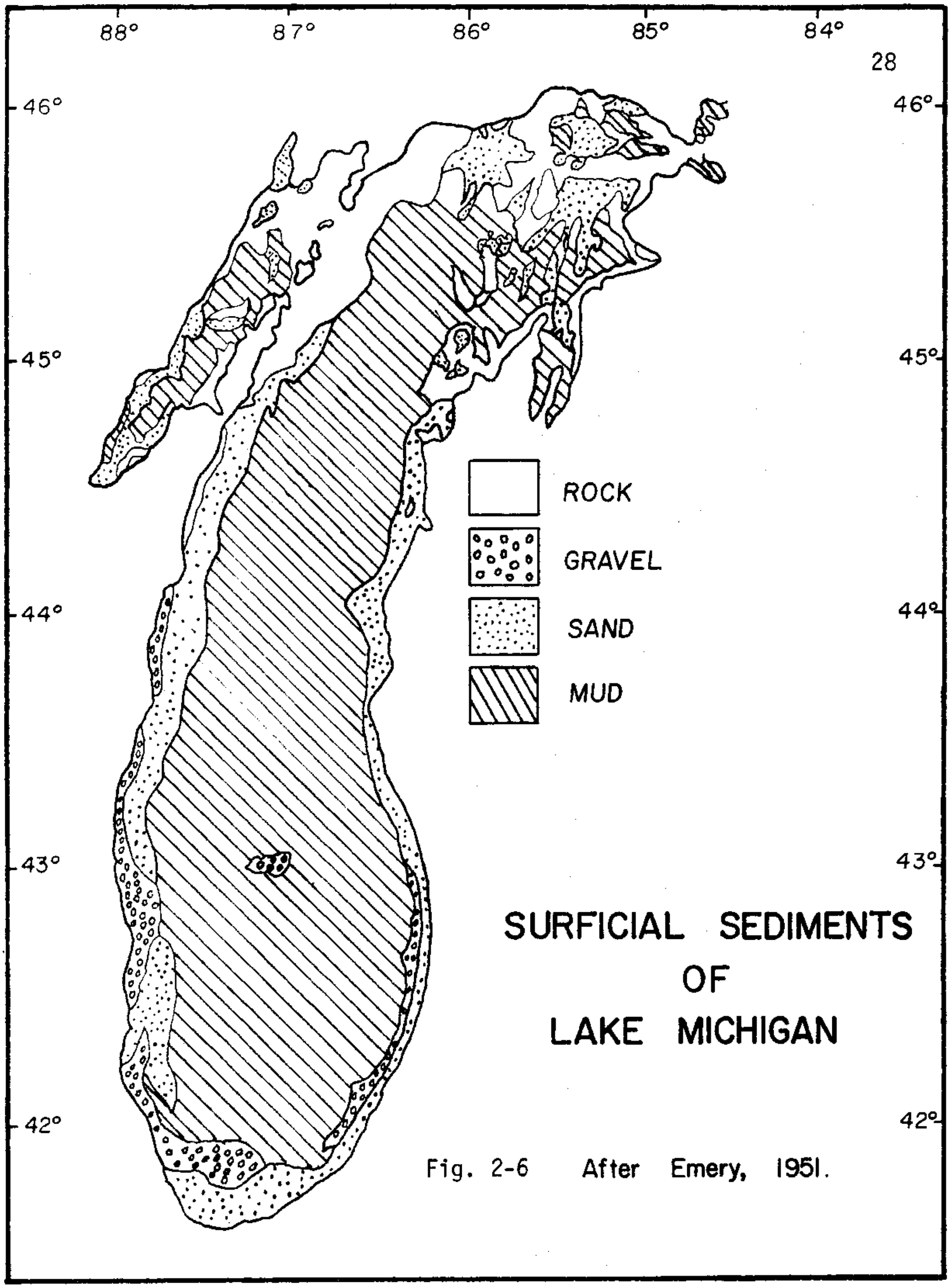


Fig. 2-6 After Emery, 1951.

name Waukegan Member, Lake Michigan Formation to the uppermost layer of dark gray to dark brown sandy silt to silty clay, sand, and gravel which was found to cover most of the middle southern basin south of Waukegan, Illinois. Through geophysical techniques, the vertical distribution of the Waukegan Member was defined, as reported by Lineback, Gross, Meyer, and Unger (1971). It was shown that this unit was thickest (39.4 feet) at the eastern end of the southern basin near Benton Harbor, Michigan. This was acribed to most of the sediment entering the lake through rivers in that area of the shoreline. Relationships between the recent Lake Michigan formation, glacial till, and Paleozoic bedrock in the lake basin south of Milwaukee, Wisconsin and Grand Haven, Michigan is shown in a series of high-resolution seismic profiles reported in Lineback, Gross, and Meyer (1972). The extent, mineralogy, and trace element concentration of the Pleistocene sediments in southern Lake Michigan are discussed in Gross, Lineback, Shimp, and White (1972).

While no detailed study of the sediments of the entire northern basin has yet been done, Moore (1961) completed a detailed investigation of both texture and mineralogy of the sediments in the northeastern portion of the lake between the Straits of Mackinac, Petoskey, Michigan, and Beaver Island. Hough (1958) named the topography in this area the Ridge and Valley Province. It is these topographic features which control the recent sediments found in the area, with the ridges and flanks being overlain with gravel and sand in contrast to the troughs, which contain clay or sandy clay. Illite, mixed layer clay material (undifferentiated) and chlorite were the major clay minerals present along with dolomite and occassional calcite. Like Hough (1935) when studying the southern basin, Moore (1961) named the glacial drift deposits on the adjacent land as the source of these lake sediments.

The sediments of Lake Michigan, then, can be characterized as having been influenced considerably by the glacial drift on the adjacent land areas. Exposed glacial drift, with no overlying recent sediments, is common on the lake floor. The clays which are prevalent are chlorite and illite with clay and silt-size components of quartz, feldspar and dolomite.

In addition to these previous studies of the lake sediments, several researchers have focused their attention on the nearshore, littoral, and beach zones. Krumbein (1950) wrote that along the western shore, the beaches are seldom wider than 100 feet, with 1:30 being an average slope. That the net littoral drift along the western shore is southward, with eroded bluff material from the shore along the Door Peninsula being the source, is also reported by Krumbein. Maximum amounts of littoral sand transport are about 40,000 cubic yards annually but an average amount would probably be 5,000 to 10,000 cubic yards (Ibid.) This volume would, of course, vary with the nature of the shoreline, the material available for transport, and the extent of man-built barriers.

While no data have been published as yet, the U.S. Army Coastal Engineering Research Center established, in 1971, a Littoral Environment Observation Program along the eastern shore of Lake Michigan. Parameters measured include wave and weather characteristics, the nature of the longshore current, and beach attributes (Bruno, 1972).

The stability of the nearshore bottom along the eastern shore of the lake has been studied in two recent research programs. Two separate sites were selected for study by Davis and McGearly (1965), both in southwestern Michigan. They learned that even after minor storms, bottom topography, which included offshore bars and sediment distribution remained relatively stable. Minor variations were discovered in the form of these offshore bars, but the sediment patterns remained unchanged. Saylor and Hands (1970) similarly reported that the offshore bar structure along the eastern shore of Lake Michigan are relatively stable and permanent but that they do respond to changes in the lake level and incident wave energy.

Davis (1965) used two sites in southeastern Lake Michigan as localities for studying the physical parameters affecting ripples in the nearshore environment. Olson (1958) reported on the relationships between dune development and physical conditions on the lake.

One sediment study has been conducted in the vicinity of the Point Beach Nuclear Power Plant by the Botany Department of the University of Wisconsin - Milwaukee (1972) under a grant from industry. Sampling began in 1969 (before the plant began operating) and continued through 1971. Both texture and radioactivity levels were determined for the sediments collected. Samples were taken at nine sites, both at the shoreline and in the nearshore area, with each site being sampled repetitively during the course of the study.

It has been reported that, texturally, the nearshore sediments were finer than those in the swash zone. Exceptions to this were the samples taken at the offshore site in the area through which the plume commonly sweeps. At this site, the sediment was as coarse as the swash zone material. The added energy input of the discharge water is thought responsible for this coarsening. This observation was confirmed by contrasting the samples taken at this site before and after the power plant was put into operation. A distinct coarsening of the sediment was noted after water discharge was begun.

RATES OF SHORELINE EROSION

Rates of erosion along the Wisconsin shoreline of Lake Michigan have been documented since about 1850, albeit incompletely. Crossman (1889) compiled information from personal reports showing erosion rates from 4 to 8 feet per year along this shoreline. Krumbein (1950) estimated the erosion near Milwaukee, Wisconsin to be about two feet per year, while the rate to the south is believed to be greater, about three feet per year. Locally, especially in areas with low sand banks bordering the lake, erosion, of ten feet per year has been recorded (Ibid.)

The Beach Erosion Board (1946), using both the distances measured by the United States Land Survey and aerial photographs, calculated erosion rates in Milwaukee County. This rate varies from 0.2 foot to 4.0 feet per year and averages 2.1 feet for this county annually. Further, a comparison of erosion rates and lake level were made showing that when the maximum lake level in a given year was 579 feet, the erosion rate was 1.0 foot per year; when the lake level was 581 feet, the erosion rate was 2.1 feet per year; and when the lake level was 583 feet, the erosion rate was 3.2 feet per year. Clearly, a sympathetic relationship exists between lake level and erosion.

WEATHER AND CLIMATE

Meteorological conditions of the Lake Michigan basin have a prominent effect on the wave and current regime and on the water level fluctuations in the lake itself. "It is well known that winds impart significant amounts of momentum to water if they are reasonably steady in direction and are given enough time." (von Arx, 1962, p. 154). It is through this sort of energy input into the lake - the coupling of air movements with the lake surface - that the meteorological situation affects the littoral transport, the sediment dispersal offshore, and the rates of erosion along the lake-land interface.

Lake Michigan lies in a climatic zone which is humid continental, characterized by warm summers and severe winters. The Federal Water Pollution Control Administration (1967) reported that two main paths of low pressure storm centers cross the Lake Michigan basin. One begins in the Northern Rockies and moves across southern Lake Michigan eastward or northeastward, most commonly in the winter. The other storm track comes from Alberta, Canada during winter and summer to cross northern Lake Michigan to the east.

At Milwaukee and Green Bay, Wisconsin, the U.S. Department of Commerce maintains weather stations which record wind speed and direction. Monthly mean and maximum wind speeds and directions for the period 1949 through 1970 have been compiled for these two stations and are reproduced in Tables 2-1 and 2-2. At the Green Bay station, the mean wind speed ranged from 8.0 to 11.7 miles per hour with the mean prevailing direction being southwest except in March, April and May when it was northeast. At the Milwaukee station, the mean wind speed ranged from 9.5 to 13.3 miles per hour. During the winter months, the prevailing direction was west-northwest with variable prevailing directions during the remainder of the year.

While these data are the most complete long-term information available for the area, on-land meteorological stations can reflect a somewhat misleading picture of what is happening over the lake. From data recovered from a series of buoys set out in the lake, the Federal Water Pollution Control Administration (1967) compared the lake and land winds. Deviations of prevailing direction averaged 32 degrees. Furthermore, for the month of September, the month in which this particular experiment was undertaken, wind speeds were higher by 17% over the lake as compared to those measured on land. The Federal Water Pollution Control Administration speculates that this trend is usual during the summer and fall but reverses during the late winter and spring. They also wrote, "... it would appear that winds over Lake Michigan can be 96% greater than those over the City of Chicago at certain times of the year." (Ibid., p. 320)

Krumbein (1950) reported from records kept at Northwestern University in Evanston, Illinois, on the southwestern shore of the lake, that northerly winds occur 17% of the time, easterlies - 6.9%, northeasterlies - 7.5%. and southeasterlies - 8.9%.

A common phenomenon along the lake shore is the lake breeze, caused by air temperatures over the lake being considerably cooler than those over land. Mid-morning wind shifts from westerly winds to easterly winds characterize the lake breeze along the Wisconsin shore of Lake Michigan (U.S. Department of Commerce, 1970b). The location of land meteorological stations (as at Milwaukee where it is three miles west of the lake shore) can prohibit the recording of this phenomenon. Only two or three times per month does this breeze reach the Milwaukee recording station (Ibid.)

Table 2-1 MEAN AND EXTREME WIND SPEEDS, GREEN BAY, WISCONSIN

Month	Mean Speed	Prevailing Direction	Fastest Mile Speed	Fastest Mile Direction	Fastest Mile Year
January	11.0	Southwest	61	West	1950
February	10.8	Southwest	66	West	1951
March	10.9	Northeast	68	West	1951
April	11.7	Northeast	59	Southwest	1964
May	10.8	Northeast	54	Southwest	1968
June	9.3	Southwest	73	Southwest	1953
July	8.2	Southwest	70	Northeast	1957
August	8.0	Southwest	50	Southwest	1950
September	9.2	Southwest	66	West	1951
October	10.1	Southwest	65	Southwest	1951
November	11.4	Southwest	67	West	1955
December	10.9	Southwest	52	West	1957

From: U.S. Department of Commerce, 1970a

Table 2-2 MEAN AND EXTREME WIND SPEEDS, MILWAUKEE, WISCONSIN

Month	Mean Speed	Prevailing Direction	Fastest Mile		
			Speed	Direction	Year
January	12.8	West-Northwest	62	West	1950
February	12.8	West-Northwest	58	Northeast	1960
March	13.3	West-Northwest	73	Southwest	1954
April	13.3	North-Northeast	66	Southwest	1947
May	12.2	North-Northeast	72	Southwest	1950
June	10.4	North-Northeast	57	South	1953
July	9.6	Southwest	59	West	1952
August	9.5	Southwest	50	West	1949
September	10.7	South-Southwest	62	South	1941
October	11.6	South-Southwest	60	South	1949
November	12.9	West-Northwest	72	West	1955
December	12.7	West-Northwest	62	Southwest	1948

From: U.W. Department of Commerce, 1970b

Wind speed and direction in the study area are recorded at a meteorological station at Point Beach Nuclear Power Plant. These data are presented for seven time periods, each consisting of the dates of one sampling sequence and the week preceding. No data were recorded furing July, 1971. The wind roses, Figures 2-7 through 2-13, are based on readings taken every six hours, commencing at 0600 hours.

TEMPERATURE STRUCTURE

Lake Michigan follows an annual temperature stratification cycle typical of lakes in the temperate zone. The Federal Water Pollution Control Administration (1967) stated that the southern and northern basins follow similar but unique cycles. In the southern basin, two patterns develop during the course of the year. Beginning near the shore in March, stratification develops which is complete throughout the lake by late May. The depth of the thermocline during the summer is about 22 meters (Verber, 1965). This can increase to 30 meters by late fall. Ayers, et al. (1958) reported a well-developed thermocline during June, 1955, found at 20-50 feet in the southern basin, and at 50-60 feet in the northern basin. By August, 1955, the thermocline reached 50-100 feet throughout the lake. By November, the stratification breaks down and mixing occurs. No reverse stratification develops during the winter months and the temperature may reach 2.3° C from top to bottom during this time.

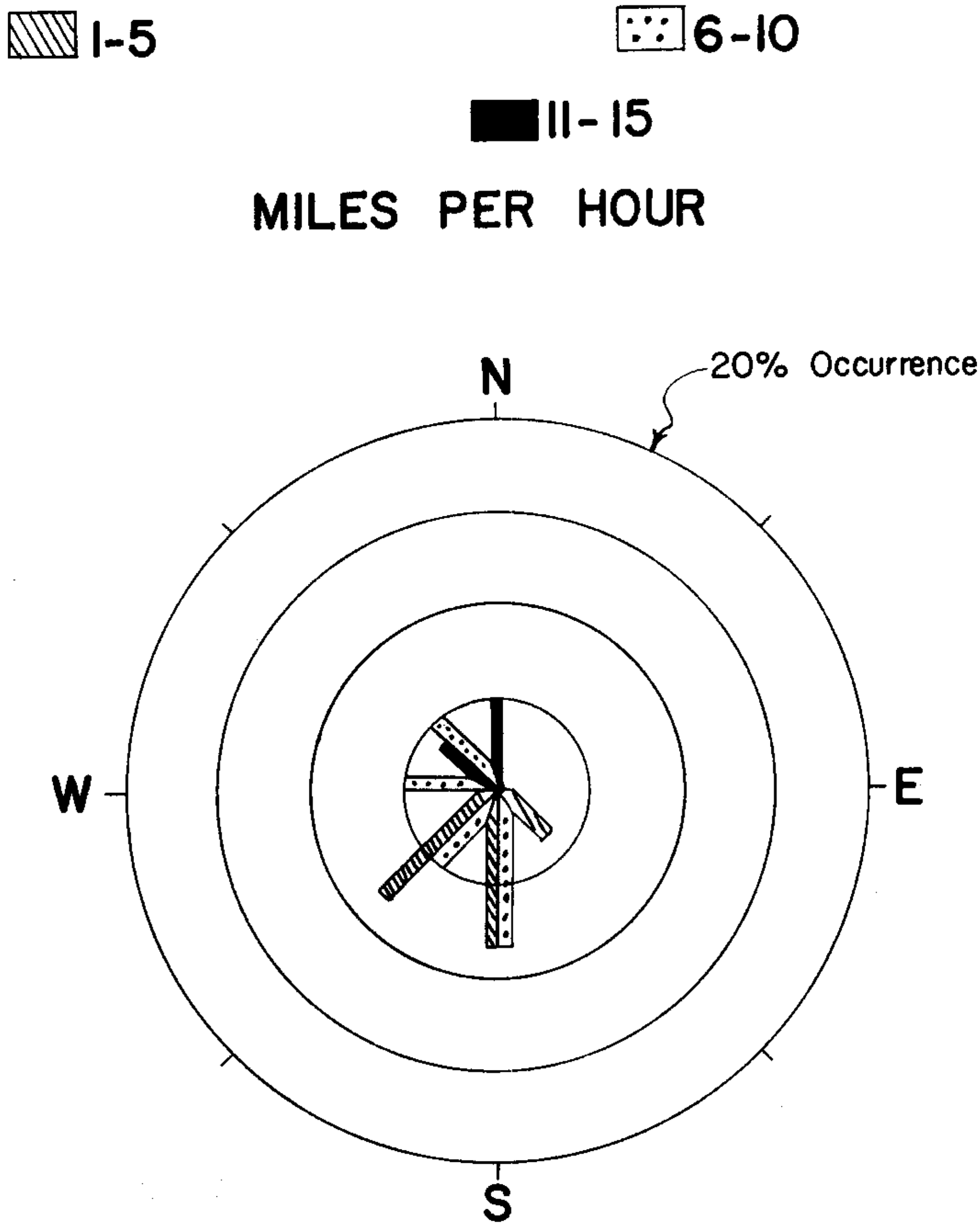
In the northern basin, the cycle is pushed back later into the year with the summer stratification not complete until late June and the winter isothermal stage not occurring until December. After a short isothermal period in the fall (and again in late spring), a winter reverse stratification develops. The reverse thermocline can be found between 120-180 meters. Thus mixing can take place in the northern basin during a very limited part of the year, usually only during one month out of twelve.

CURRENTS

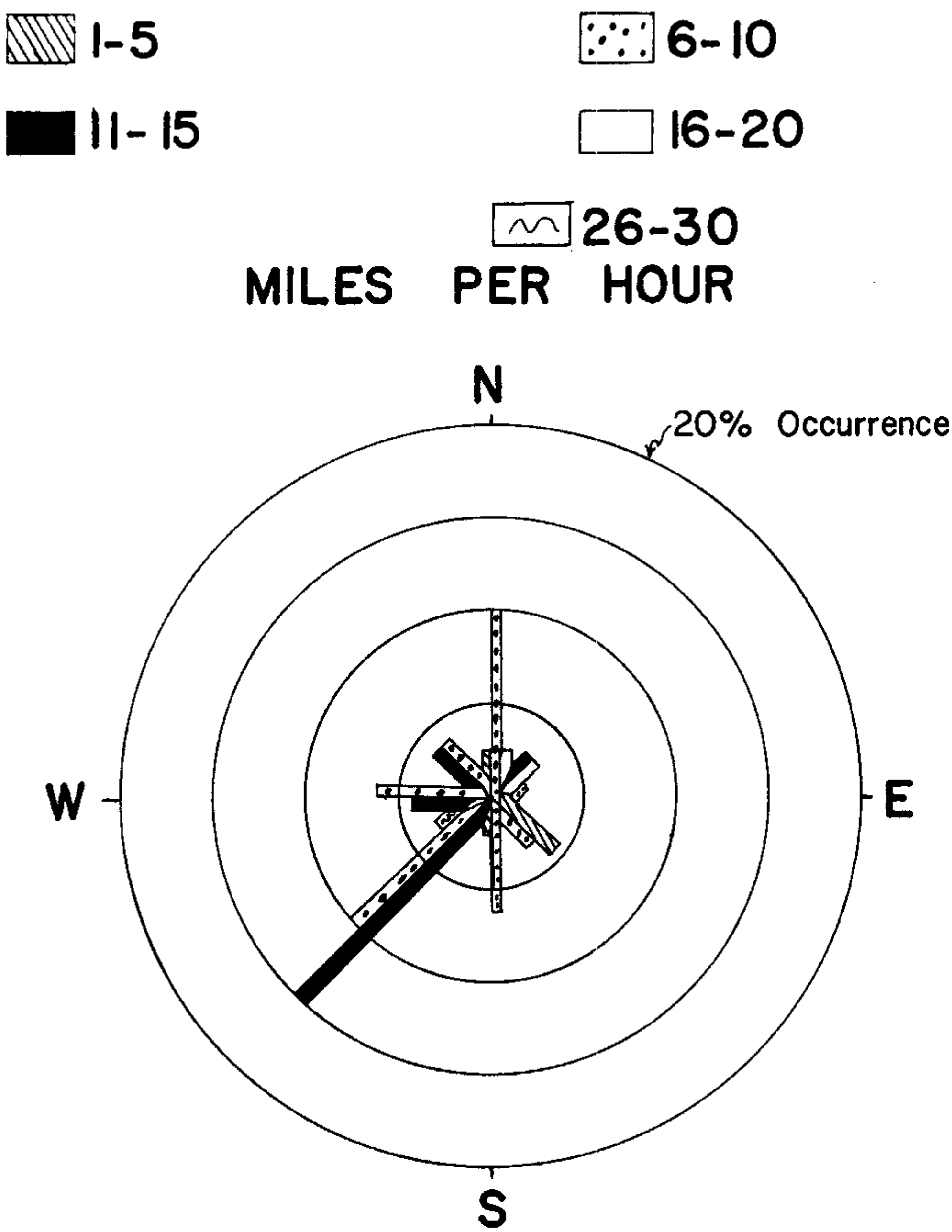
The current system of Lake Michigan is most completely described in two reports, one by the Federal Water Pollution Control Administration (1967), and the other by Ayers, et al., (1958). Using data obtained during 1963-1964 from a set of moored buoys, the Federal Water Pollution Control Administration (1967) has described the seasonal circulation patterns in the lake. Ayers, et al., (1958) reported the results of synoptic cruises on four days in June and August, 1955, during which a variety of parameters, including temperature and drift bottles movements, were measured. Dynamic height calculations, along with the drift bottle movement information, yielded current patterns.

Four basic current patterns are reported in the Federal Water Pollution Control Administration study, two each in winter and in summer. Figure 2-14 shows the winter circulation pattern as developed by north-northwest winds. This particular pattern is estimated to exist during 25-30% of the year. During 20-25% of the year, another winter circulation pattern, as seen in Figure 2-15, is developed under the influence of south-southwest winds.

Current patterns in the study area of this research project are reversed in these two circulation patterns. In the first, it can be seen that a southerly flow occurs, with a northerly flow predominating under the effect of south-southwesterly winds.

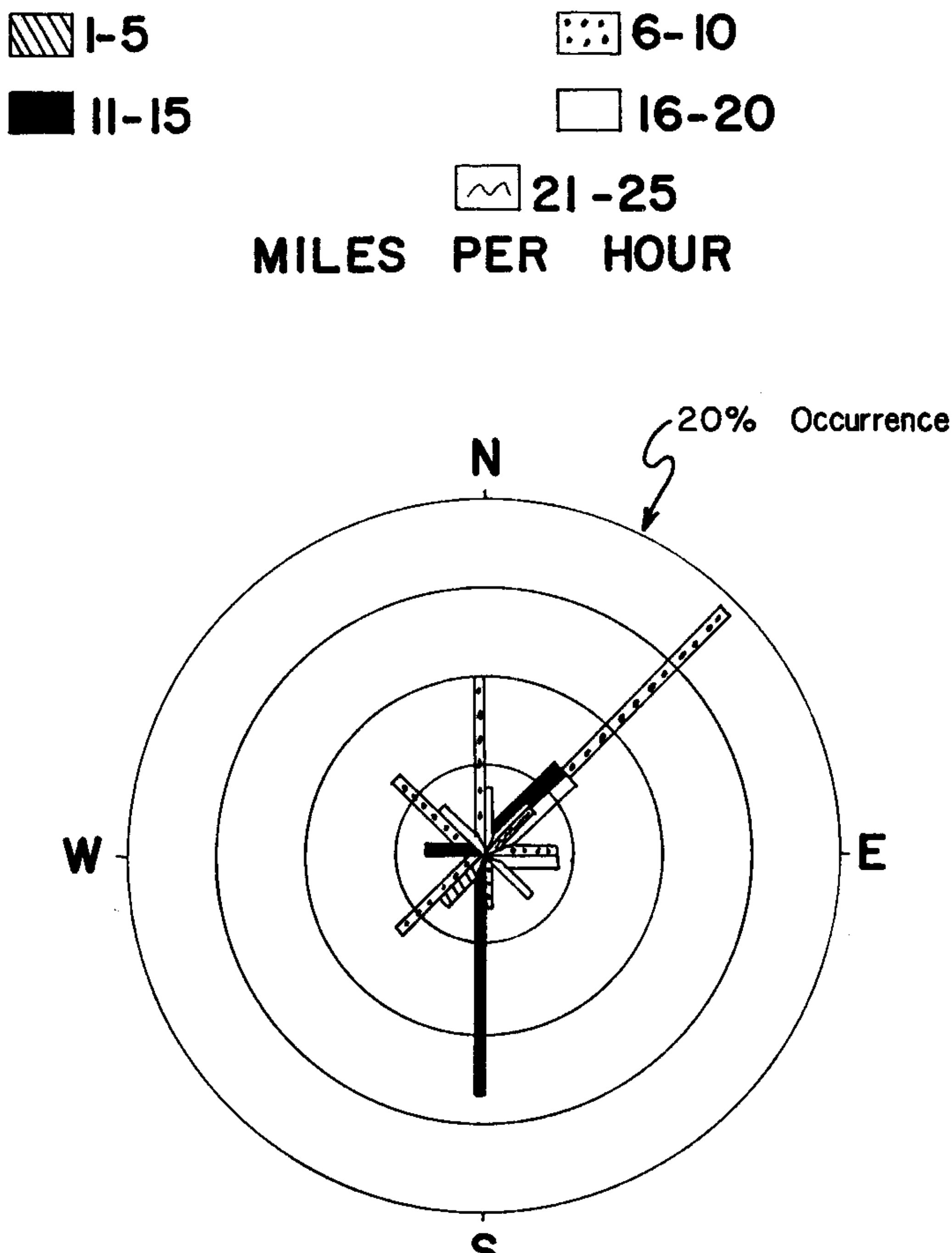


WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
MAY 31 - JUNE 8, 1971
Fig. 2-7

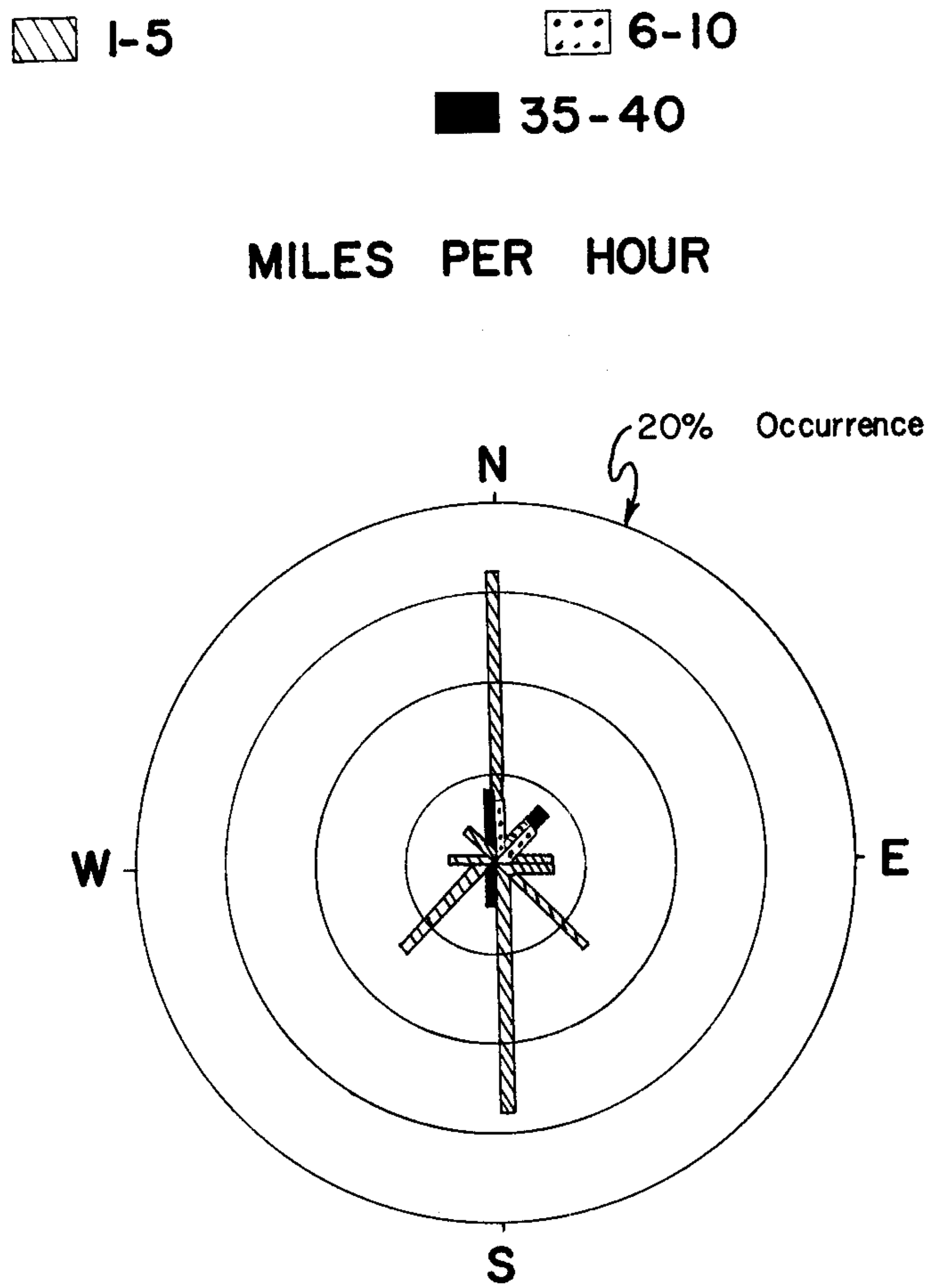


WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
AUGUST 9-21, 1971

Fig. 2-8



WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
APRIL 8-15, 1972
Fig. 2-9

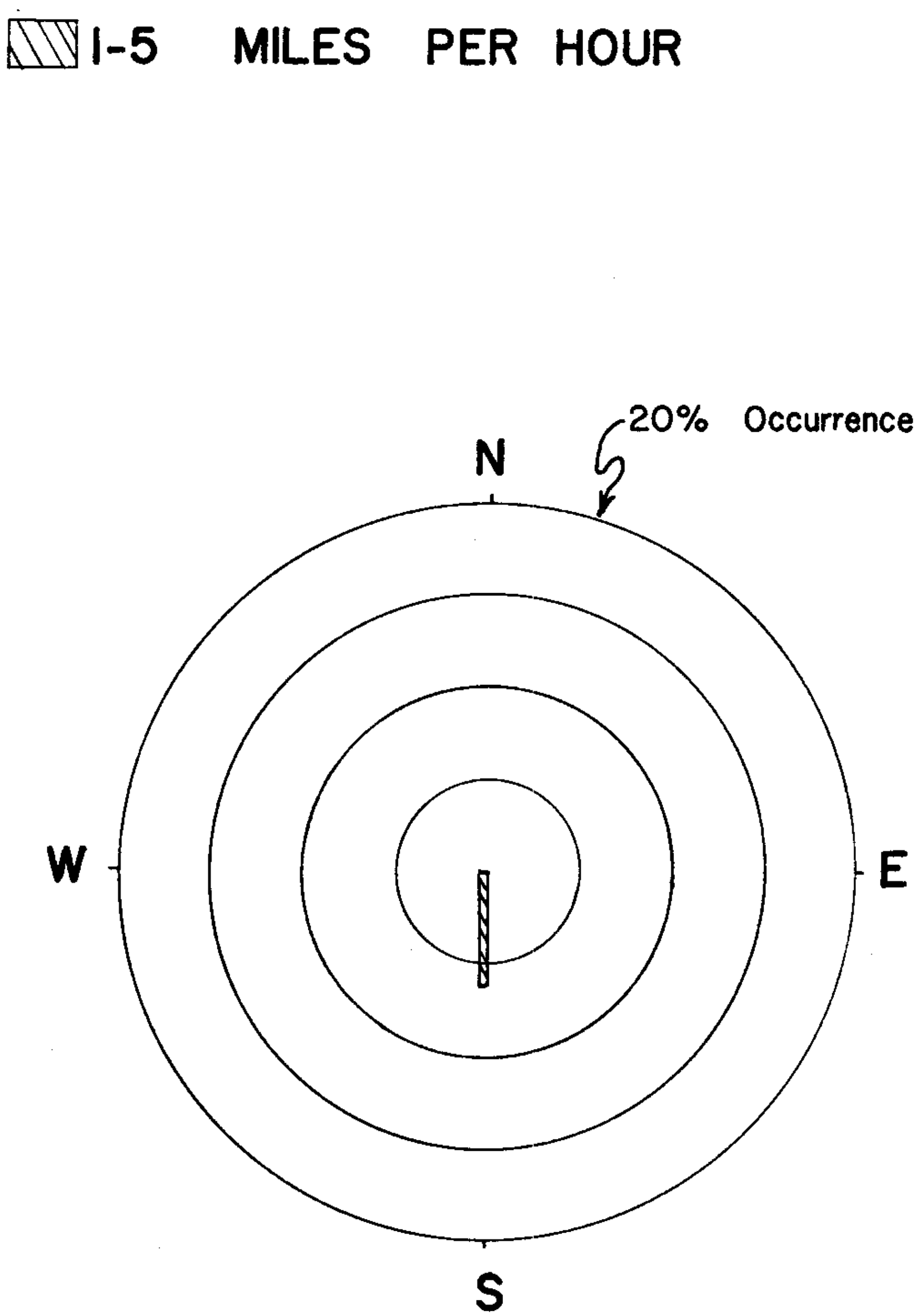


WIND ROSE

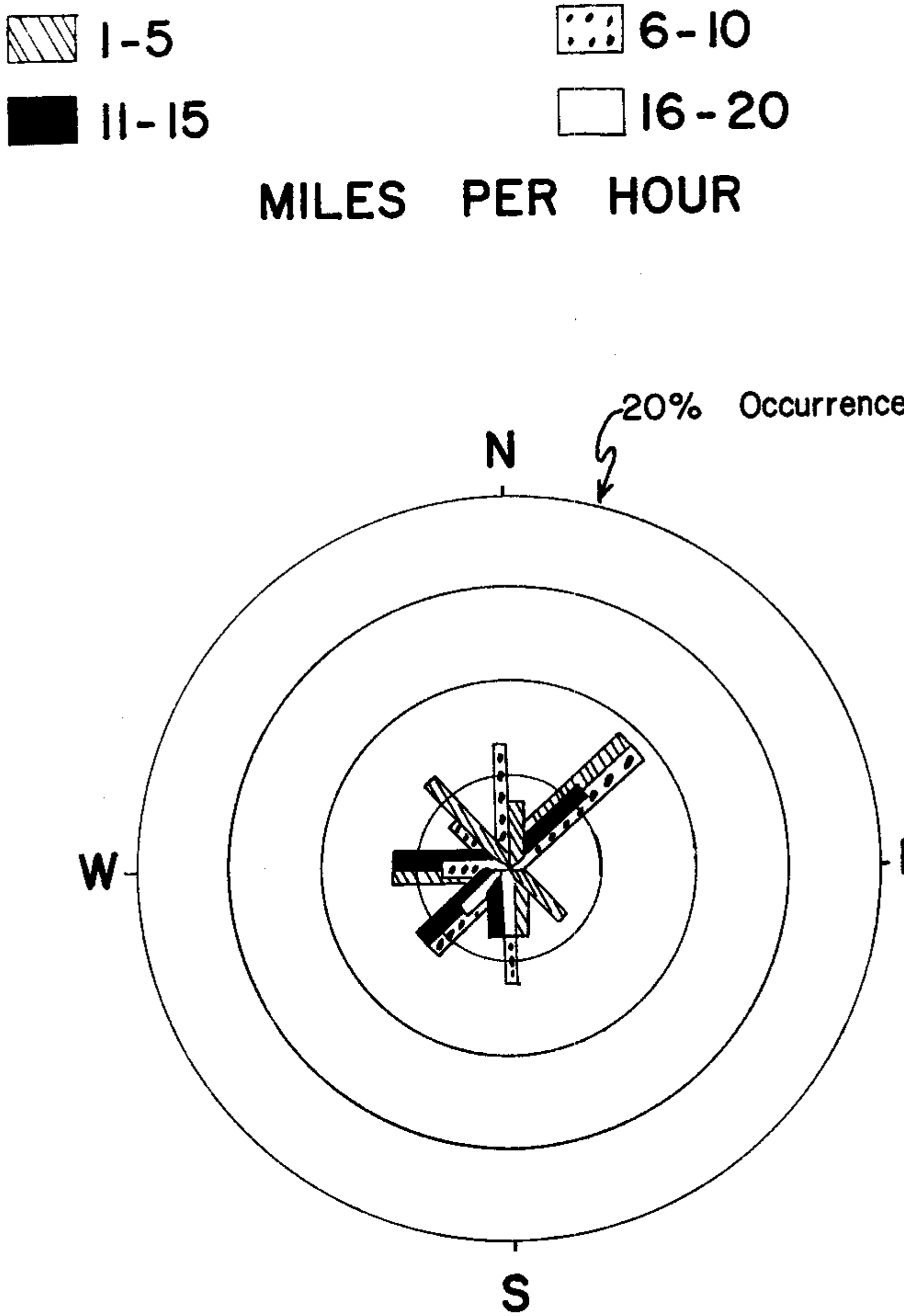
POINT BEACH NUCLEAR POWER PLANT

MAY 22 - JUNE 8, 1972

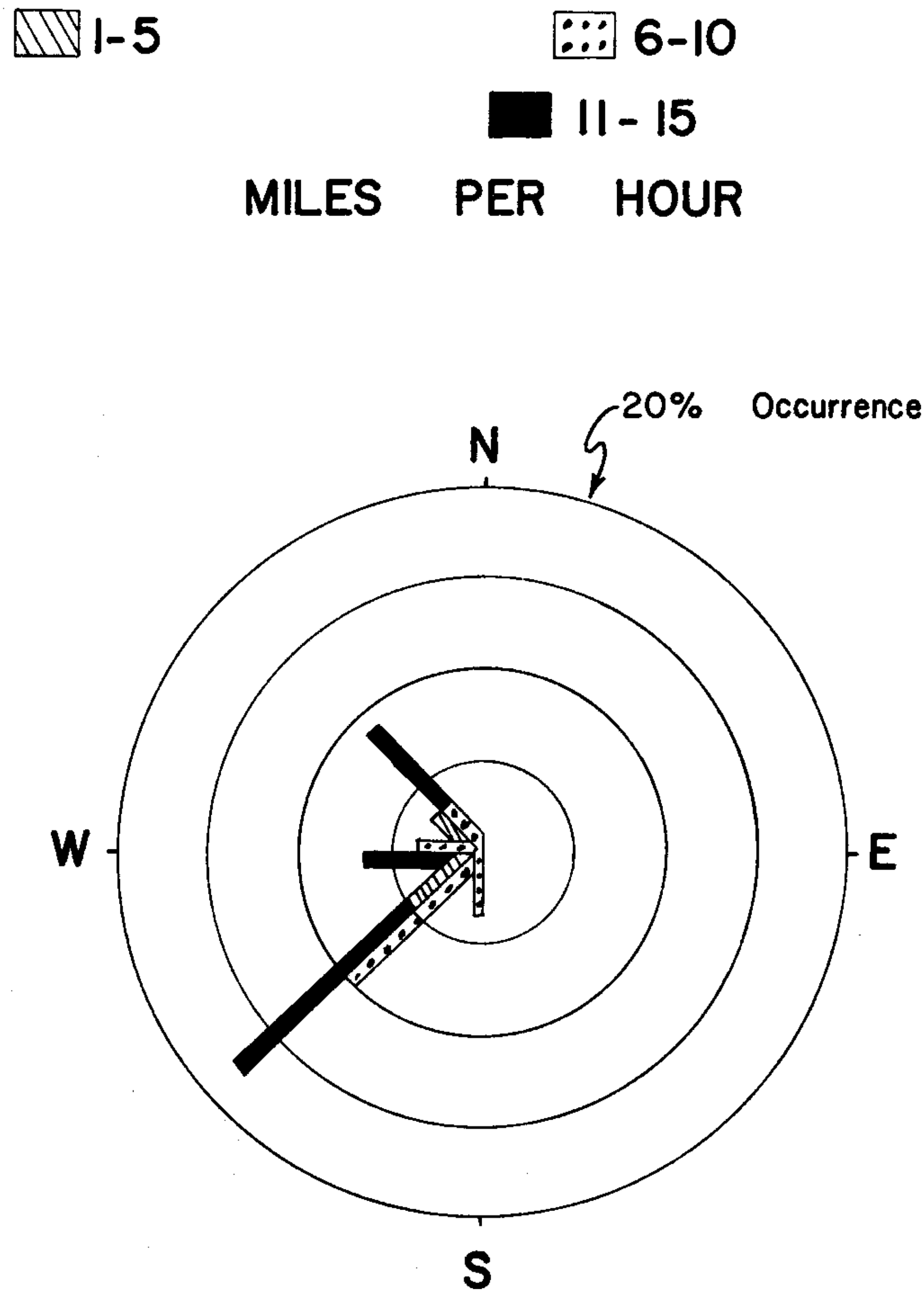
Fig. 2-10



WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
JUNE 28 - JULY 6, 1972
Fig. 2-11



WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
SEPTEMBER 11-18, 1972
Fig. 2-12



WIND ROSE
POINT BEACH NUCLEAR POWER PLANT
NOVEMBER 21-27, 1972
Fig. 2-13

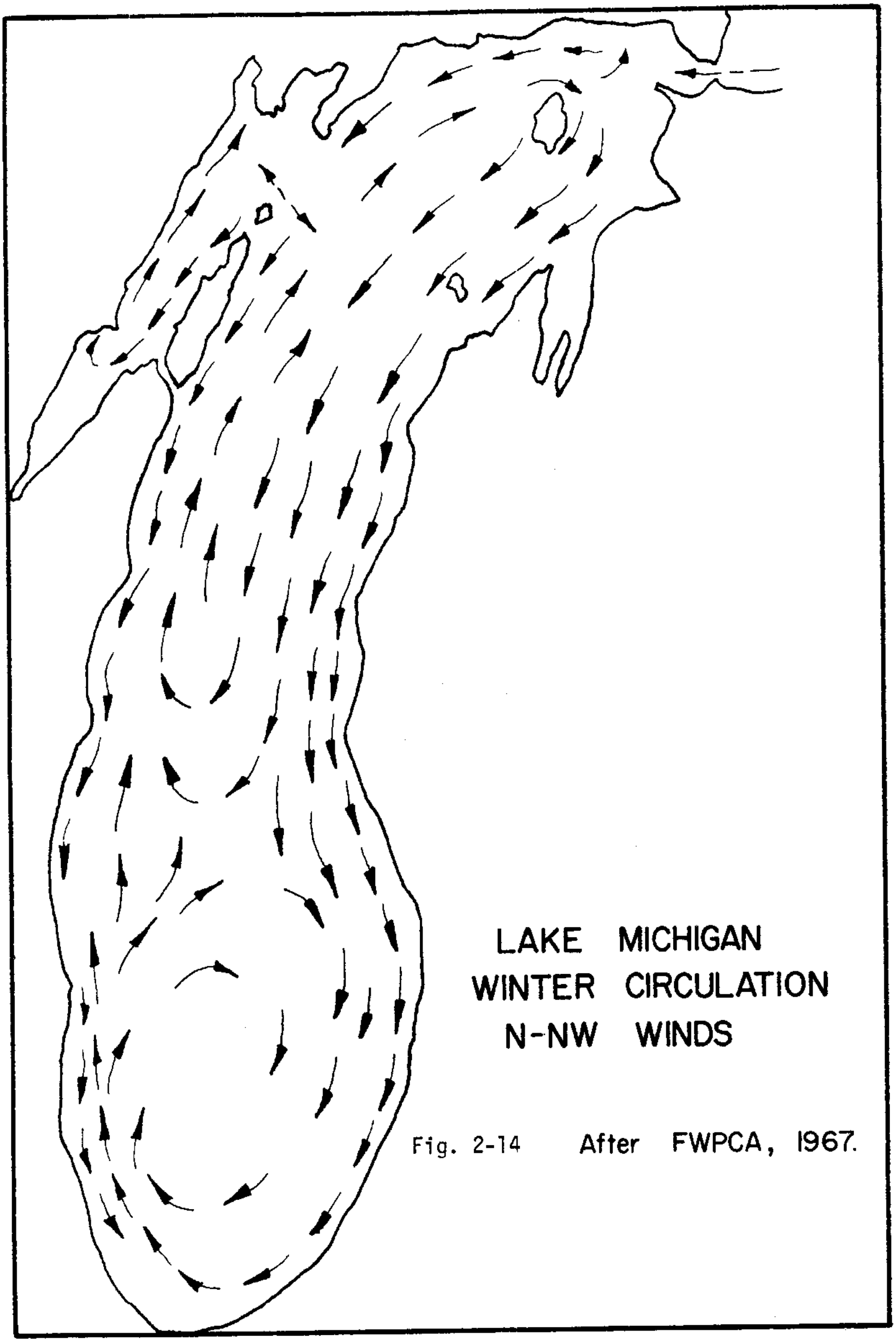


Fig. 2-14 After FWPCA, 1967.

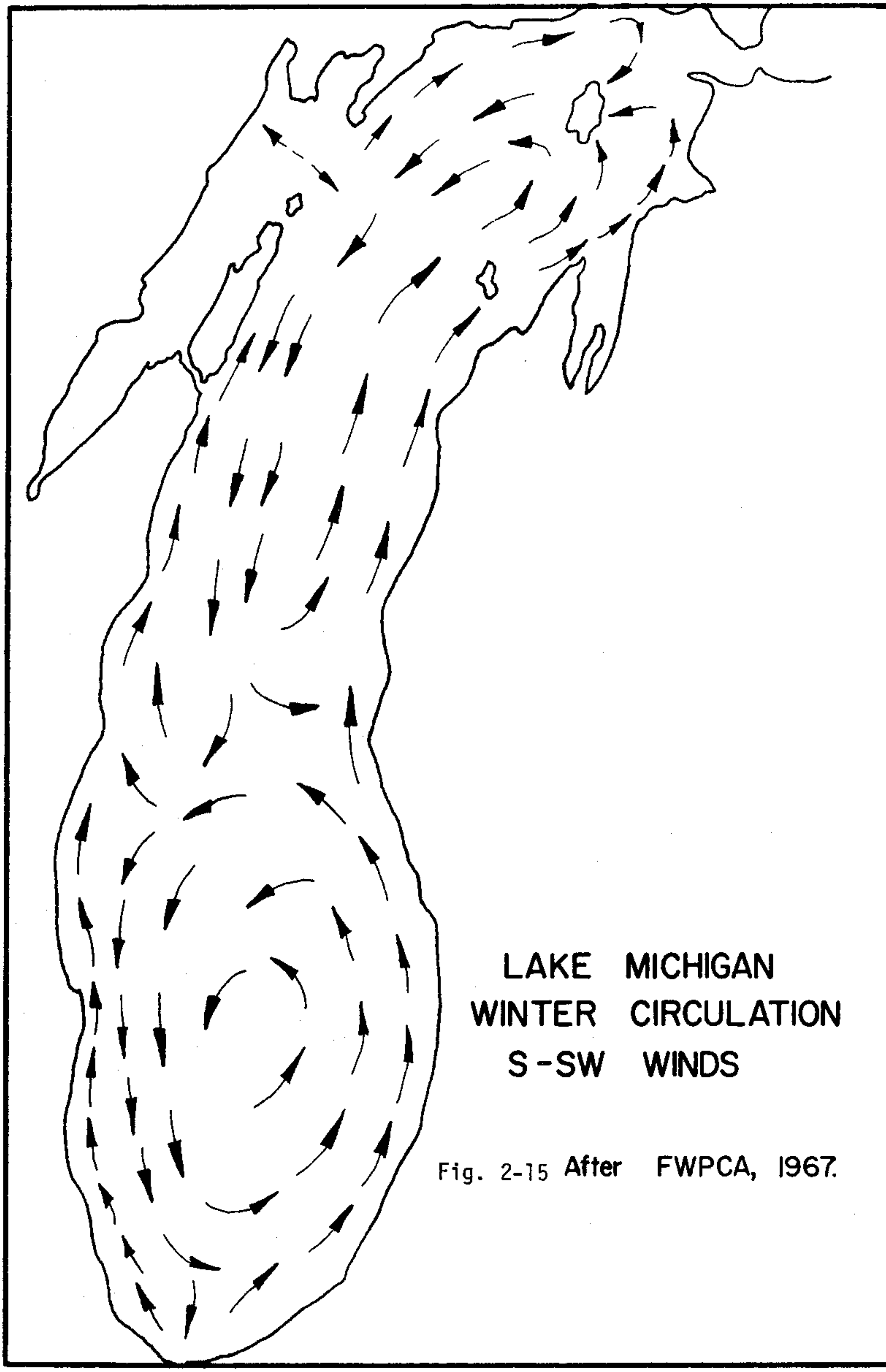


Fig. 2-15 After FWPCA, 1967.

During the summer, north-northeasterly winds (Fig. 2-16) set up a pattern different from south-southwesterly winds (Fig. 2-17). The first pattern predominates, occurring 40% of the year, with the second being present only about 10% of the time. Again, the current pattern through the study area is opposite for each of these circulation patterns, but is southerly for the majority of the summer. Ayers, et al, (1958) showed four surface current patterns, reproduced in Figures 2-18 through 2-21. Surface currents in the area of this sediment study are again shown to be variable.

Figure 2-22, reproduced from the Federal Water Pollution Control Administration (1967) shows a subsurface flow to the south at the 60 meter contour past the outside edge of the study area. Ayers, et al, (1958) reported that during the two June days, a southerly bottom current was found in the offshore area of the study area, with possible upwelling at Rawley Point and at Kewaunee, as shown in Figures 2-23 and 2-24. During August, an offshore, easterly flow was apparent in the bottom currents. (Figures 2-25 and 2-26).

From these two studies, it becomes immediately apparent that the currents in the offshore areas of the study area are quite variable. Winds are the principal agents involved, as the Federal Water Pollution Control Administration (1967) current patterns indicate. Inshore areas have flow patterns influenced almost exclusively by the winds and the topography. The point at which the thermocline intersects the lake bottom determines the division between inshore and offshore circulation patterns (Ibid.). Because the separation between the inshore and offshore circulation patterns can vary between two and ten miles offshore, both patterns can influence the sediment dispersal within the area of this sediment study.

A detailed analysis of current structure to depth in Lake Michigan is reported by Verber (1965). He found that "at the 30 meter level in the northern basin, the water tends to flow southerly along the western shore." (Ibid., p. 367). Also, Verber reported that wind stress on the lake surface is translated into movement at depths as great as 90 meters during the summer and as great as 240 meters in early fall and late winter. One storm with winds of 17 meters per second, of six hour duration, increased the flow from 3 cm/sec to 8 cm/sec at 180 meters depth.

Figure 2-27 reproduces Verber's compilation of flow speeds versus duration. While the average speeds are interesting in themselves, the right-hand tails of the plots are of particular interest to the sedimentologist. It is these periodic fast flows which can transport volumes of sediments when they come in contact with the lake bottom.

In addition to the general current patterns, several other types of large-scale motions can occur, including thermal bars, surface seiches or surges, internal seiches formed at the thermocline, and tides. These phenomena have been discussed by Verber (1964), Rodgers (1965), Mortimer (1965), Csanady (1967), and Fox and Davis (1970).

LAKE LEVELS

It is well known that all of the Great Lakes display both long-term and seasonal fluctuations in water level. Lakes Michigan and Huron are considered to be one hydrologic unit. Annually, the water level reaches a low during the winter months

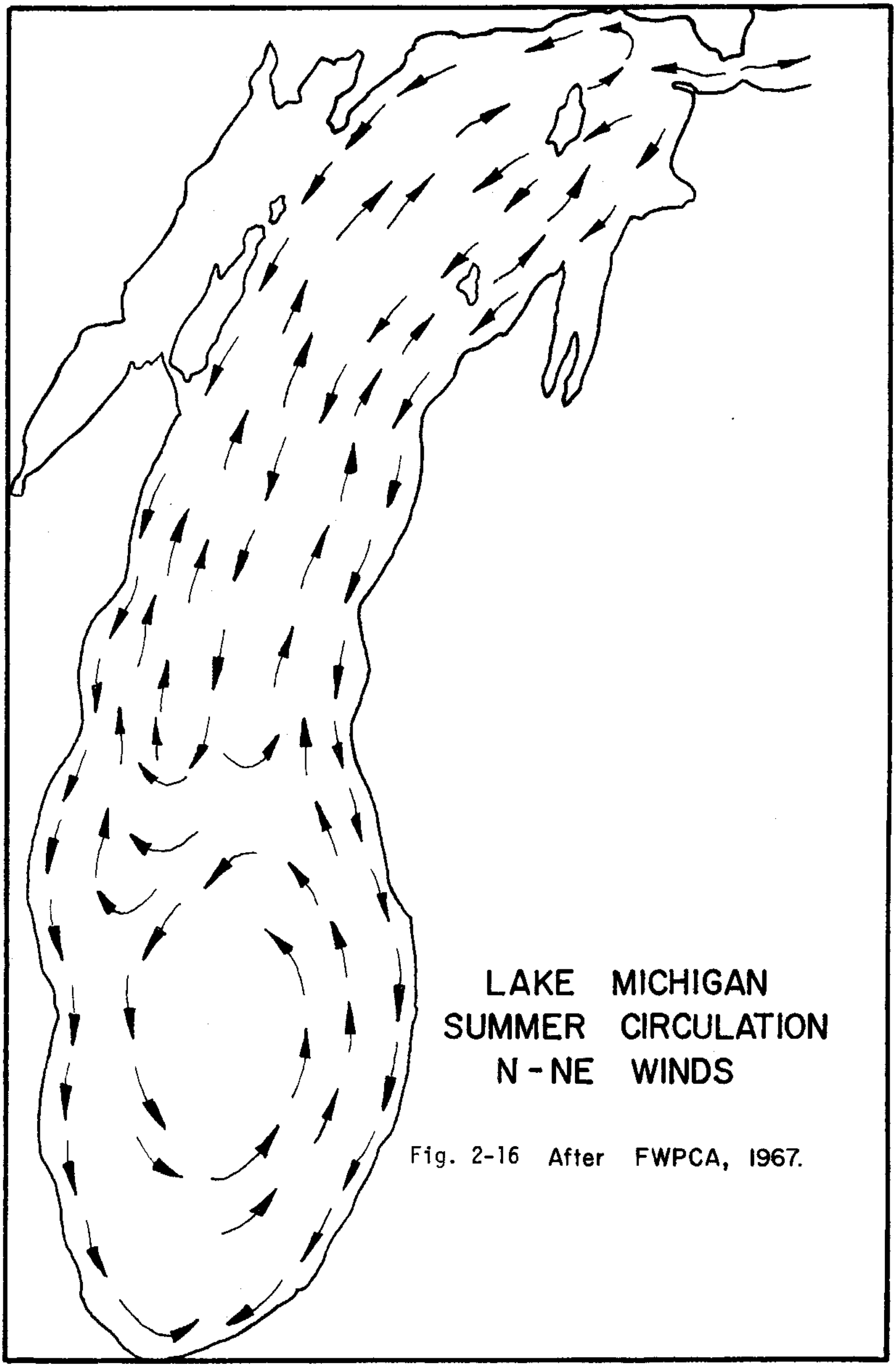


Fig. 2-16 After FWPCA, 1967.

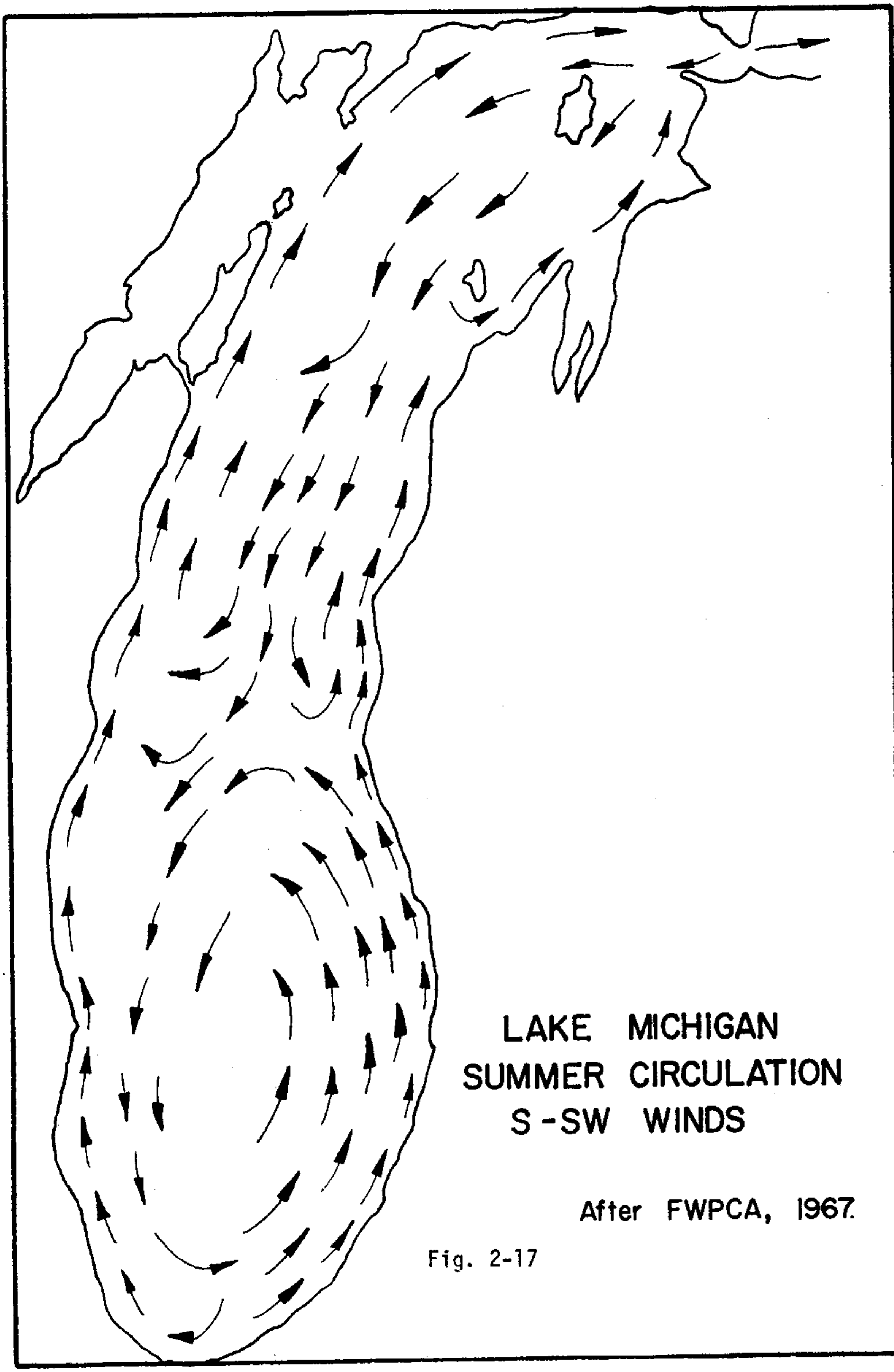
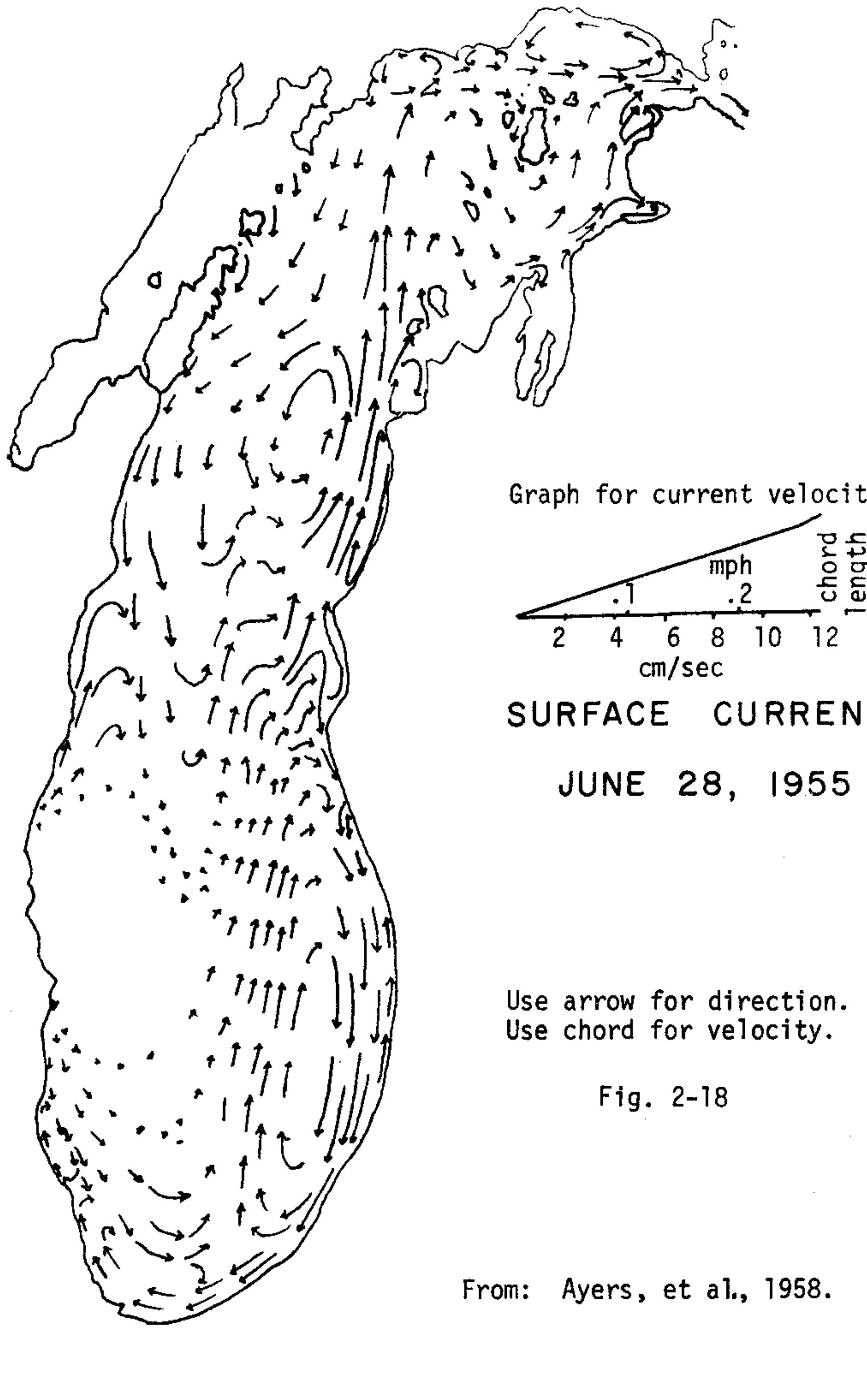

LAKE MICHIGAN
SUMMER CIRCULATION
S-SW WINDS
After FWPCA, 1967

Fig. 2-17



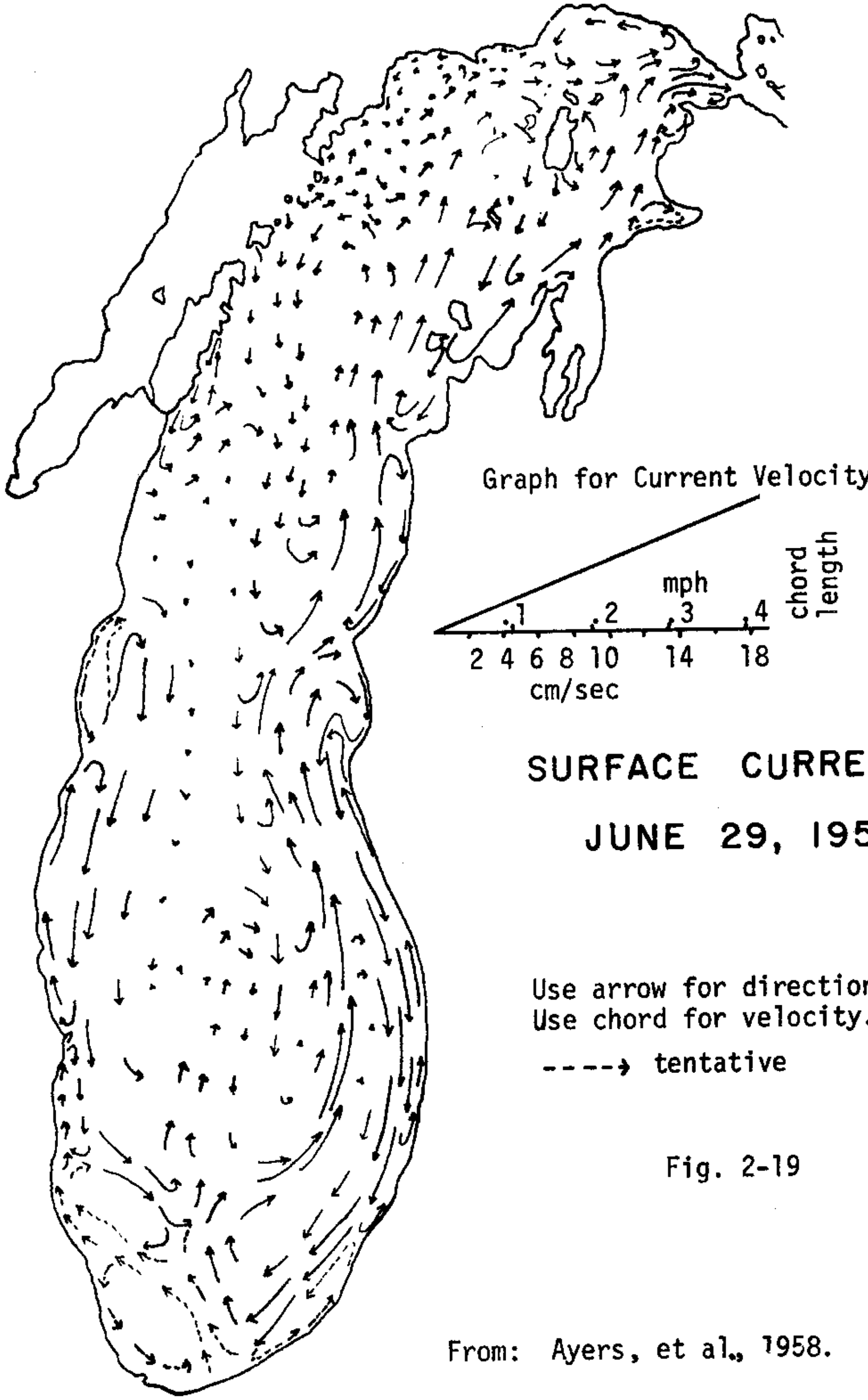
SURFACE CURRENTS

JUNE 28, 1955

Use arrow for direction.
Use chord for velocity.

Fig. 2-18

From: Ayers, et al., 1958.



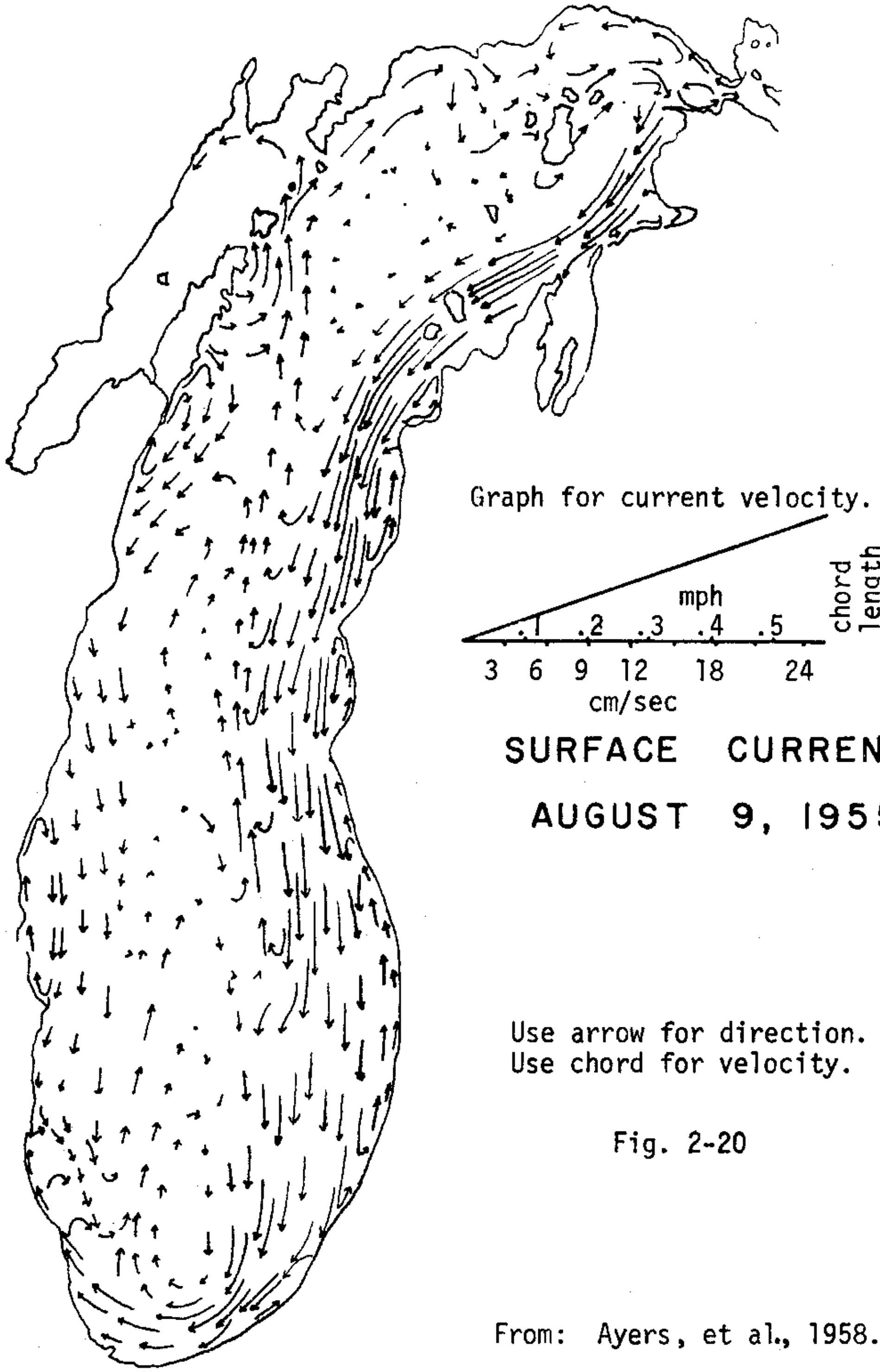
SURFACE CURRENTS

JUNE 29, 1955

Use arrow for direction.
Use chord for velocity.
----→ tentative

Fig. 2-19

From: Ayers, et al., 1958.



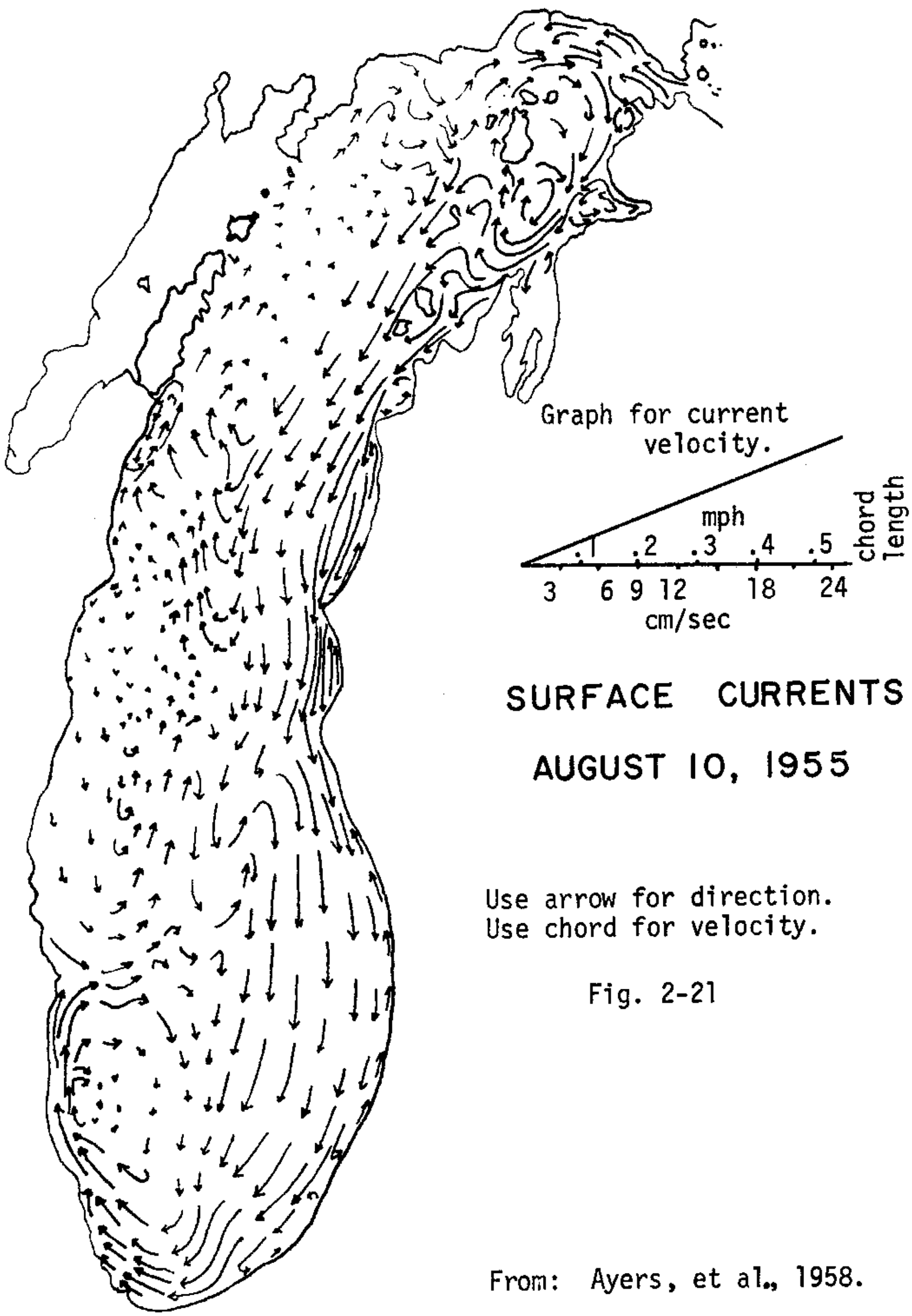
SURFACE CURRENTS

AUGUST 9, 1955

Use arrow for direction.
Use chord for velocity.

Fig. 2-20

From: Ayers, et al., 1958.



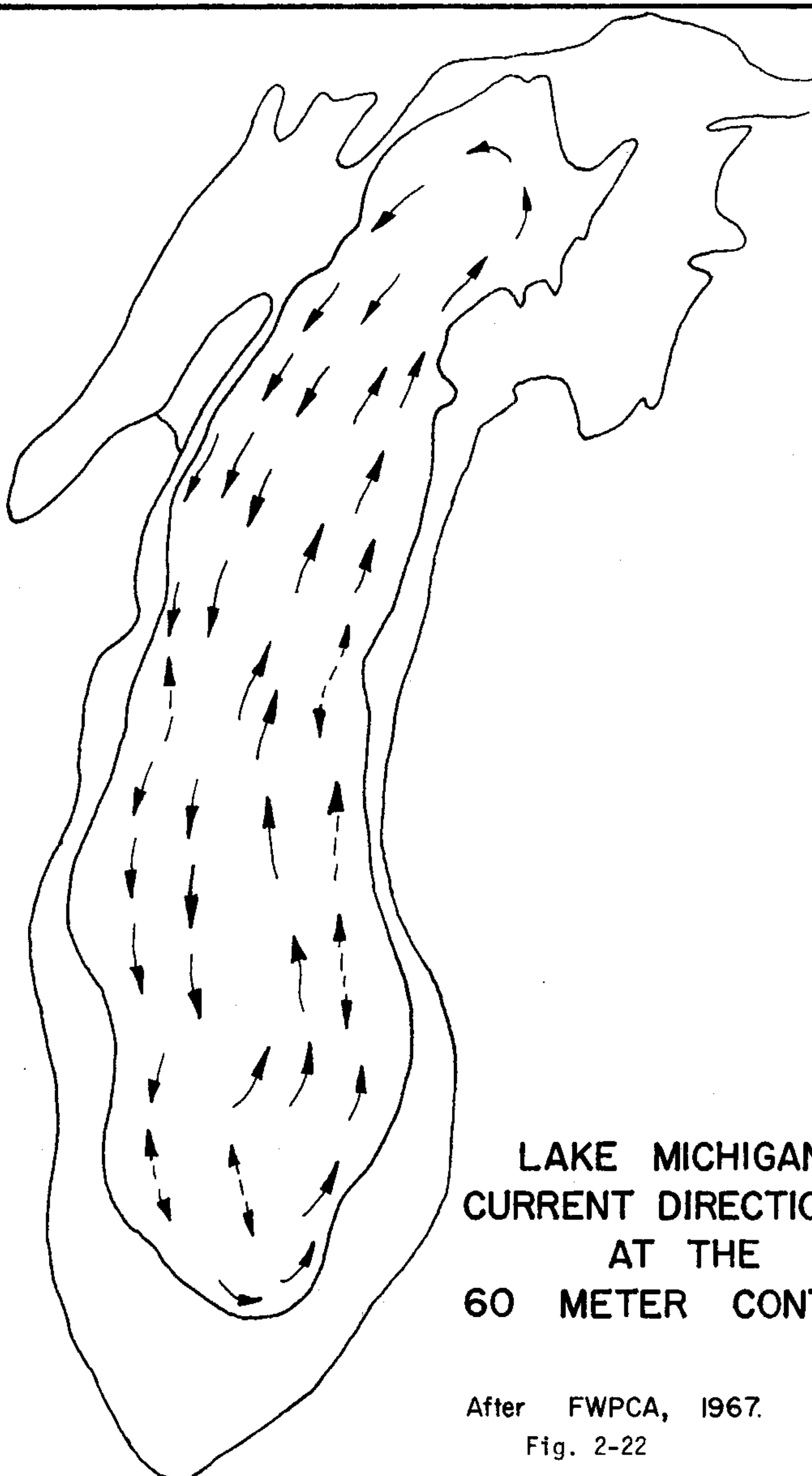
SURFACE CURRENTS

AUGUST 10, 1955

Use arrow for direction.
Use chord for velocity.

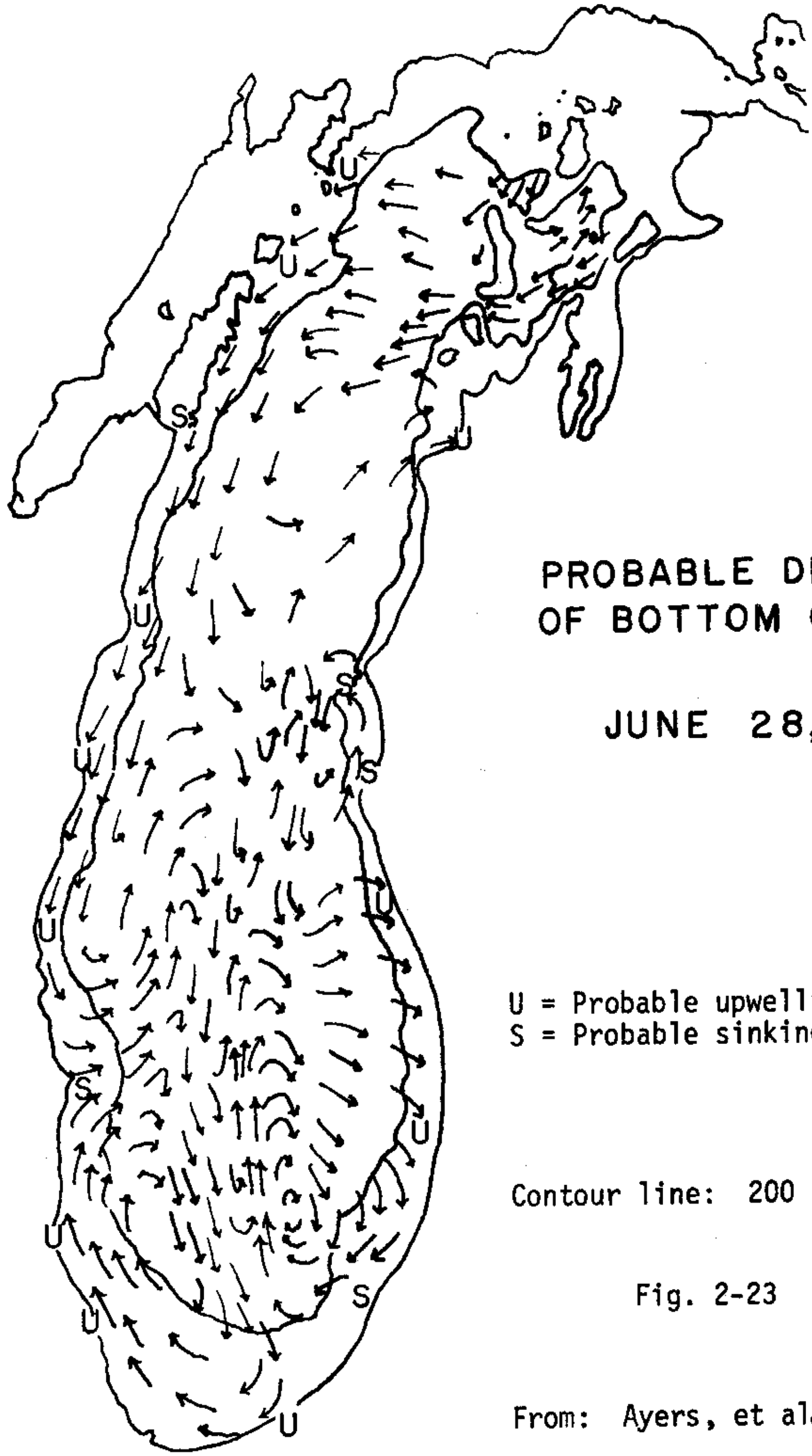
Fig. 2-21

From: Ayers, et al., 1958.



LAKE MICHIGAN
CURRENT DIRECTIONS
AT THE
60 METER CONTOUR

After FWPCA, 1967.
Fig. 2-22



PROBABLE DIRECTIONS OF BOTTOM CURRENTS

JUNE 28, 1955

U = Probable upwelling.
S = Probable sinking.

Contour line: 200 feet.

Fig. 2-23

From: Ayers, et al., 1958.

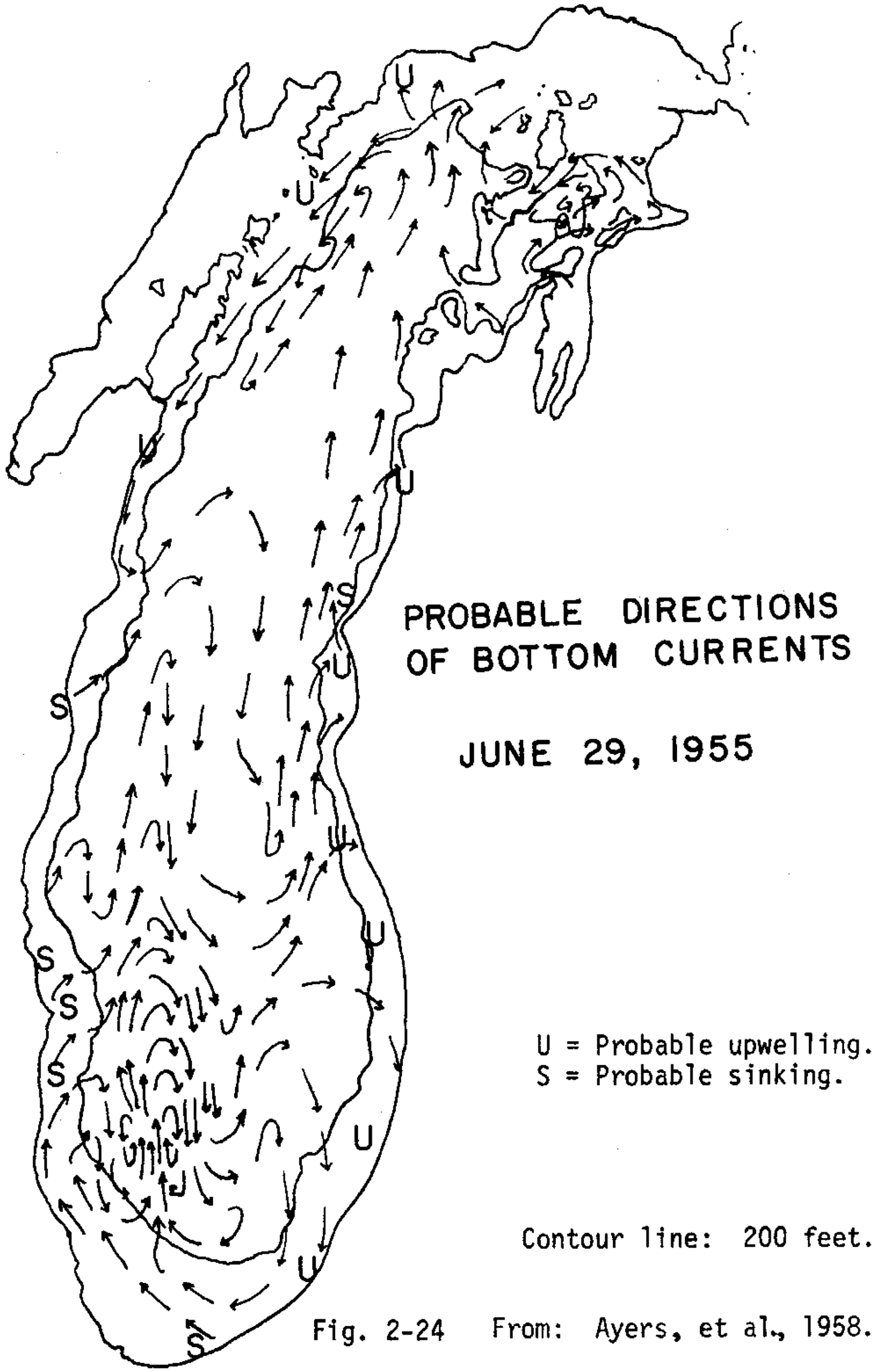
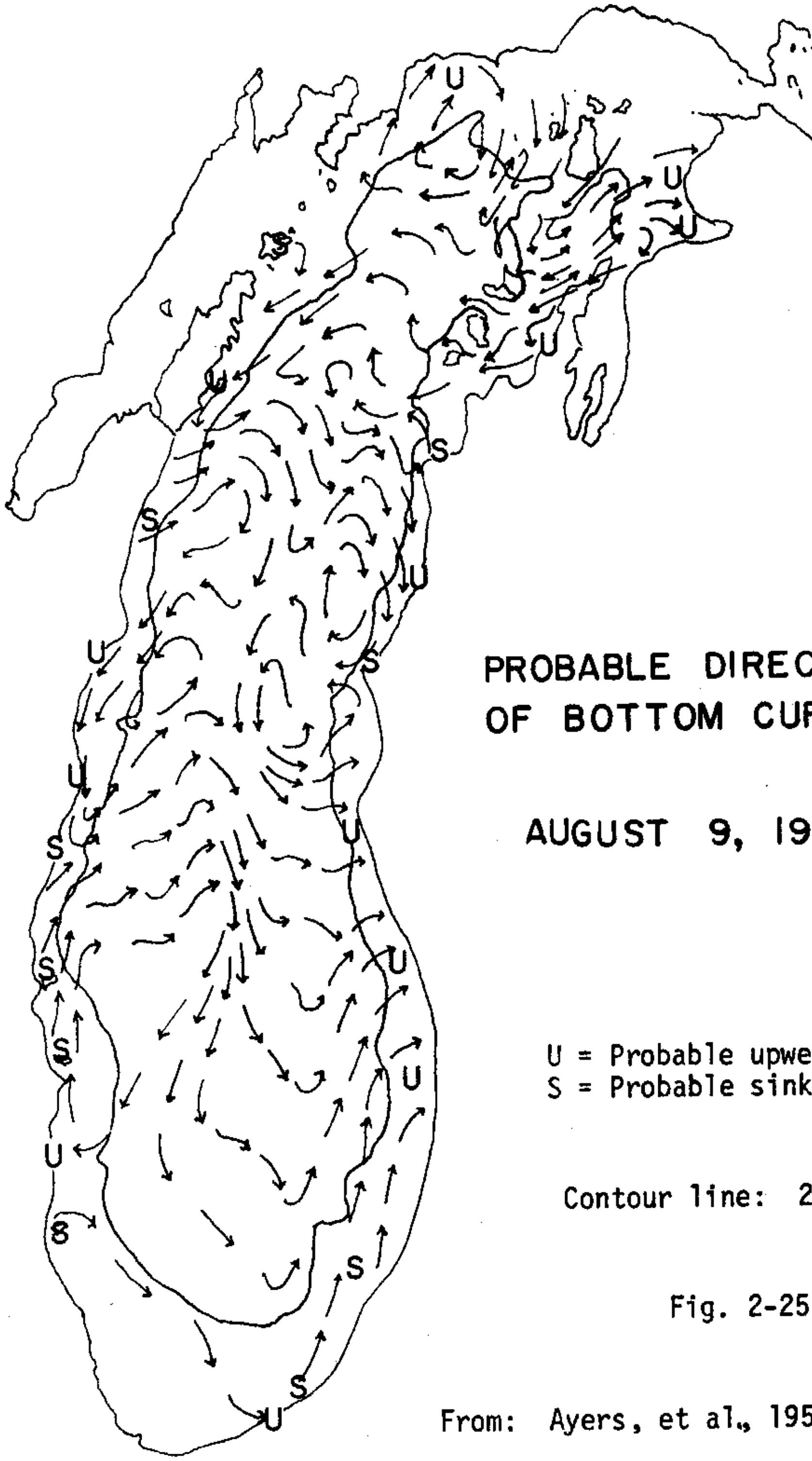


Fig. 2-24 From: Ayers, et al., 1958.



PROBABLE DIRECTIONS OF BOTTOM CURRENTS

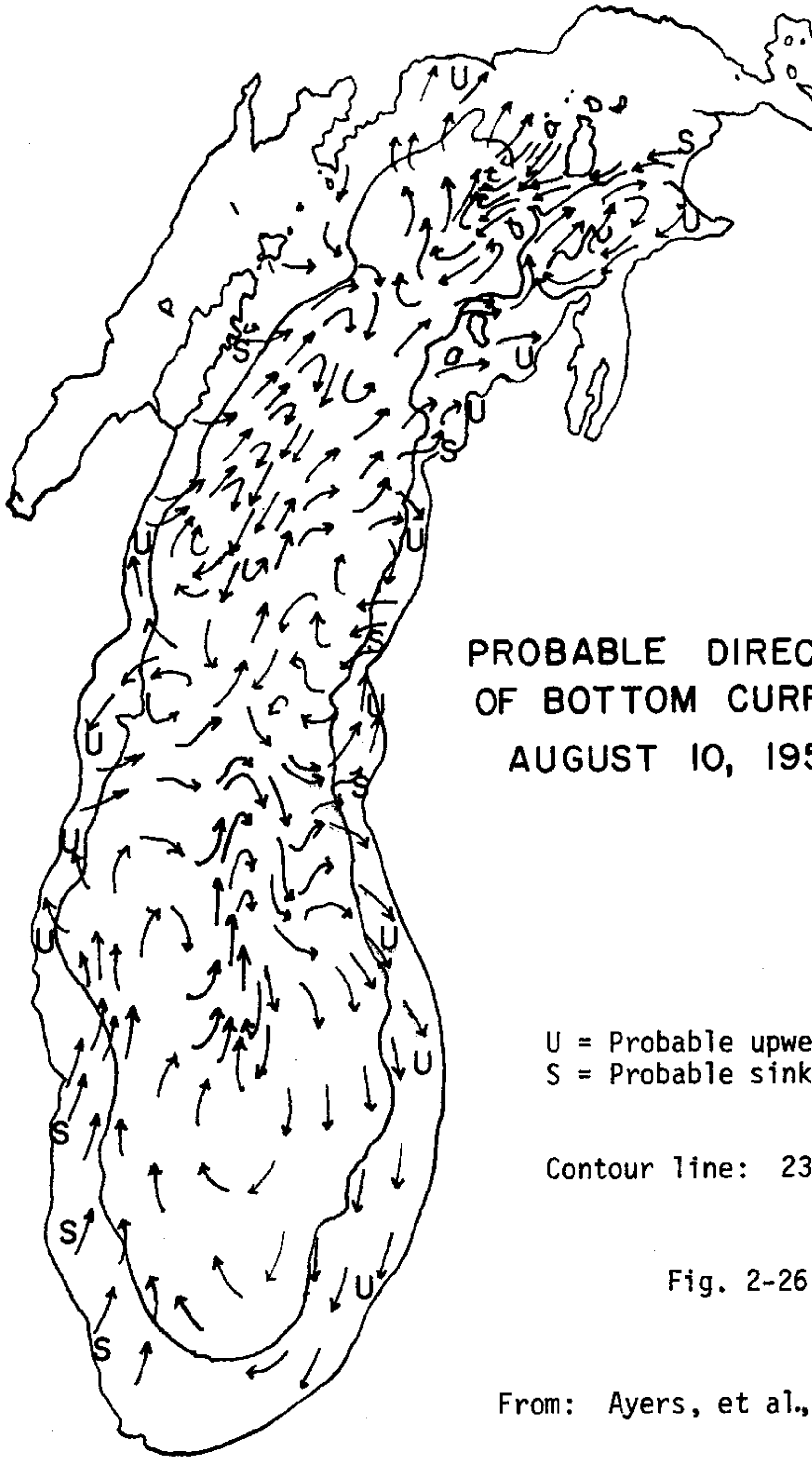
AUGUST 9, 1955

U = Probable upwelling.
S = Probable sinking.

Contour line: 230 feet.

Fig. 2-25

From: Ayers, et al., 1958.



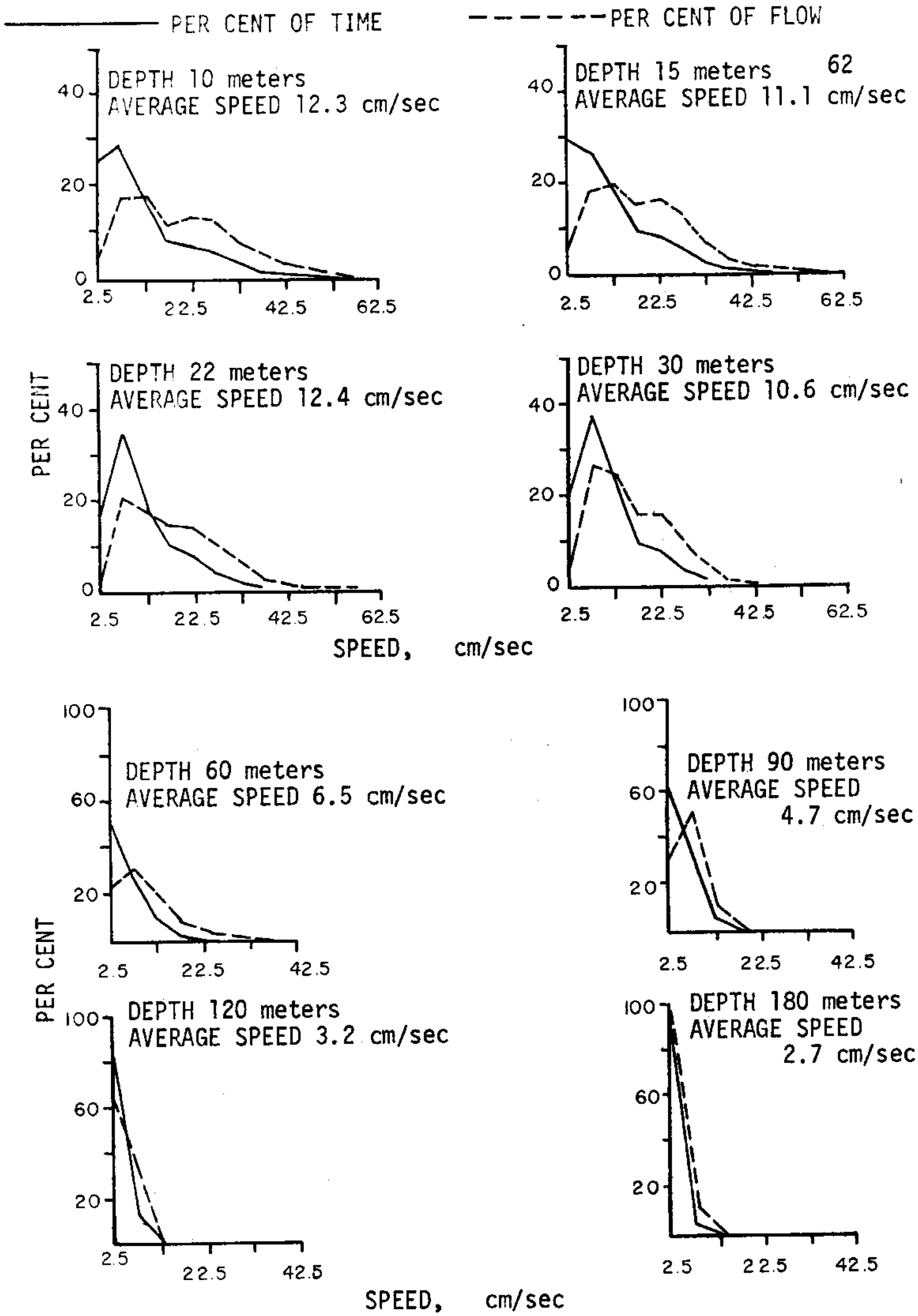
PROBABLE DIRECTIONS
OF BOTTOM CURRENTS
AUGUST 10, 1955

U = Probable upwelling.
S = Probable sinking.

Contour line: 230 feet.

Fig. 2-26

From: Ayers, et al., 1958.



Average Speed At Various Depths vs. Percent of Time in Lake Michigan
Fig. 2-27 From Verber, 1965.

(February and/or March) and a high during the summer, commonly peaking in August. The annual range is normally between 1.0 to 1.5 feet. Monthly changes are due to variation in the flow from Lake Superior, evaporation, precipitation, and diversion (Beeton and Chandler, 1963). Figure 2-28 reproduces the hydrograph of lake levels compiled by the U.S. Department of Commerce (1973). Table 2-3 shows the mean monthly levels during the course of this study.

Long-term changes in water level are discussed by Brunk (1961). During the last century, the ten-year mean level has been lowered about 1.5 feet and this is attributed to "the natural and artificial changes in the outlet control system of Lake Huron." (Ibid., p. 71).

SHORE ICE

Because of the severe winter conditions in the Lake Michigan basin, the role of shore ice on the beach and nearshore zone must be considered. This topic has been the object of very few studies. Zumberge and Wilson (1953) introduced the term "ice-foot" to denote a mass of ice firmly attached to the shore, formed when spray from the surf zone is blown onto the foreshore and is then frozen. A lake which remains free of fast ice in the center is thus required for the formation of ice boundaries along the beach.

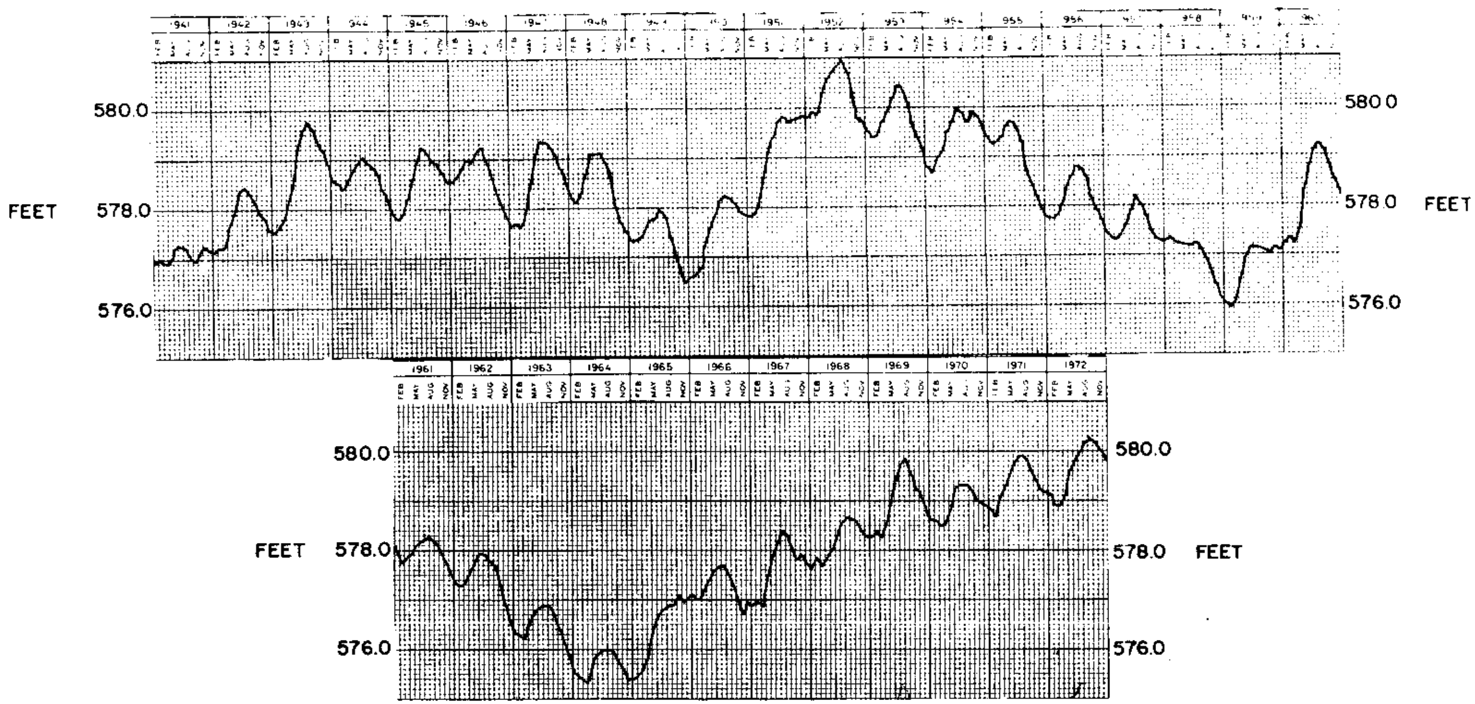
The effect of this ice formation on the nearshore sedimentary environment is touched upon in this same report. While its exact nature is not known, the authors speculate that, by protecting the sandy beaches from wave attack, the wave energy is concentrated into the shallow water zone. By this mechanism, a readjustment in the profile possibly takes place. Although the extent of this effect of the nearshore zone is unknown, it was noted that sand was found frozen into the ice-foot, indicating a scouring action (Ibid.). Snider (1971) also reviewed the process of formation of the ice-foot structure on beaches.

The interaction of wave energy, the ice cover on the beaches, and the nearshore sedimentary environment is discussed by O'Hara and Ayers (1972). They also note the presence of sand frozen into the ice-foot structure along the beaches. While very violent wave energy can break up this ice, lesser energy inputs will cause erosion of sand beneath the ice ridges.

BACKGROUND RADIOACTIVITY

With the advent of nuclear weapons testing in the atmosphere and nuclear power installations along the shoreline of Lake Michigan, interest in the radioactivity levels of the lake's waters, biota and sediments has increased. The availability of lake water for cooling purposes has made nuclear plant sites along the shoreline extremely attractive, as they always have been for fossil fuel plants. It should be noted that some radioactive waste is released in the cooling water discharged (University of Wisconsin - Milwaukee, 1972). While the exact levels of radioactive waste have not been revealed, this same report states that they are below Federal Water Quality Standards and that equipment has been installed to "reduce the release of radioactivity to the liquid effluents to a few percent of the above limits." (Ibid., p. ii.).

During 1962-1964, the United States Public Health Service collected a large number of water samples from Lake Michigan and its tributaries in order to determine



HYDROGRAPH OF MONTHLY MEAN LEVELS OF LAKE MICHIGAN

ELEVATIONS IN FEET ABOVE MEAN WATER LEVEL AT FATHER POINT, QUEBEC — INTERNATIONAL GREAT LAKES DATUM

Fig. 2-28

FROM: U. S. DEPARTMENT OF COMMERCE, 1973.

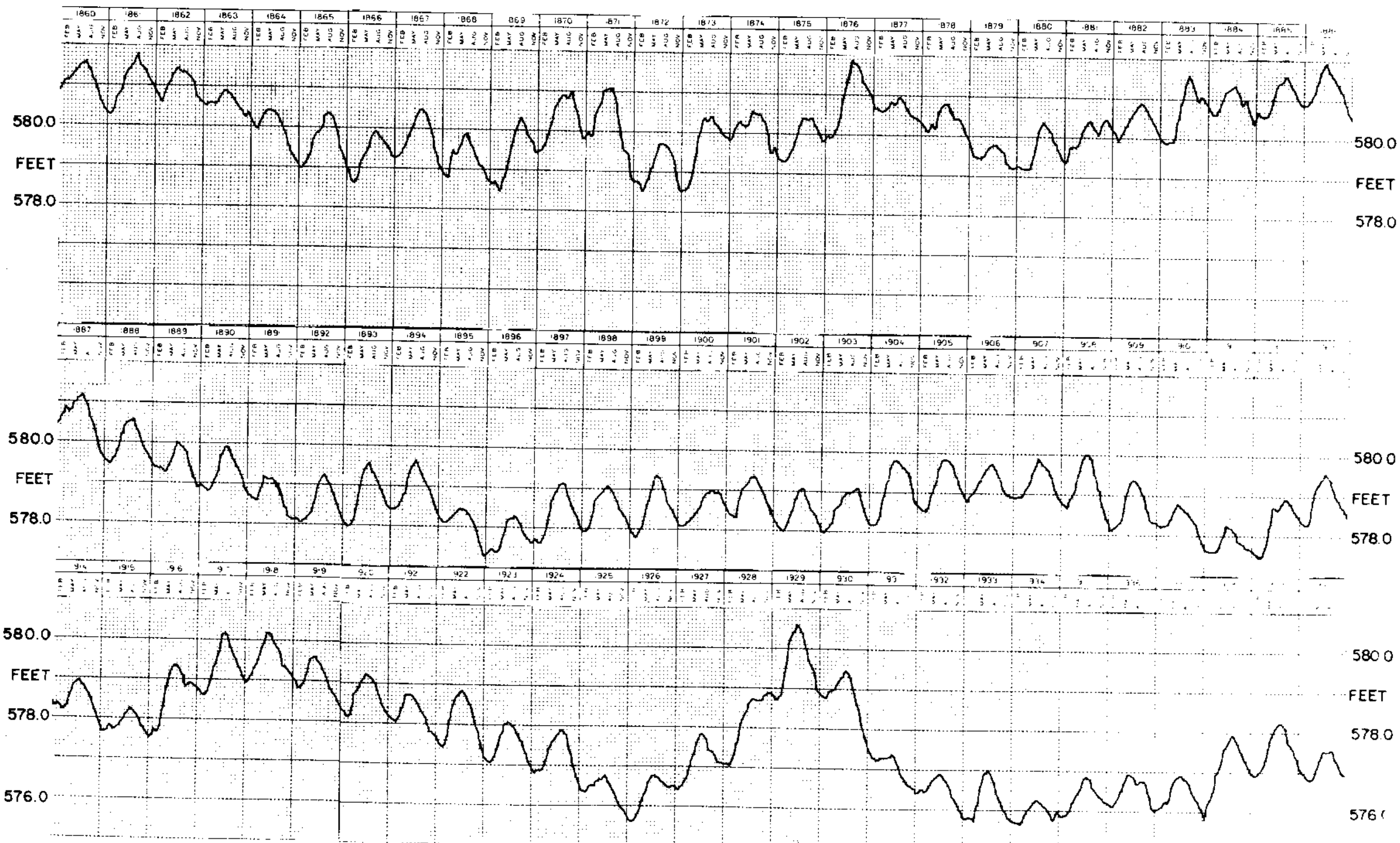


Fig. 2-28

(CONTINUED)

TABLE 2-3 LAKE MICHIGAN WATER LEVELS

Measured from a Base Level of 576.8 Feet

June, 1971	+3.00
July	+3.11
Aug.	+3.06
Sept.	+2.90
Oct.	+2.67
Nov.	+2.42
Dec.	+2.32
Jan., 1972	+2.23
Feb.	+2.08
March	+2.08
April	+2.30
May	+2.86
June	+3.01
July	+3.18
Aug.	+3.38
Sept.	+3.44
Oct.	+3.28
Nov.	+3.22
Dec.	+3.07
Jan., 1973	+3.09
Feb.	+3.12

From: Kewaunee Project Office, U.S. Army Corps of Engineers radioactivity levels in the dissolved and suspended solids. Risley (1965), reporting on this study, noted that 97% of the water samples had alpha-radiation values of 3 picocuries per liter or less. In general, somewhat higher values were found on the eastern side of the lake than on the western side. It was determined that the alpha-radioactivity was concentrated in the suspended solids in the water samples. The source of the alpha-radioactivity in the suspended material has not been determined.

Beta-radioactivity measurements revealed that water samples taken nearshore in southern Lake Michigan had higher beta values than those taken in deeper waters (Ibid.) Average values ranged from 1-15 picocuries per liter. Considerably higher values were found in Green Bay (9-33 picocuries per liter). Beta analyses of the bottom sediments in Lake Michigan, reported by Risley and Abbott (1966), show a range of 1-2100 picocuries per gram. Figure 2-29 shows the distribution of beta activity in the sediments of Lake Michigan.

Radioactivity studies in Lake Michigan near the Big Rock Point Nuclear Power Station (Little Traverse Bay, Michigan) are discussed in Fetterolf and Seeburger (1971) and Nelson, et al. (1971). No determinations were made, however, of radioactivity in the bottom sediments.

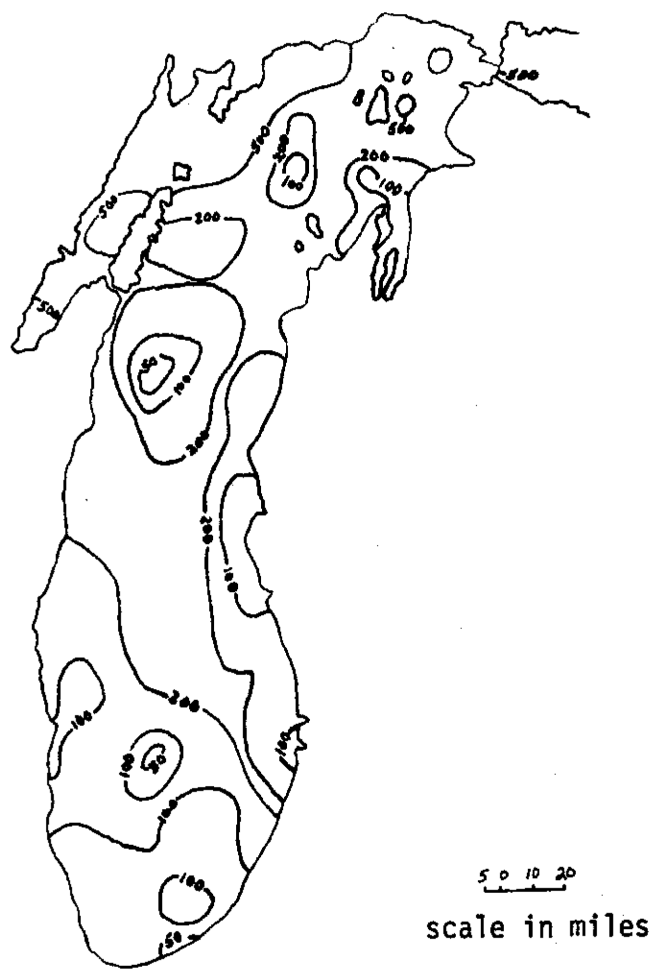
Recently, the U.S. Environmental Protection Agency (1972) has measured the radioactivity of the bottom sediments of Lake Michigan. While they found the gross alpha-radioactivity to range from less than 1 to 10 picocuries per gram dry weight, the beta-radioactivity measurements ranged from less than 10 to 38 picocuries per gram dry weight. The textural types related to these values were not reported.

The most complete measurements of bottom sediment radioactivity levels in the area of Point Beach Nuclear Power Plant were made by the University of Wisconsin - Milwaukee (1972) for the Wisconsin Electric Power Company and the Wisconsin Michigan Power Company. Both offshore and swash zone samples were analyzed after separation into 1 ø size fractions. Levels ranging from trace to 29.04 picocuries per gram are reported, with the higher values generally occurring in the 3 ø, 4 ø, and +4 ø size fractions. No change in radioactivity levels was found during the period 1969-1971.

PHYSICAL CHARACTERISTICS OF THE COOLING WATER PLUME

The interaction of the plume with its receiving water is currently being investigated by a team of Wisconsin Sea Grant researchers under the direction of Dr. Theodore Green III. The pattern of surface temperatures in the plume and surrounding lake waters has been charted on numerous occasions and many temperature measurements have been made to depth. Also, the velocities of the plume water have been measured at the surface and at depth. However, the nature of the interfaces, both beneath the plume and at its sides, is not well known.

While cross-sectional form and velocity structure of the plume, along a line parallelling its direction of travel, is not known in detail, there are indications of its structure from the temperature measurements. It is believed that the plume water sweeps through the entire depth of the water column, and in doing so impinges on the bottom for several hundred feet after leaving the flume. It then begins rising to the surface because of its lesser density than the receiving lake water. It is known that the plume water leaves the bottom and be-



Lake Michigan bottom sediments gross beta radioactivity contours in pc/g.

Fig. 2-29

From: Risley and Abbott,1966.

gins rising to the surface at varying distances from the end of the outfall structure. (S. Roffler, personal communication, 1973). On what this distance depends is not understood. Further, it is believed that this distance is usually on the order of 400-500 feet from the end of the flume, but no data on the frequency of any particular point of separation from the bottom is available. It is the opinion of the researchers studying the structure of the plume that as the warmer water leaves the bottom, a reverse current is set in motion underneath it (S. Roffler, personal communication, 1973). If this indeed occurs, it would be due to entrainment of the receiving lake water by the plume from below. As lake water is removed from beneath the plume by entrainment and swept lakeward by the plume, it must be replaced. Thus, a reverse current would be set up. (Fig. 2-30)

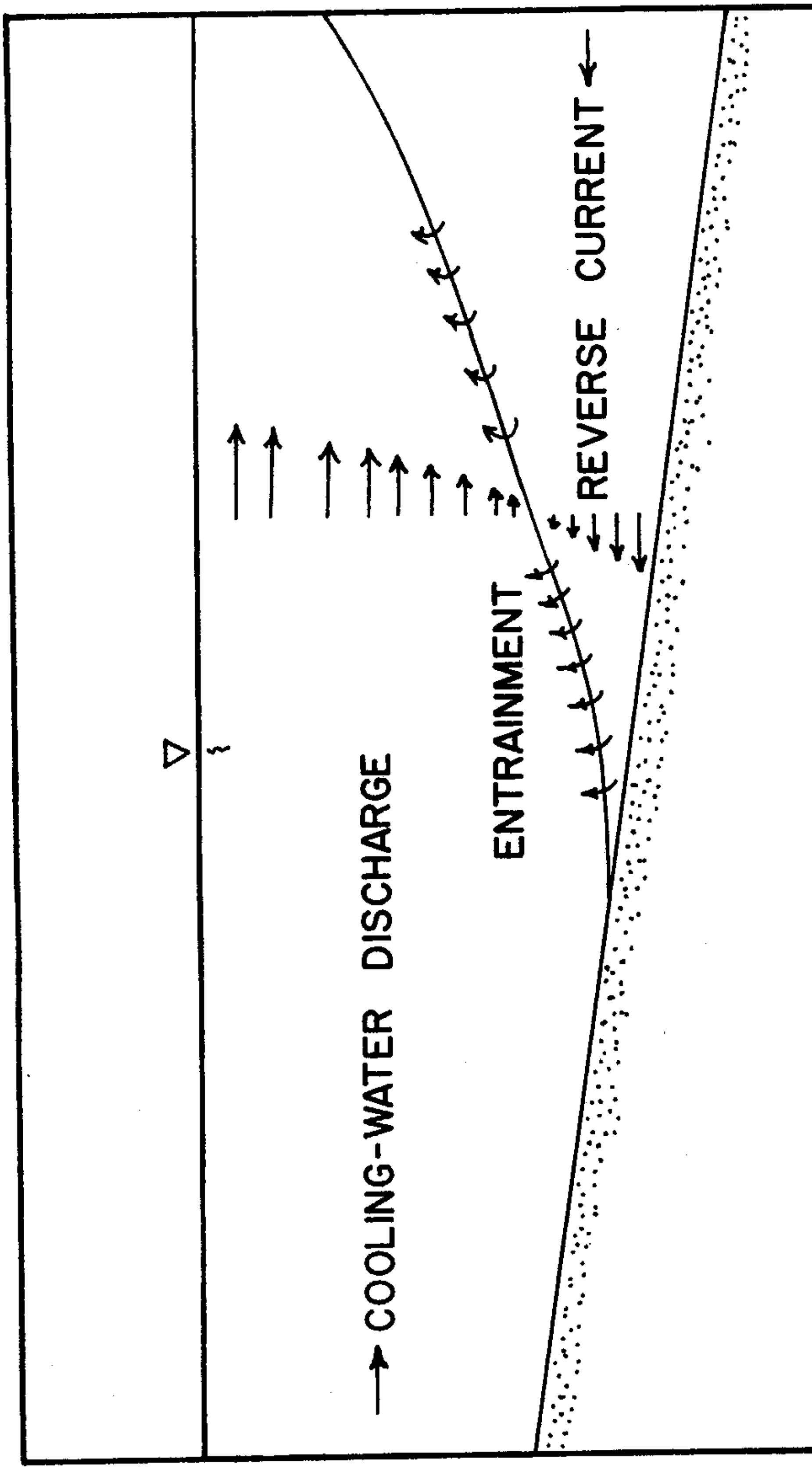
While the nature of the side interfaces of the plume is unknown, aerial photographs show the relations at the surface between the turbid littoral receiving water and the clearer plume waters. Several aerial photographs taken in early April, 1972 are reproduced in Figures 2-31 through 2-33. During the time these photographs were taken, the littoral current was moving toward the south.

The aerial photographs show that the littoral current, as evidenced by the zone of turbid water, hugs the shore far to the north of the power plant. As it moves south, approaching the flume structure, the turbid zone enlarges, spreading lakeward. As it enlarges, it is characterized by turbulent zones extending further out from shore. When the northernmost flume structure is encountered, the turbulent water encompasses the end of the flume. When the flow of turbid water encounters the outflowing plume as it leaves the end of the outfall structure, a sharp interface is formed. As the plume flows out further from the outfall structure, this interface becomes more diffuse. While the northern side of the plume is observable further distances from the outfall, it is characterized by eddies. The plume water can be identified in the aerial photographs for about 100 feet south of the outfall. However, temperature measurements can identify the plume water for as far as a mile from the outfall.

The mixing process of the suspended material in the turbid water and the plume water is unclear. Obviously, the plume water eventually mixes with the receiving lake water. As these two water types mix, their temperatures, densities, and suspended material contents become more equal. However, the rate of mixing of the two water types is not known.

Because the plume has a forward velocity and exists as a discrete water mass for considerable distance from the outfall, water flowing toward it at a right angle as the littoral current does, is deflected in the direction of the flow of the plume. Because all of the water in the littoral current appears not to become entrained immediately in the plume water, and is therefore deflected, the current flowing perpendicular to it appears to be decelerated as it approaches the plume edge.

Large eddies of turbid water, then, as seen on the aerial photographs about 1,000 feet from the end of the flume structure, may be either (1) Turbid littoral current water which has been deflected by the plume flow; or (2) The plume water itself which has entrained enough littoral current water to appear turbid on the aerial views.



THEORETICAL CROSS-SECTION OF COOLING-WATER PLUME

Fig. 2-30

Fig. 2-31 Aerial view of cooling water plume

Fig. 2-32 Aerial view of cooling water plume

Fig. 2-33 Aerial view of cooling water plume

VARIATIONS IN DIRECTION AND VELOCITY OF THE PLUME

Describing the form and velocity structure of the plume is further complicated by variations in the path which the plume follows after leaving the outfall, the volume of water discharged, and its velocity. From July 28 through August 30, 1972, an observer on the outfall recorded the path of the upwind edge of the plume and its velocity from 0600-2100 hours. Figure 2-34 shows the area most oftenswept by this upwind edge. Because the plume is most often bent to the south as it leaves the outfall, it is believed that the longshore transport in the immediate area is predominately to the south. However, on some days the plume bends north. Figure 2-35 shows the paths on several such occasions. During the period July 28 through August 30, 1972, the plume swung northward on nine days.

A second variable of the discharge water is its volume. It varies as a function of three parameters within the power generation system:

1. Gross electrical output. As the amount of electricity generated increases, so does the amount of surplus heat, thereby requiring a greater heat capacity in the cooling system.

2. Thermal output of the reactor system. Efficiency levels of the electrical generating equipment fluctuate so that variations occur in the amount of heat within the closed feed-water system cooling the reactor unit.

3. Cooling water temperature increase. Because the temperature of the discharged cooling water is regulated by State and Federal agencies, the volume of water must be increased as greater amounts of heat are exchanged from the feed-water system to the cooling water. (Petersdorf, 1973)

Table 2-4 lists the average volume of water by month discharged from Unit I. Wisconsin Electric Power Company (Ibid.) supplied these data in gallons per day and this author converted it to gallons per minute.

Changes in the volume of water discharged and changes in the dynamics of the receiving water such as the opposing force of incoming wave energy result in variations in the flow velocity of the plume. These velocities ranged from 90 feet/ minute, with 150, 170, and 200 feet/minute being the most common velocities.

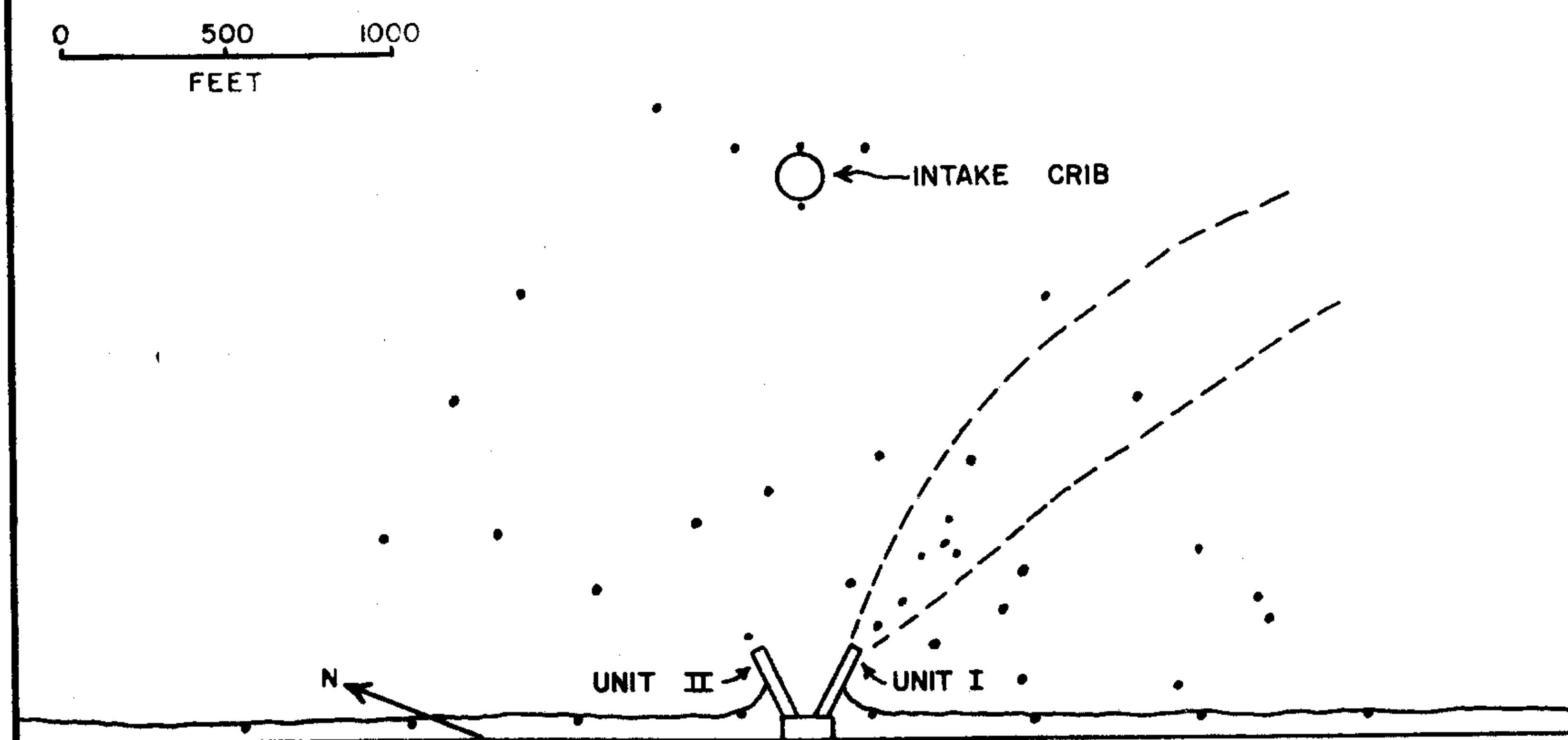


FIG. 2-34 AREA MOST OFTEN SWEPT BY THE UPWIND EDGE OF THE PLUME

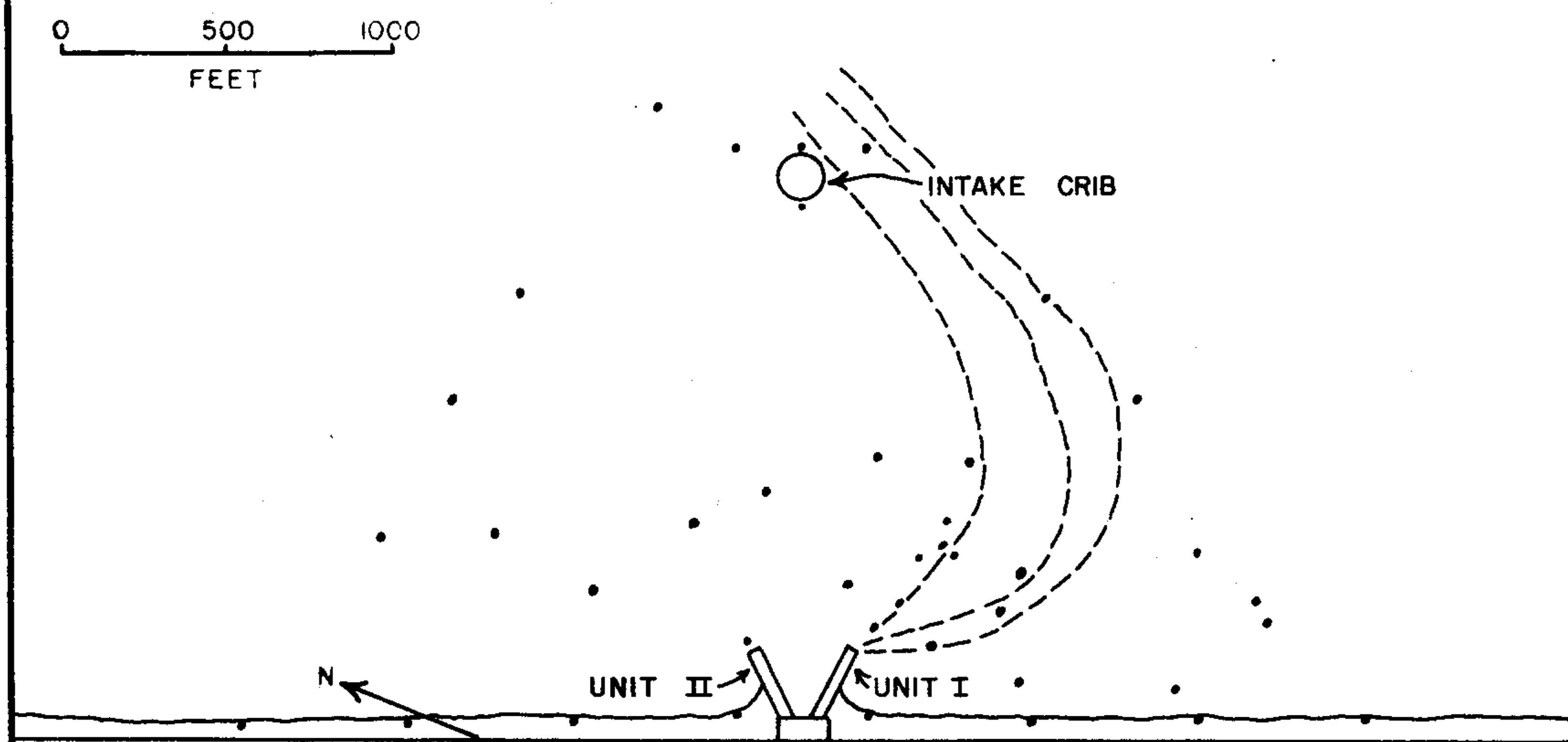


FIG. 2-35 TYPICAL PATHS OF A NORTHWARD BENDING PLUME

Table 2-4 VOLUME OF WATER DISCHARGED - UNIT I

POINT BEACH NUCLEAR POWER PLANT

Month	Volume Gallons Per Minute
November, 1970	236,000
December, 1970	195,000
January, 1971	260,000
February, 1971	291,000
March, 1971	338,000
April, 1971	161,000
May, 1971	303,000
June, 1971	344,000
July, 1971	340,000
August, 1971	344,000
September, 1971	319,000
October, 1971	333,000
November, 1971	285,000
December, 1971	223,000
January, 1972	Not Available
February, 1972	Not Available
March, 1972	210,000
April, 1972	301,000
May, 1972	390,000
June, 1972	397,000
July, 1972	397,000
August, 1972	391,000
September, 1972	391,000
October, 1972	Unit not in operation

From Petersdorf, 1973.

III. TECHNIQUES AND METHODS

This investigation utilized both field procedures and laboratory analyses. Field work centered on the collection of surficial sediment samples in both spatial and temporal sequences. In the laboratory, several parameters were measured to characterize each sample.

DELINEATION OF THE OFFSHORE SAMPLING AREA

Several factors influenced the determination of the geographical limits of the offshore sampling area. Most importantly, a judgment of the possible area of effect of the discharge water plume had to be made. A conservative estimate seemed to be best. A distance of four nautical miles offshore was chosen to delineate the eastern boundary. This included almost all depths of less than 100 feet, and in some areas included depths to 150 feet. That this was an appropriate beoundary was confirmed during the first sampling cruise, when it was found that the sand-muddy sand interface was enclosed by the boundary. Because of the inclusion of this interface, the depths at which the wave and inshore current patterns influence the bottom were quite conservatively included in the study area. Certainly sediment transport by littoral and near-shore lake current mechanisms along the coast could be discovered in this area.

To the north, it became important to interface with a team of researchers from the University of Wisconsin-Green Bay headed by Dr. John Pezzetta, investigating the sedimentary regime near the Kewaunee Nuclear Power Plant, 3-1/2 miles north of Point Beach Power Plant. Because Dr. Pezzetta's research was confined to the beach and nearshore regimes, it was necessary to extend our survey north of the Kewaunee Power Plant. A limit 5 miles (Nautical) north of Point Beach Power Plant was settled upon. To the south, the tip of Rawley Point seemed to be a logical morphological limit for a study of transport. This limit was extended, however, 2-1/2 miles to the south in June of 1972. By doing so, the entire offshore region of the length of Point Beach State Forest was surveyed.

SELECTION OF A SAMPLING GRID

After an area for study was defined, the questions arose of how many samples were necessary to describe the surficial sediment pattern therein, and how often a complete survey was necessary to detect any significant change in the sediment pattern, without interference from the natural variability of the "background". Or, having defined the limits of the population, how many samples with what spacing were necessary to characterize that population.

How closely and in what pattern then, do samples need to be taken to obtain a meaningful idea of the sediments? Communication theory has several concepts which apply here. The band width is defined as the range of frequencies of a signal, the frequencies being the reciprocal of the period of a sine wave or the number of peaks per second. In sedimentology, the frequency can be interpreted simply as the rate of change or the natural fluctuations of the system, in space or time. If the bandwidth is W, then the time 1/2 W is called the "Nyquist Interval" (Nyquist, 1928; Young, 1971). To measure the nature of the signal, it is necessary to sample once every 1/2 W seconds, or once during each Nyquist interval. Young (1971, p. 69) wrote that, "It is not necessary for the samples to start from zero time or even for them to be equally spaced in time at all, provided that there is one sample at some known point of time within each interval 1/2 W seconds.

Of the several well-known sampling patterns known to statisticians, two fit this criteria of one sample within one equal time interval. Systematic sampling is a method in which the samples are equally spaced, one within each interval. Stratified random samples are taken at unequal spaces, but still with one and only one sample per interval. (Krumbein and Graybill, 1965). See Figure 3-1.

While the rate of change of offshore sediments is not known until they are sampled, previous experience can be used to judge the probable rate. Also, it is better to sample too often, at the beginning at least, before defining the interval, than to miss variations completely. Hence, a sampling grid was established in which east-west transects were made at 1/2 mile north-south intervals. Transects along which samples were taken at 1/4 mile east-west intervals alternated with those with a 1/2 mile spacing. Figure 3-2 shows the pattern of the first sampling grid. Each east-west transect measured the changes encountered with change in depth and with distance from shore, while the series of transects measured the changes along the coastline. While the method of systematic sampling was the objective and was approached, the method of stratified random sampling was in fact used.

It is well known that oceanographic stations may not be precisely where they are shown on the charts, although this situation has improved considerably with the advent of a variety of electronic navigation devices. ITT Decca Marine (no date) reports that its radar unit, Model RM316, installed on the vessel used in this study, has an accuracy of 1% of the range or 50 yards, whichever is better. It follows that those stations 1/4 mile from shore are actually somewhere within a circle of radius 5 yards, while the stations 4 miles offshore are within a circle of radius 50 yards. This becomes important when patchy bottoms are encountered, where 100 yards can mean the difference between retrieving a well sorted sample and retrieving a very gravelly sand.

SEQUENTIAL SAMPLING

Sequential sampling of the area followed somewhat the criteria for sample spacing, but important constraints were present. As no winter use of the AQUARIUS is possible, the surveys had to be accomplished during the summer field season, May through November. During the first field season, 1971, three surveys were taken to define the short term variability of the system, while one complete survey was taken during 1972, with attempts to complete a survey in November, 1972. The dates of offshore surveys are shown in Table 3-1.

SAMPLING EQUIPMENT

The R/V AQUARIUS, the University of Wisconsin research vessel, was used as the platform for all sampling. Figure 3-3. This shallow draft 41-foot boat was ideally suited to working in the shallow and intermediate depths in the area.

All offshore samples were taken with a Shipek Sediment Sampler (Hydroproducts). (Figure 3-4.) This device is a spring-loaded grab sampler. It will retrieve a surficial sample from sand, clay, mud and gravel bottoms. Depth of sample secured varies from the top four inches from sand bottoms to just a surface scrape from desiccated clays. There were no wash-out problems in the water depths encountered in the study area. Upon sample retrieval from the bottom, all

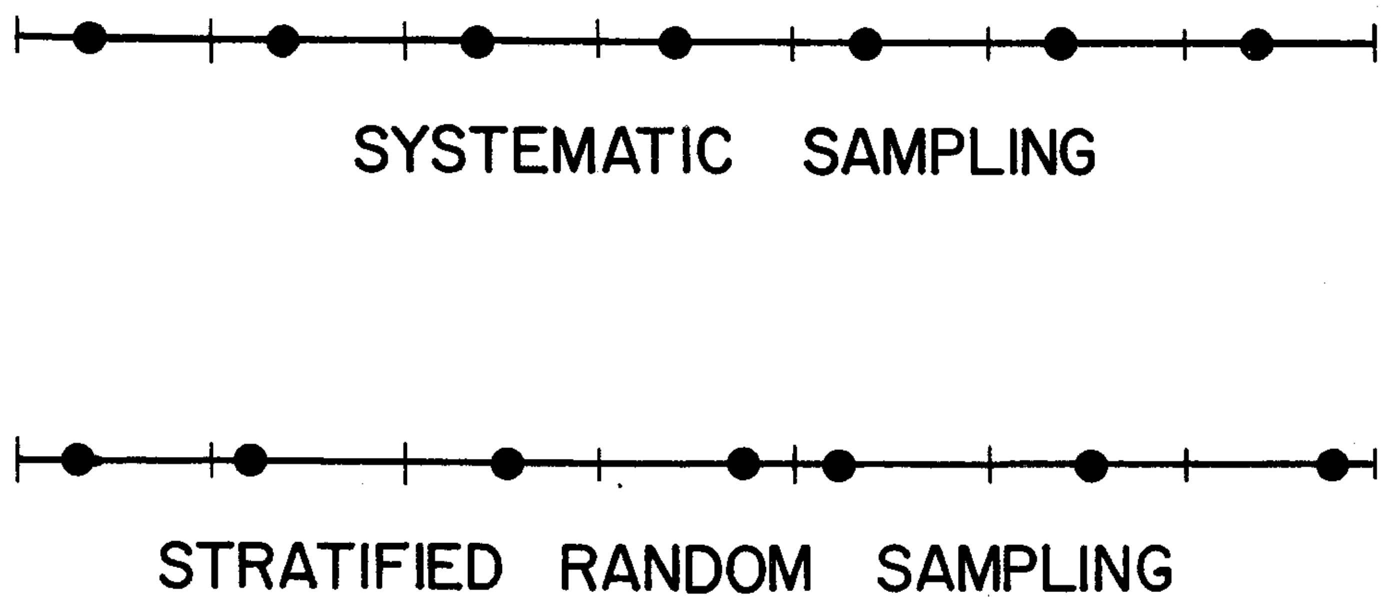
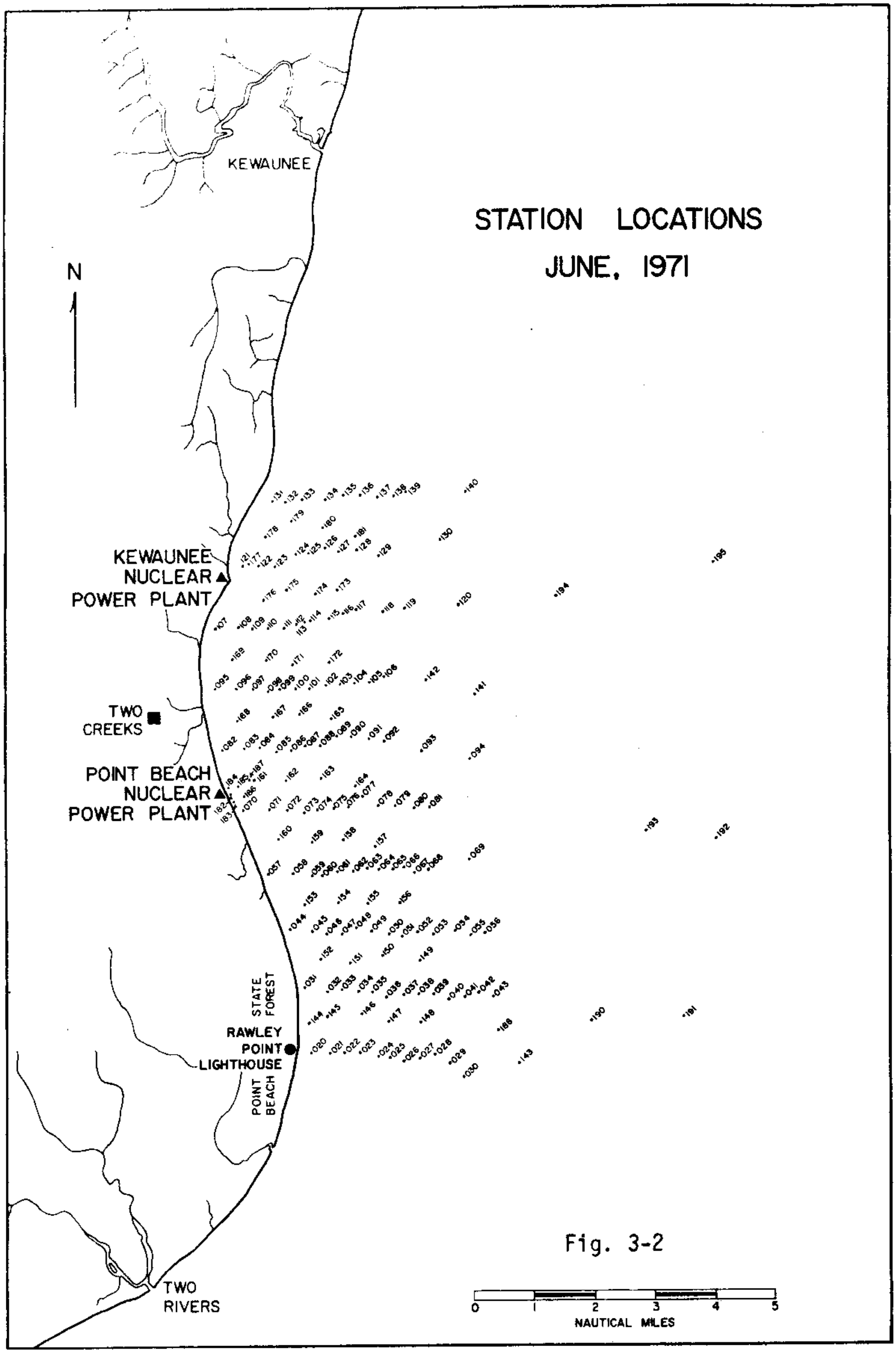


Fig. 3-1 FROM KRUMBEIN AND GRAYBILL, 1965.



STATION LOCATIONS
JUNE, 1971
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 3-2

Table 3-1 DATES OF OFFSHORE SAMPLING

June 2 through June 8, 1971
July 26, 1971
August 19 through August 21, 1971
May 29 through June 8, 1972
November 27, 1972

Fig. 3-3 R/V AQUARIUS

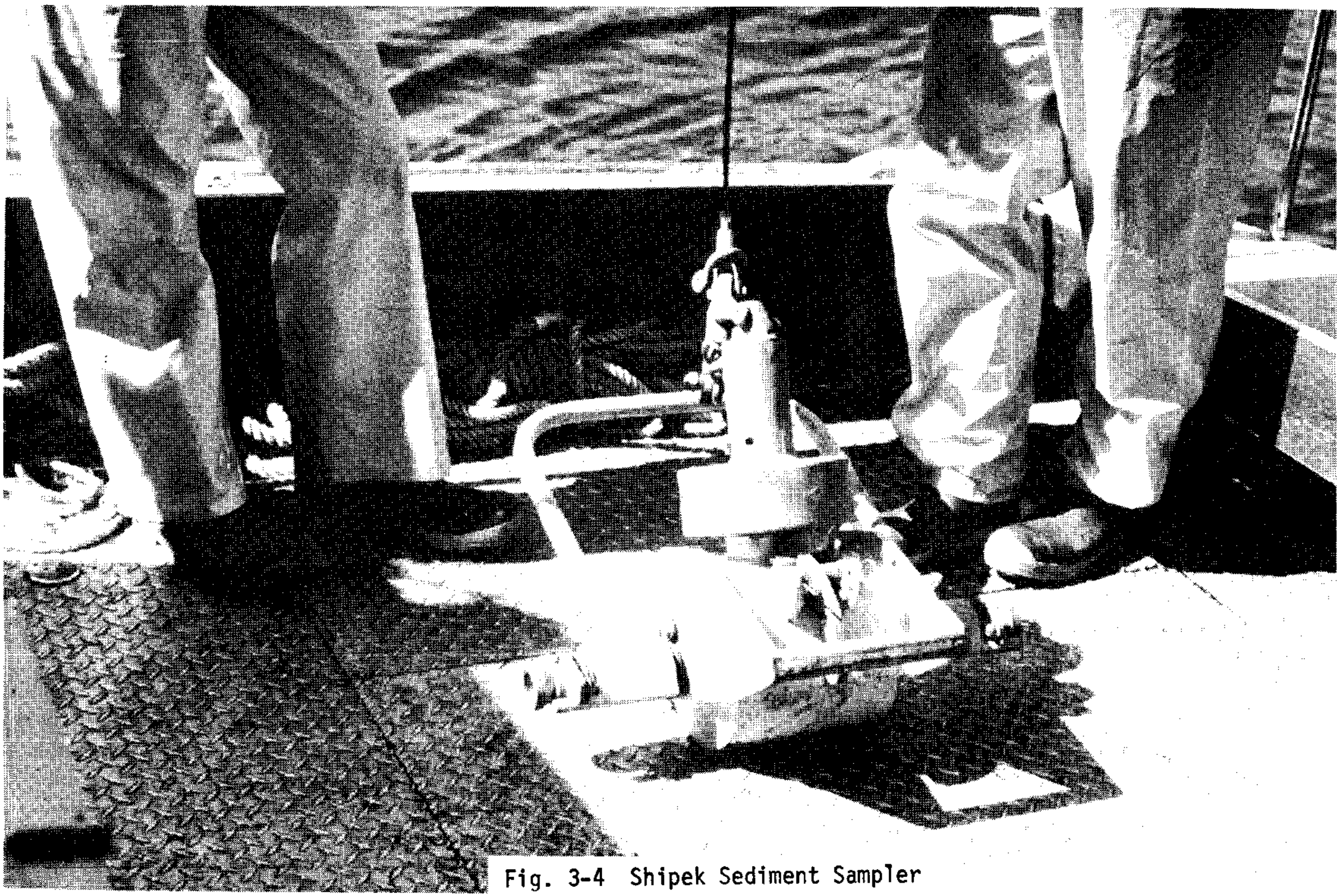


Fig. 3-4 Shipek Sediment Sampler

samples were placed in heavy duty plastic bags for temporary storage and returned to the Marine Research Laboratory in Madison.

Because it was believed that large rocks covered the bottom in patches in the northern part of the study area, an additional sampler was necessary. A large, very heavy duty chain drege was constructed. Figure 3-5. This device consisted of a rectangular steel head with a chain bag at the back. Thus, the head dislodged the rocks from the bottom and the bag collected them. This chain bag dredge was dragged along the bottom for only 100-150 feet at each sample station. In most cases, these rocks were measured, described, and thrown overboard.

No cores were taken. The sandy and desiccated clay bottoms in the study area precluded this type of sampling.

BEACH PROFILE SITES

A program of beach sampling and profiling was initiated to complement the offshore surveys and to monitor the interface between sea and land. The amount of erosion was thus measured and the quantity of material added to the sediment system of the lake along this stretch of shoreline was determined.

Nine beach profile sites were originally selected in August, 1971. Their locations, as shown in Figure 5-3, coincided with the inshore ends of the offshore sampling traverses. This resulted in profiles being taken every 1/2 mile from Rawley Point Lighthouse to 1/2 mile north of the Point Beach Power Plant. No profile site was established immediately south of Point Beach Power Plant because rip-rap had been installed and no beach of any sort exists.

On October 21, 1971, six foot steel fence stakes were cemented into both the bluff behind the beach and the beach itself to permanently mark these sites. A hole 2 feet deep was dug with a post-hole digger. After the stake was put into place, very coarse gravel was put into the bottom of the hole, and a sand, pebble, and cement mixture was poured into the hole to form a large concrete plug. Sand and/or sod was used to cover the concrete. It was anticipated that these would stay in place and could be used as profile site locators in the years to come. Six sites were thus marked. The three sites in the State Forest were not marked because of the problems inherent in so marking beaches bordering state recreational areas. This was not deemed serious, however, as permanent landmarks were abundant.

The rate of erosion was greater than expected. During the first winter beach reconnaissance, it was discovered that both the bluff and beach stake from Profile Site D were gone. Table 3-2 summarizes the introduction and erosion of the profile site markers. Inspection of the bluff showed that considerable erosion had indeed taken place as evidenced by a number of trees which had fallen onto the beach proper. The remainder of the stakes were intact during the winter.

In April, 1972, a new stake was cemented into the bluff at this profile site. By June, 1972, it too had been washed away. (Fig. 3-6)

In April, 1972, one beach profile site, located at Two Creeks Boat Access, 1-1/2 miles north of Point Beach Power Plant, was added.

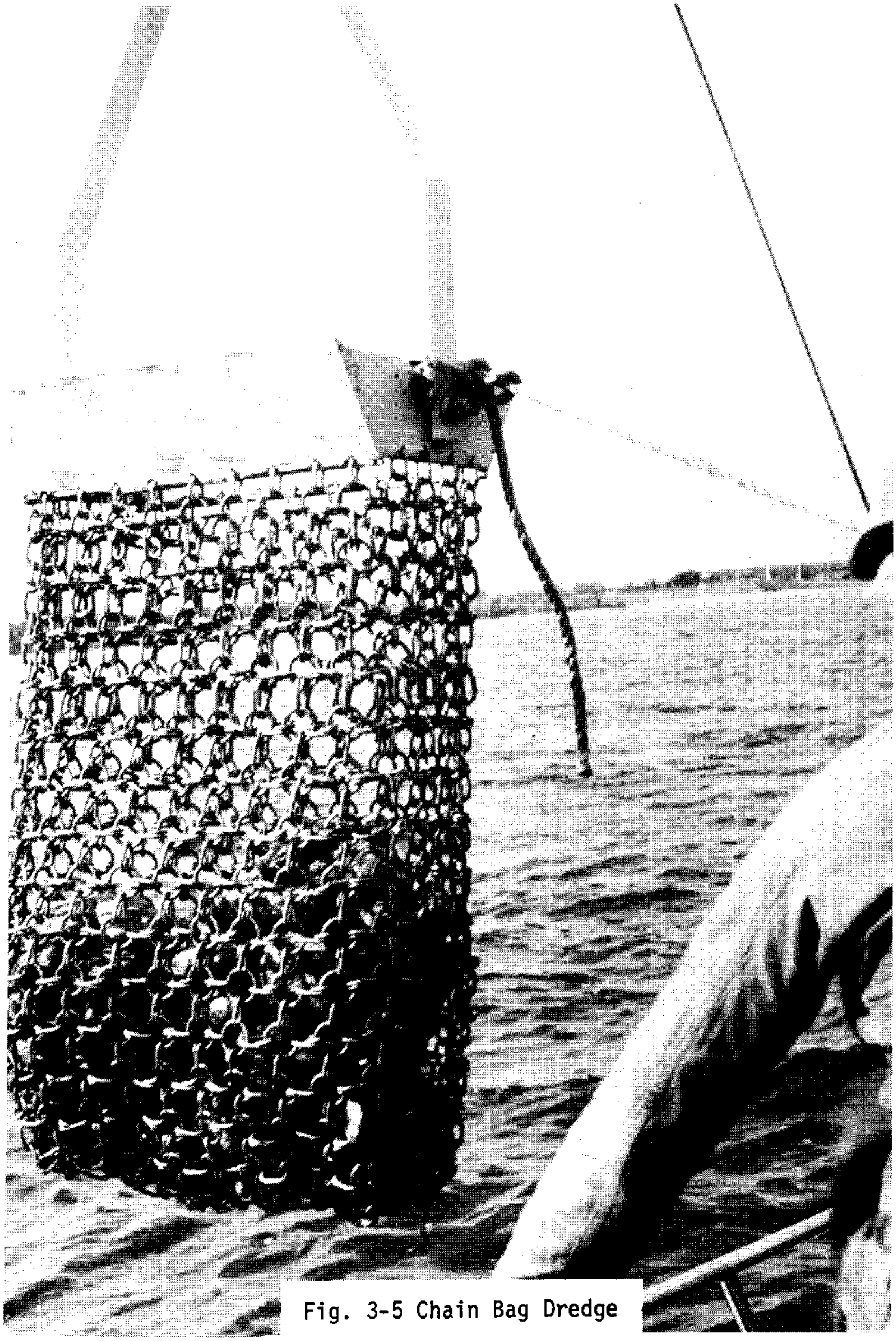


Fig. 3-5 Chain Bag Dredge

TABLE 3-2 — PROFILE SITE MARKERS

	Oct. 21, 1971	Jan. 3, 1972	Feb. 16, 1972	April, 1972	June, 1972
Site D	Two Stakes 1 - Bluff 1 - Beach	Both Missing	Both Missing	New Stake Put in	New Stake Missing
Site E	One stake on Beach - Old Boat Launch on Top of Bluff Used as Second Landmark	Intact	Intact	Intact	Intact
Site F	Two Stakes 1 - Bluff 1 - Beach	Intact	Intact	Intact	Intact
Site G	One Stake on Beach	Intact	Intact	Intact	Intact
Site H	Two Stakes 1 - Beach 1 - Bluff	Intact	Intact	Intact	Bluff Stake Intact - Beach Missing
Site I	Two Stakes 1 - Beach 1 - Bluff	Intact	Intact	Intact	Intact
Site J					

	July, 1972	September, 1972	October, 1972	November, 1972
Site D	New Stake Missing	New Stake Missing	Three Stakes 1 - Beach 2 - Bluff	Intact
Site E	Intact	Missing Stake and Old Boat Launch	One Beach Stake Put in - Bird Bath on Top of Bluff as Landmark	Stake Missing - Bird Bath Intact
Site F	Intact	Both Missing	Three Stakes 1 - Beach 2 - Bluff	Intact
Site G	Intact	Intact	Intact	Intact
Site H	Intact	Missing	Three Stakes 1 - Beach 2 - Bluff	Intact
Site I	Intact	Missing	Three Stakes 1 - Beach 2 - Bluff	Intact
Site J			Three Stakes 1 - Beach 2 - Bluff	Intact

Fig. 3-6 Beach erosion

By September, 1972, all of the original stakes, with the exception of the one beach stake at Site G, had been eroded away. On October 26, 1972, another set of stakes was cemented into the beach and bluff at the six sites previously marked, along with a seventh at the Two Creeks Boat Access. All remained stationary through the November profiles.

BEACH SAMPLING AND PROFILING

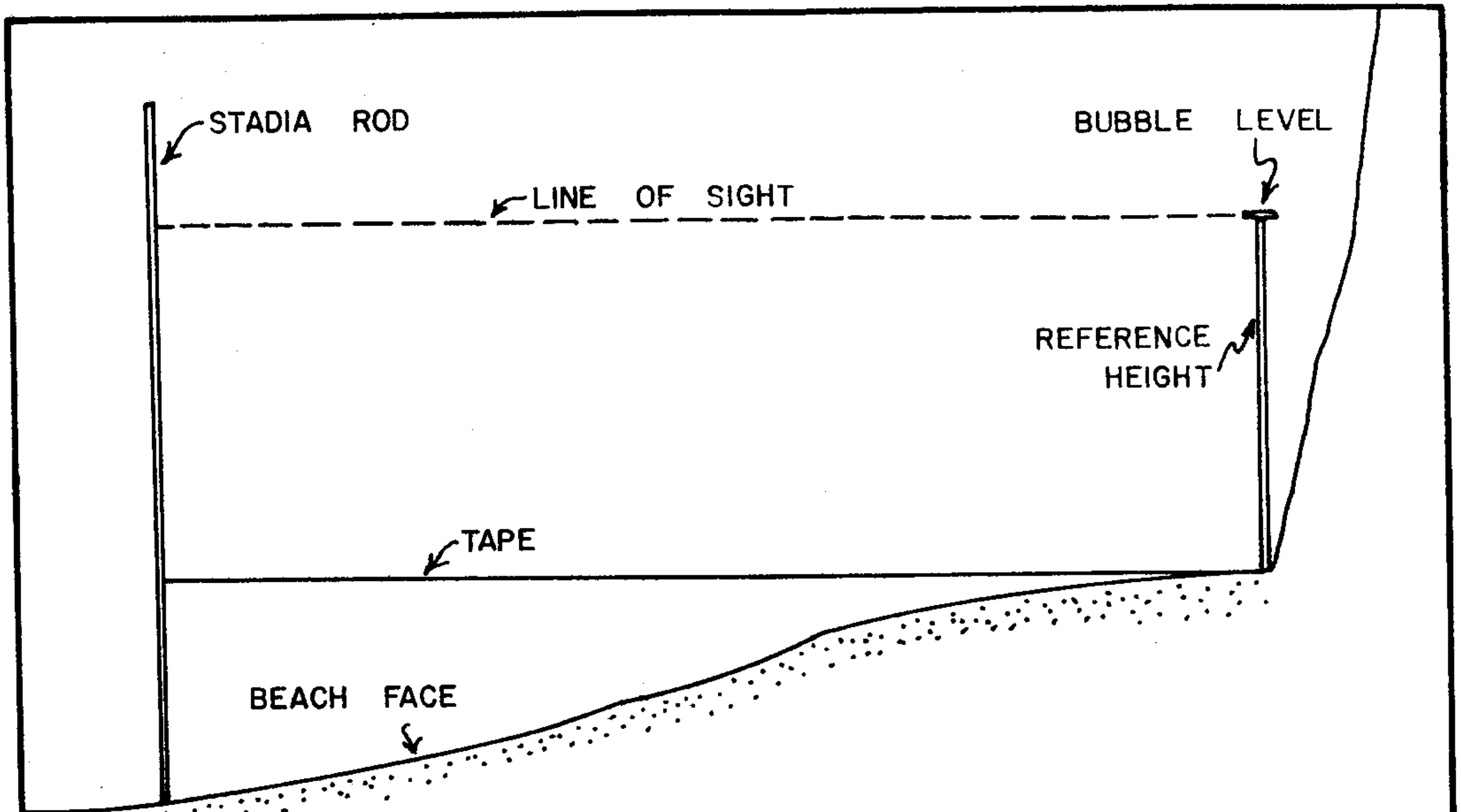
At each selected profile site, the slope of the beach and the texture of the beach material was measured. A simple triangulation method was used to determine the slope while surficial sampling allowed laboratory textural analysis of the beach material.

Each profile was taken using a simple hand bubble level, a stadia rod with tenth of a foot gradations, a steel tape, and a five foot reference rod. The steel tape was used to measure horizontal distances perpendicular to the shoreline across the beach while the five foot rod was used as a reference point on which the bubble level was held at the head of the profile. Figure 3-7 illustrates this triangulation method. The hand level was held on top of the five feet reference rod at the beginning point of the profile. At a short distance from the reference rod, as measured by the steel tape, the stadia rod was held upright. By sighting through the bubble level and by centering the bubble, vertical distance on the stadia rod could be measured. This level point and the horizontal distance at which it was measured was recorded. In addition, a surface sample was taken at the point on the beach where the stadia rod was held. This procedure was repeated at increasing distances towards the water resulting in a set of triangulations which, upon reduction, equalled the shape of the beach slope. Taken together with the textural analysis of the surface samples, this information was used to characterize the beach.

When a cemented stake was present at a profile site, the reference rod was placed right next to it. If no stake was present, as in the cases of the profile sites in the State Forest, the profile was begun at the vegetation line. Taken together with the water line measurements and the change in water level information as recorded by the Corps of Engineers in Kewaunee, a comparison could be made of beach slopes from one month to the next.

The horizontal distances at which the vertical measurements, and hence the surficial samples for textural analysis, were selected subjectively by the profiling team. In all cases, the horizontal interval was altered with changes in the nature of the beach slope. In general, all of the highs and lows of the beach were measured, along with the water line point. If the slope appeared to be irregular, very short (two-three feet) horizontal intervals were used for placement of the stadia rod. If, on the other hand, the beach slope was gradually sloping without notable ridges or textural changes, a longer interval was used. In all cases, the same interval was not used throughout one particular profile but varied according to conditions.

Surficial sediment samples were taken from the top one-half inch using a dust pan. Each sample thus represented the very last material deposited on the beach and that material which was currently in equilibrium with the physical regime and the morphology of the beach. Using a dust pan allowed the field worker to take not only a very shallow skim of the surface, but also to take the sample



BEACH TRIANGULATION

Fig. 3-7

from a very restricted area, one square foot of beach surface or less. Samples were stored as for the offshore samples, in heavy duty plastic bags.

BEACH SEQUENTIAL SAMPLING

Beginning in August, 1971, each profile site was periodically surveyed and sampled. This was done in order to recognize temporal changes in the nature of the beaches to complement the sequential offshore sampling. Profiles were taken on August 16, 1971; April 17; June 3; July 5; September 18 and November 27, 1972. While no profiles could be taken during the winter months because of the ice cover on the beaches, two winter reconnaissance trips were made on January 3 and February 16, 1972 to view and photograph the ice conditions. The only other constriction on this mode of sampling was the weather conditions on the days set aside for profiling. On several occasions, severe storms came up which necessitated eliminating one or two profiles from the series. As each profile series was meant to convey a synoptic picture of the stretch of beach, it was not feasible to return after the storm to take the missing profiles.

CURRENT MEASUREMENTS

Longshore currents were measured using drogues which were suspended to a depth of six feet (bottom end of drogue) into the water. The drogues themselves consisted of four vanes of aluminum sheeting at right angles to each other, attached by a line to a float. The almuninum sheets were three feet high. A line fifteen meters long was tied to the drogue and then to one of the buoys near Point Beach Power Plant. The period of time necessary for the drogue to drift to the full extent of the fifteen meter line was measured along with direction of drift.

DYED SAND EXPERIMENT

The movement of surficial sand near the discharge water outfall was investigated in a tracer sand experiment. Colored sand was chosen as a tracer over radioactive tagged methods because of the legal difficulties involved in putting radioactive material in the lake in the vicinity of a nuclear power plant still trying to demonstrate its environmental safety, and also because of the complicated instrumentation needed to determine the location of the tagged sand after dispersion.

Ingle (1966) discussed several methods of dyeing sand. This author first tried a technique using agar-agar as a binder and Anthracene (yellow-green) as a fluorescent dye. Two hundred pounds of sand, predominately in the fine sand class and thus compatible with the offshore sediment, were collected from the beach in the study area. This sand was blended with the Anthracene dye (0.1 kg. of dye per 100 kg. of sand) in a large mixer, and a solution of agar-agar dissolved in water was added. Following thorough mixing, the sand was allowed to dry. Upon examination of the sand under the microscope, it was found that the dye had not adhered to the grains.

A second attempt was made using the same binder and process but with a yellow-orange non-fluorescent dye called Primulene. Examination showed that while the dye appeared to adhere to the grains, the color was not obviously different from undyed mineral grains found in the area. While this dyed sand was somewhat satisfactory, it was not as excellent a choice as possible.

Another attempt to dye the sand was made again using Anthracene dye but utilizing chloroform as a binder, a technique also described by Ingle (1966). A solution of 17.6 grams of Anthacene in one liter of chloroform was mixed with the sand, which was then dried. Again, inspection proved that this technique did not work.

Finally, spray paint (Glidden Blue) was used to color code the sand (Ingle, 1966). The grains were repeatedly sprayed and mixed, then rolled out to thoroughly disaggregate them. While this method did allow a very thin film of color to be deposited on each grain, it is not recommended because high surface-to-mass ratios in sands of this size necessitates many man-hours to accomplish the dyeing process.

The results of these dyeing attempts were fifty-five pounds of yellow-orange sand and one-hundred pounds of blue sand.

July 19, 1972 was selected for the commencement of the tracing experiment. This proved to be a poor week to conduct an experiment of this sort because of very dense fog coupled with a virtually flat sea. Nevertheless, the sand was injected at two points, the blue color being placed between buoys 7 and 8 (see Figure 3-8) south of the outfall and the yellow north of the outfall between buoys 13 and 14 and between buoys 1 and 2. By slitting a small hole in the plastic bags containing the coded sand before lowering them to the bottom, the sand was deposited directly on the sediment surface when the bag was sharply pulled back up. Time of sand placement was 0900 for the blue and 9020 for the yellow. Sampling began immediately afterwards.

Ingle (1966) recommends the use of 3" x 3" pieces of white poster board coated with vaseline and then pressed against the sediment surface. This technique allows only the surface of the sand to be sampled. Three separate crews were assigned to sample the beach, the nearshore regime, and the intermediate waters near the intake crib. The beach team used rods with square wooden mounts at one end to press the vaseline-coated cards onto the sediment just below the water line. The second crew in a small boat attached their cards to the bottom of a small weight which was lowered to the sediment surface. Using a similar sampling device, a third crew sampled near the outer buoys.

Beach sampling was hindered by rip-rap, installed to protect the shoreline, which extended down to water level. These large cement blocks made travel along the beach south of the outfall slow and treacherous. Offshore sampling was slowed by dense fog which made it very difficult to locate the buoys marking the sampling position.

Upon completion of the experiment, which lasted three days, each sample card was microscopically examined and the sediment classified into the standard Wentworth size classes (Wentworth, 1922) in addition to inspection for colored grains.

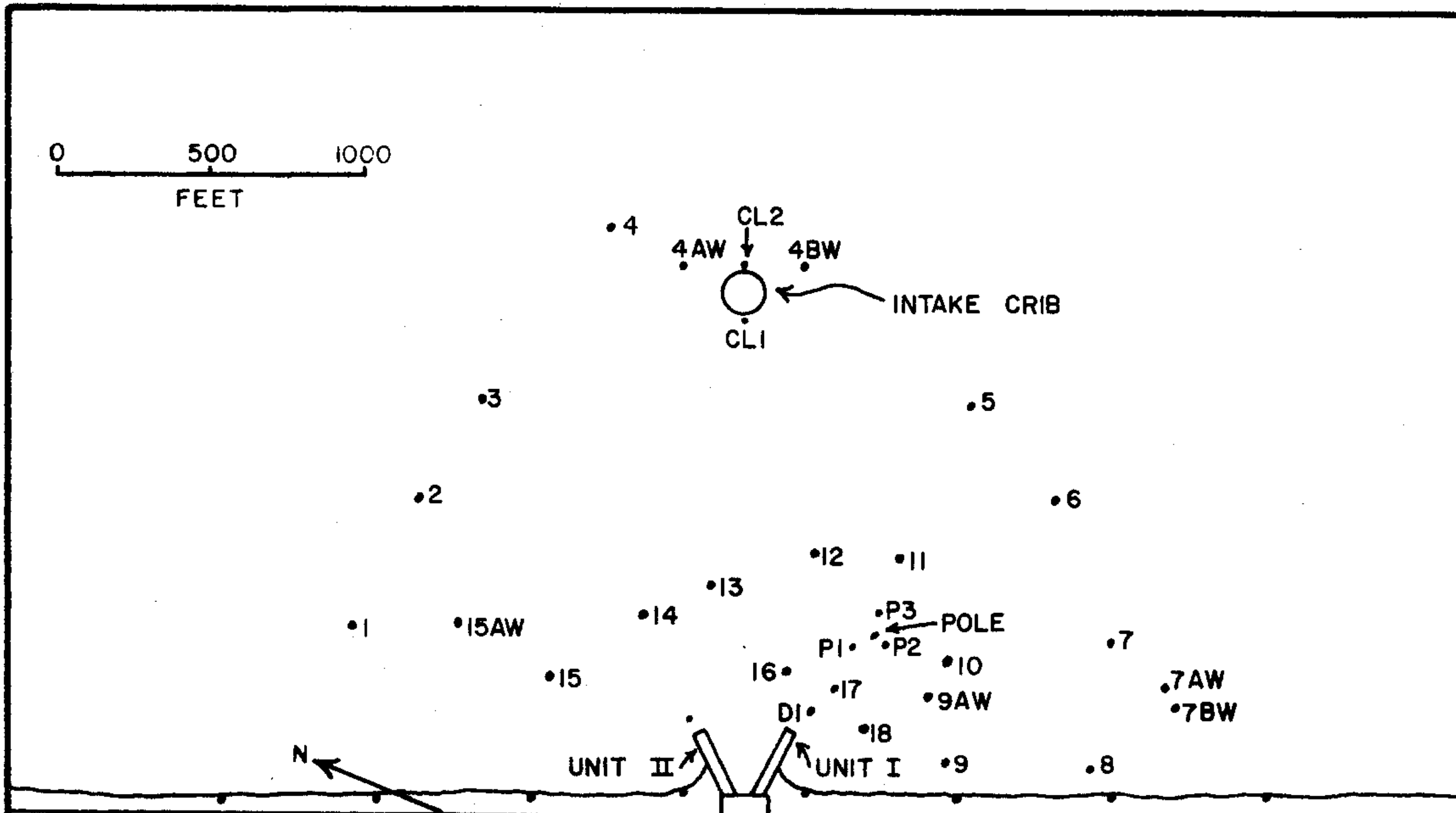


FIG. 3-8 BUOY LOCATIONS – DYED SAND EXPERIMENT

SAMPLE PREPARATION

A standard procedure was used in the laboratory for processing both beach and offshore bulk sediment samples. Each sample bag was cut open and laid flat so that the sediment inside could be spread out for rapid air-drying. Periodic stirrings of the sample speeded the drying process, and most samples dried within five days.

After drying, samples were placed in 32 ounce glass jars with screw-on lids. Each sample was clearly marked with masking tape, both around the jar and on the lid. bearing the sample number and the date of collection. If the volume of sample exceeded the capacity of one jar, the remainder was placed in a second, identically marked jar. Both sample numbering tags were noted to show the existence of a twin storage jar.

Exceptions to this drying procedure were made for the clay material dredged from offshore. These samples were put immediately into their storage jars.

Three cuts were made of each sample. To take a statistically significant section of a large volume of sample, a Humboldt Sample Splitter (Model G-3980) was employed. This device divides the sample into two equal parts. By repouring the sample through the splitter, the desired size cut is obtained. If any clumps of sand were formed during the drying process, these were lightly disagregated with a rubber stopper. In the case where the original bulk sample was stored in two jars, both of these containers were emptied through the sample splitter to ensure that a representative cut was obtained.

TEXTURAL ANALYSIS

Textural analysis leads to a set of statistical parameters which describe the distribution by weight of particle size within a bulk sample. Such descriptions are useful in determining the processes and environments of deposition and in determining the relationships between samples from a particular area.

For textural analysis, a cut of 50-75 grams was used if the material was sand-sized. Up to 200 grams were used if the sediment was pebbly and for bimodal samples in which the sand was mixed with cobbles. The cuts were weighed to 0.01 grams and placed in four ounce glass jars.

Textural analysis was completed using a nest of U.S. Standard Sieves and a U.S. Tyler Sieve Shaker (Model 10309). One-half phi intervals were used from -2.0ø (4mm.) to 4.0ø (0.062 mm.). Table 3-3 lists the relation between phi size and the Wentworth size classes (Wentworth, 1922). For samples composed in part by cobbles, a sieve of -6.0ø (64 mm.) mesh was added. After shaking for fifteen minutes, the particles on each sieve were cleaned off with a brush and weighed to the nearest 0.01 grams. Weights were recorded on standardized data sheets.

A computer program was developed for reduction of the sieve weights into useable statistical parameters. Given the weights retained on each sieve, the computer linearly interpolated between points to compute conventional moment statistics. Table 3-4 lists the formulas for these parameters. Measures computed included the mean, a parameter measuring the central tendency of the curve; the median or the simple midpoint of the total distribution; the standard deviation (disper-

TABLE 3-3 WENTWORTH SIZE CLASSES

MILLIMETERS	PHI (ø)	SIZE CLASS
		Boulder
256	-8.0	
		Cobble
64	-6.0	
		Pebble
4	-2.0	
		Granule
2.00	-1.0	
		Very Coarse Sand
1.00	0.0	
		Coarse Sand
0.50	1.0	
		Medium Sand
0.25	2.0	
		Fine Sand
0.125	3.0	
		Very Fine Sand
0.0625	4.0	
		Silt & Clay

From: Wentworth, 1922.

TABLE 3-4 MOMENT MEASURES

MEDIAN = ϕ_{50} (Midpoint of Curve)

MEAN $\bar{x}\phi = \frac{\Sigma fm}{n}$

STANDARD DEVIATION $\sigma\phi = \sqrt{\frac{\Sigma f(m-\bar{x}_\phi)^2}{100}}$

SKEWNESS $Sk\phi = \frac{\Sigma f(m-\bar{x}_\phi)^3}{100\,\sigma\phi^3}$

KURTOSIS $K_\phi = \frac{\Sigma f(m-\bar{x}_\phi)^4}{100\,\sigma\phi^4}$

WHERE f = weight percent (frequency) in each grain-size grade present,

m = midpoint of each grain-size in phi values,

n = total number in sample which is 100 when f is in percent.

From: McBride, 1971

sion), known in sedimentology as the sorting, indicating the distribution around the mean; the skewness, the third moment measure which measures the symmetry of the distribution about the mean; the kurtosis, the fourth moment measure which measures the sorting on the outer parts of the distribution curve as compared to the center; and the modes, the size classes which contain more sample by weight than the two size classes on either side of it. The computer then calculated the phi-size at which 84% and 95% of the sample was coarser.

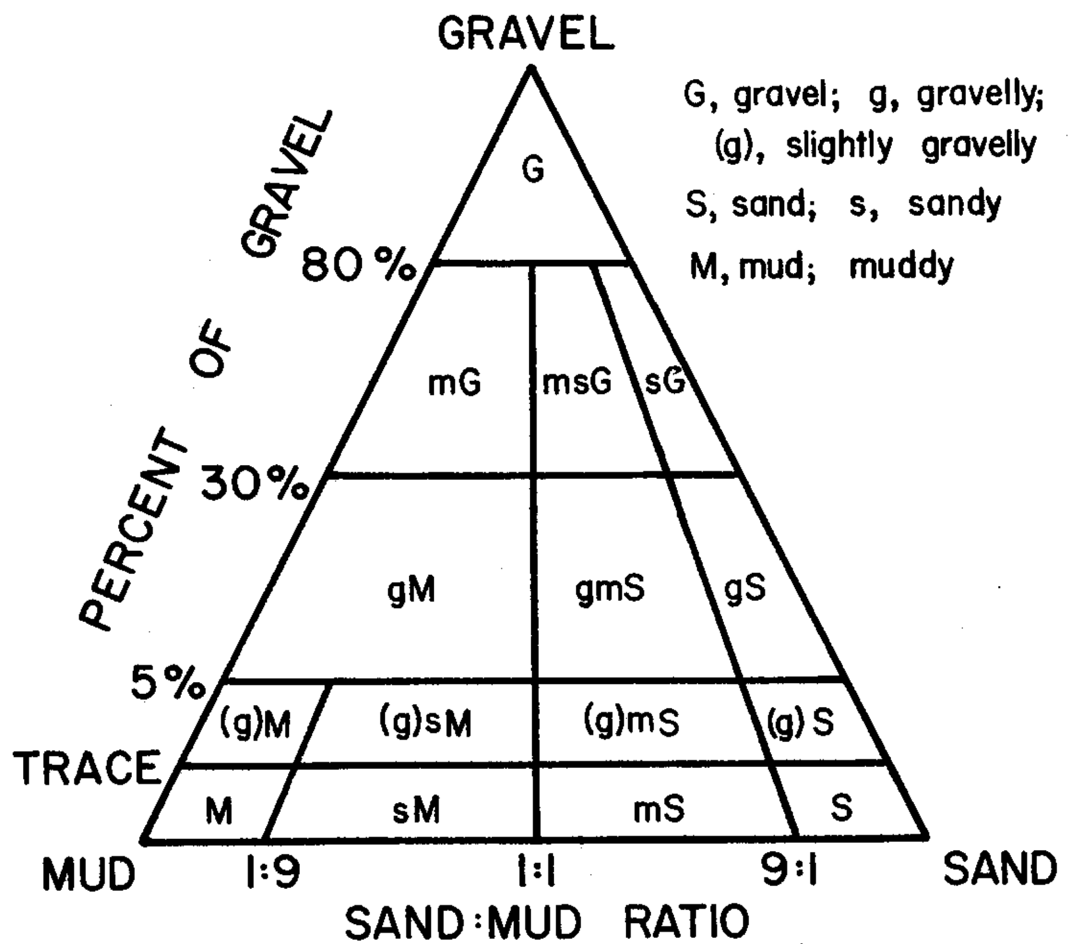
In order that surficial sediment charts might be drawn of the offshore sampling area, a set of descriptive categories was established, a modiifcation of the Folk classification (Folk, 1962). See Figures 3-9 and 3-10. In the classification system used, the three end members of the triangular diagram are sand, gravel and mud. By comparing the two classification system diagrams, it can be seen that the one used in this study is in fact simply a less complicated version of the right hand half of the Folk classigication diagram, plus the category mud. The nature of the sediments in the study area allowed this modification without loss of completeness. Because of the very patchy surficial sediments in the northern part of the sampling area, the categories of the sandy gravel and gravelly sand were combined and the slightly gravelly sand category was eliminated altogether.

HEAVY MINERAL ANALYSIS

Heavy mineral assemblages were analyzed in order to trace dispersal patterns in the area, to identify areas of deposition and erosion, and to determine the source of the sediment. Separating the so-called heavy minerals from a cut of the sample is accomplished using a high density liquid in which the light minerals such as feldspar and quartz will float while the denser particles such as magnetite and the pyroxenes will sink.

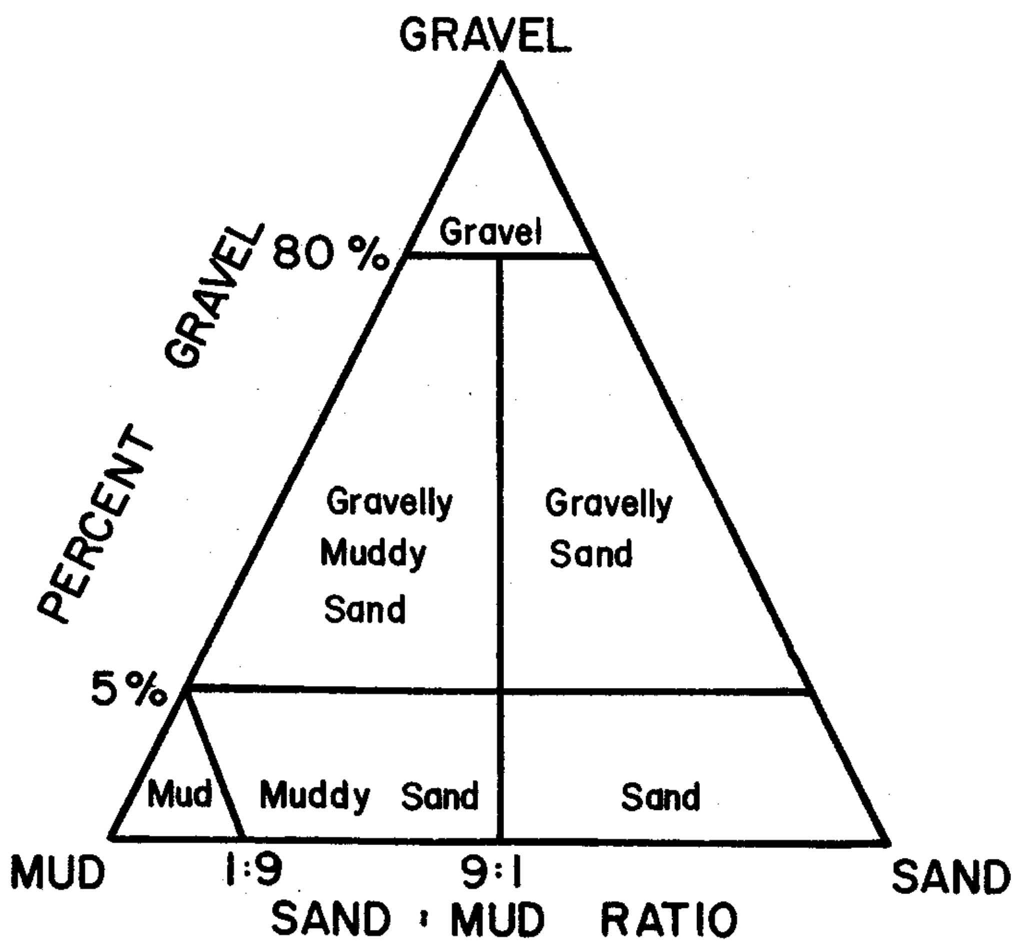
After a cut is split from the sample, it is hand-shaken through a 1ø mesh sieve to remove the coarse sand and larger fraction. A cut with a final weight of between 80-100 grams was obtained. About 400 milliliters of tetrabromoethane (specific gravity 2.97) was poured into a pear-shaped separatory funnel along with the prepared sample. Repeated stirrings facilitated the gravity separation. When the two fractions were completely separated, they were each drained onto filter papers and washed thoroughly with acetone. The dried fractions were then weighed on the filter paper. After the mineral grains were brushed from the filter paper and stored in vials, the filter paper was again weighed. Calculations were made to find the percentage by weight of the heavy minerals in the size fractions used.

In order that the principal minerals in the heavy mineral concentrate be identified and that relative amounts of each of these minerals in the different samples could be compared, x-ray diffraction analysis was done on each of the heavy mineral fractions. A Spex Industries Ball Mill with a tungsten carbide-lined grinding chamber and ball was used to reduce the size of the particles in the heavy mineral concentrate. This is necessary in x-ray diffraction in order that all possible crystals planes will be recorded during the x-ray process. An internal standard of $Al(OH)_3$ was added to each ground sample in the quantity 5% by weight of the total. Before being packed into the sample holder, the mixture was thoroughly blended.



FOLK'S SEDIMENT CLASSIFICATION

Fig. 3-9 FROM FOLK, 1968.



SEDIMENT CLASSIFICATION

Fig. 3-10

An iron x-ray tube was used which generated radiation of wavelength 1.9373 Å. Full scale deflection was 100 counts per second with a scanning rate of 1° per minute from 5° to 60° 2ø.

FELDSPAR STAINING

Characterization of the mineralogy of the sand fraction was important to complete the description of the sediments in the study area and to define the source of the material. A method of selective staining in which the two types of feldspar were differentially colored while the other minerals were left untouched was chosen (Lainz, et al., 1964). This procedure seemed ideal to this study because of the large number of samples to be processed and the large quantities of feldspar and quartz in the samples as compared to any one other mineral. Initial experimentation indicated that the procedure followed did result in the feldspars being differentially colored.

A cut of the bulk sample was prepared for feldspar staining by seperating the grains into the size fractions 0ø and coarser, 1ø, 2ø, 3ø, and the fine fraction. The coarsest and finest were thrown out while the 1,2, and 3ø fractions were mounted on glass slides with Lakeside #70 thermoplastic cement. Care was taken during the mounting process so that the grains rose above the level of the cement on the slide. Each slide was clearly etched with the sample number and size fraction.

Using 52% hydrofluoric acid, each slide was etched for fifteen minutes. This step was accomplished by pouring a small amount of hydrofluoric acid into a small shallow plastic box. Three slides could then be laid over the top, grains face down over the acid, about 1/2 inch over the acid surface. Following a water rinse and a dip into a saturated sodium cobaltinitrate solution for two minutes, rinsed in water and dried under a heat lamp. When dry, a thirty second bath in 5% barium chloride was followed by another water rinse. A compressed air jet was used to rapidly dry the slide surface. An Amaranth solution (1 ounce of F.D. & C. Red No. 2 in two liters of water) was used in the next step. After immersion for forty-five seconds, the slides were quickly dipped in water and the air jet was again used for drying.

The result of these steps was that the plagioclases including albite were stained a bright red, while the potassium feldspars, orthoclases, were bright yellow. Quartz remained translucent.

Using the line counting method, the grains on each slide were classified into five categories; red, yellow, quartz, dark and the other. The line method entails the use of a mechanical stage on a petrographic microscope which allows the operator to move the slide by fixed graduations in either the vertical or horizontal directions.

A line count was begun at one corner of the slide. Moving along in the horizontal direction, the operator identified each grain that was brought under the cross-hairs and recorded the result on a Clay-Adams Laboratory counter. At the end of the slide the mechanical stage was moved in the vertical direction so that a line above the one just counted could be traversed. In this manner unique grains were counted on each traverse until a total count of 300 was reached, resulting in a number frequency of each of the five grain types. Because each slide was mounted with grains within a very close size range, these number frequencies approximated a number percentage. From a statistical evaluation of probable errors at various confidence levels, Galehouse (1971) determined that maximum accuracy coupled with a minimum time investment was reached when 300 grains were counted.

A computer program was used to reduce the raw line counting data into useable form. Percentages of each grain type in each phi size were calculated.

CLAY X-RAY DIFFRACTION

Offshore and beach sampling showed that a similarly appearing drift formed both the bluffs at the back of the beach and the nearshore consolidated lake bottom in the area north of the Point Beach Power Plant. These bluffs were previously identified as the Valders Till. To determine if this was in fact the same material and to determine if these bluffs, after being eroded, were a source of the unconsolidated offshore sediment, x-ray diffraction analysis of the clay-size material was performed.

Samples were selected from two points along the bluff, several offshore stations where consolidated clay-like material alone was exposed and from several stations near the lakeward limits of the sampling grid where an appreciable silt-clay size fraction was known to exist in the samples.

After the clay was dispersed in distilled water and allowed to settle for one minute, the liquid was pipetted onto glass slides. During the drying process, the platey clay particles settled and became preferentially oriented so that the principal reflection was maximized on the x-ray record (Carrol, 1970). Several slides were prepared for each sample and then treated in a variety of ways. One slide was x-rayed after being merely air-dried. Five of the slides were baked for one hour at 200°, 300°, 400° 500° and 600°C before being analyzed. Baking affects the various clay lattices in different ways and the changes in either the reflection angle or reflection intensity allows the specific clay minerals to be identified. Finally, one slide of each sample was suspended over ethylene glycol solution in a closed container which was moderately warmed for two hours. (Brunton, 1955). This organic molecule infiltrates the clay lattice, replacing the water molecules and, due to its larger size than the water molecule, expands the lattice. Using a set of x-ray records from samples so treated allowed the clays to be identified by their behavior during each of these processes (Carrol, 1970; Nelson, 1960).

A one liter sample of lake water had previously been filtered to check particle matter content. The sample was taken one foot above the bottom, 10 feet south of the intake crib. While the amount of solids caught on the filter paper was too small to be measureable in weight, it seemed important to identify the mineralogy of these solids for comparison with the bluff and sediment sample suites. Because the solids were quite firmly embedded in the filter paper and because of its very small size, special techniques were used to prepare this sample for diffraction. A very minute quantity of very fine sand, silt and clay was carefully scraped from the filter paper, ground in an agate mortar, and smeared, using distilled water, onto a glass slide.

The convential copper x-ray tube emitting radiation of wavelength 1.5418 Å was used for this set of diffractograms. Scanning at a rate of 1° per minute from

4° to 41°, the full scale deflection was 200 counts per second.

RADIATION COUNTING

To add to the parameters determining the baseline in the study area, 18 samples and two blind controls were measured for total background radiation. The samples were selected from the offshore survey of June 1971. Total background radiation was determined by the State Hygiene Laboratory using their Beckman Y-Beta unit, Model 16. Their standard operating procedure was used in which 0.1 gram of the sample is counted, the counting process being repeated three times. Total counts per minute per gram is the average of these three counting periods. To reduce the counts per minute per gram to pico (10^{-12}) curies*, division by 2.22 is necessary.

* One curie equals that quantity of any radioactive isotope undergoing 3.7×10^{10} disintegrations per second.

IV. THE OFFSHORE SEDIMENTARY REGIME

INTRODUCTION

The nature of any sediment depends on the characteristics of its source material and its treatment during transport. Pettijohn (1957, p. 7) wrote that "Sediments are the product of both heritage and environment." This is true for both the texture and the mineralogy of a sediment.

A source, or provenance, can influence the texture of a sediment by controlling the texture of the fragments immediately after they are weathered from the source. The processes of destruction of the source material - weathering - coupled with the mineralogy of the source material cause certain sizes of fragments to be formed. Further, the mineralogy of the provenance determines, at the start, the mineralogy of the detrital grains (Pettijohn, 1957). It is the nature of the source material which , when acted upon by the processes of weathering, determines both the size and mineralogy of the fragments available for transport.

The process of transport or dispersal can alter the texture and mineralogy of a sediment deposited in a particular environment compared to the original properties at the source. If the dispersal medium transports one size of particle in preference to another, a textural sorting will result. If one mineral is more resistant than another to breakdown, whether it be mechanical or chemical, during transport, a mineralogical sorting will occur. Finally, if some of the grains interact with the transporting medium differently than others do, as in the case for grains with a high density, then still another type of sorting will take place. Each of these interactions between the fragments at the source and the transporting medium will be reviewed.

THEORY OF SEDIMENT MOVEMENT

The relationship between unconsolidated detrital fragments and the energy levels of the transporting medium is well known. Hjulström's (1939) classic paper on this subject reviewed the three processes - erosion, transportation, and deposition - involved in the interaction of moving water and detrital material. As Hjulström (1939, p. 8) pointed out, "Erosion is closely related to transportation, because the individual particles come to rest often between the time they are first loosened from bed rock until they reach their final place of accumulation." Discussing erosion, he wrote, "The velocity of water can be considered as the dominant factor." (Ibid, p. 9). Further he noted, "The momentary extremes in velocity have undoubtedly a greater influence than the average velocity." (Ibid, P. 9).

Inman (1949) reviewed the interaction of sediments and the velocities in the fluid medium, stressing the principles of fluid mechanics. Central to this discussion is the difference between laminar and turbulent flow. While laminar flow is characterized by smooth movement of the fluid layers, one over the other, without random fluctuation in direction, turbulent flow is marked by irregular movement of the fluid particles accompanied by transfers of momentum within the fluid. In a fluid, a boundary layer exists, which may have the properties of either laminar or turbulent flow. Its state is a function of the length of the flow and its velocity, the velocity of the flow in the main part of the fluid, and the boundary roughness (Streeter, 1971). If the undulations of the boundary surface are sufficiently large in relation to the flow velocity, the height of the undulations of the boundary surface will exceed the thickness of a laminar boundary layer. Then, the boundary layer is turbulent. In order to lift a particle off the bottom, a turbulent flow around it is necessary. With the random velocity fluctuations in turbulent flow, forces from a variety of directions, including upward, will be exerted on the particles. Such is the nature of turbulent drag.

Hjulström (1939) found, through experiment, that the most easily erodable grains were of a diameter of 0.5 mm. This has since been reevaluated and a diameter of 0.18 mm has been assigned to the most easily erodable diameter (Inman, 1949). Why is this true? It is at this diameter that a minimum amount of turbulence at a minimum flow velocity is developed sufficient to overcome the gravitational and frictional forces holding the grains in place. Both larger and smaller particles require larger fluid velocities to be moved.

Three types of movement are possible: surface creep, saltation, and suspension (Inman, 1949). Inman (Ibid, p. 55) described surface creep as "a bed load phenomenon in which the material slides or rolls along the bottom with a velocity less than that of the fluid current." He defined saltation as "a jumping motion in which the particles momentarily bounce above the bottom and travel with the velocity of the fluid." (Ibid, p. 55).

The type of movement a grain will display is determined by the magnitude of the minimum velocity necessary to move a particle - the threshold velocity - and the settling velocity, as determined by Stokes Law (Inman, 1949). Stokes determined the drag exerted on a sphere by the fluid around it. From this relation, the Stokes Law of Settling has been derived. It is:

$$V = \frac{1}{18} \frac{(\sigma - \rho)\, g\, D^2}{\mu}$$

where V is the free-falling velocity of the spere, in cm/sec; σ is the density of the sphere, in gm/cm^3; ρ is the fluid density, in gm/cm^3; g is the acceleration of gravity in gm/cm^2; D is the diameter of the sphere, in cm; and μ is the viscosity of the fluid, in poises (gm/cm-sec) (Allen, 1970). This equation is true for particles of diameter less than 0.18 mm (Inman, 1949).

Around larger diameters, turbulence is developed during settling and the relationship given in Stokes Law does not hold. In the sizes greater than 0.18 mm, inertial forces dominate over the viscous forces in the fluid and the settling velocity varies with the square root of the diameter rather than as the square, as predicted by Stokes Law of Settling. The settling velocities for these larger grains follow the formula:

$$V = 2.3g \sqrt{\frac{\sigma - \rho}{\rho} D}$$

where the notation is the same as in Stokes Law (Rubey, 1933). Because at 0.18 mm the threshold velocity equals the settling velocity, Inman (1949) reported that these grains can move by surface creep, saltation, and suspension. Larger particles require greater fluid velocities to first move, owing to their greater mass. Their threshold velocities, however, do not exceed their settling velocities so that they move by rolling and sliding (Ibid). Finally, smaller particles also require a larger threshold velocity owing to the fact that they do not cause turbulent drag at low velocities and because the particles display inter-attractive forces resulting in cohesion. These smaller particles, however, have a low settling velocity and once put into suspension will thus be transported. Deposition occurs when the velocity of the transporting medium falls below the setting velocity of the particles in the system. Hjulström (1939) originally presented these ideas in a now famous curve, reproduced in Figure 4-1.

EFFECTS OF TRANSPORTATION ON TEXTURE

It becomes apparent from this discussion of differential movement of the various size particles that it is necessary for sedimentologists to understand the frequency of particles occurring in each of the size classes. As a means of describing the textures of sediments, sedimentologists used, in the years before the high-speed computer, a set of parameters based on certain points on the cumulative curve of the particle weight distribution. Inman (1952, p. 132) proposed one such set of parameters and described them as being analogous to "the median, standard deviation and skewness of mathematical statistics." Another set of such parameters was proposed by Folk and Ward (1957). These approximations to the statistical parameters have now been superseded by computer calculated moment measures which describe the distribution by weight of the size of the grains in the sample much more completely by taking into account the entire cumulative curve rather than two to five points on it. However, the meaning of these moment measures is the same as the older approximations.

What, then, is the relationship between erosion, transportation, and deposition and the values of the moment measures based on the size distribution of the sediment particles? The texture and hence the mean size and sorting (a measure of the distribution of sizes) of a sediment are affected by, in addition to characteristics of the source material, the transportive process as described above. Russell (1939, p. 32) discussed this relationship and wrote:

> We know that most sediments show a progressive decrease in mean grain size in the direction of transport. Though this effect has often been considered to be due almost entirely to abrasion, it may equally well result from sorting on the basis of size...In general, then, the degree of sorting shown by a sediment roughly indicates the character and the effectiveness of the sorting agent.

Two types of sorting were differentiated by Russell (1939). These are local sorting and progressive sorting. Local sorting is defined as "the assortment of the particles at a particular locality or site of deposition." (Ibid, p. 33). This parameter, then, can help to delineate "the condition of deposition at that locality." (Ibid, p. 34). Progressive sorting "consists of an assortment in the direction of transportation." (Ibid, p. 33). Russell went on to report that "These progressive changes might be in the mean grain size, mean shape, or in the mineral composition of the sediments." (Ibid, p. 34). In regard to mean grain size, Russell reported that, in general, "Progressive sorting may produce a progressive decrease in mean grain size of sediments." (Ibid, p. 34). This may be due to a decrease in the ability of the fluid to carry sediment, because of decreases in velocity, or because the larger particles move slower

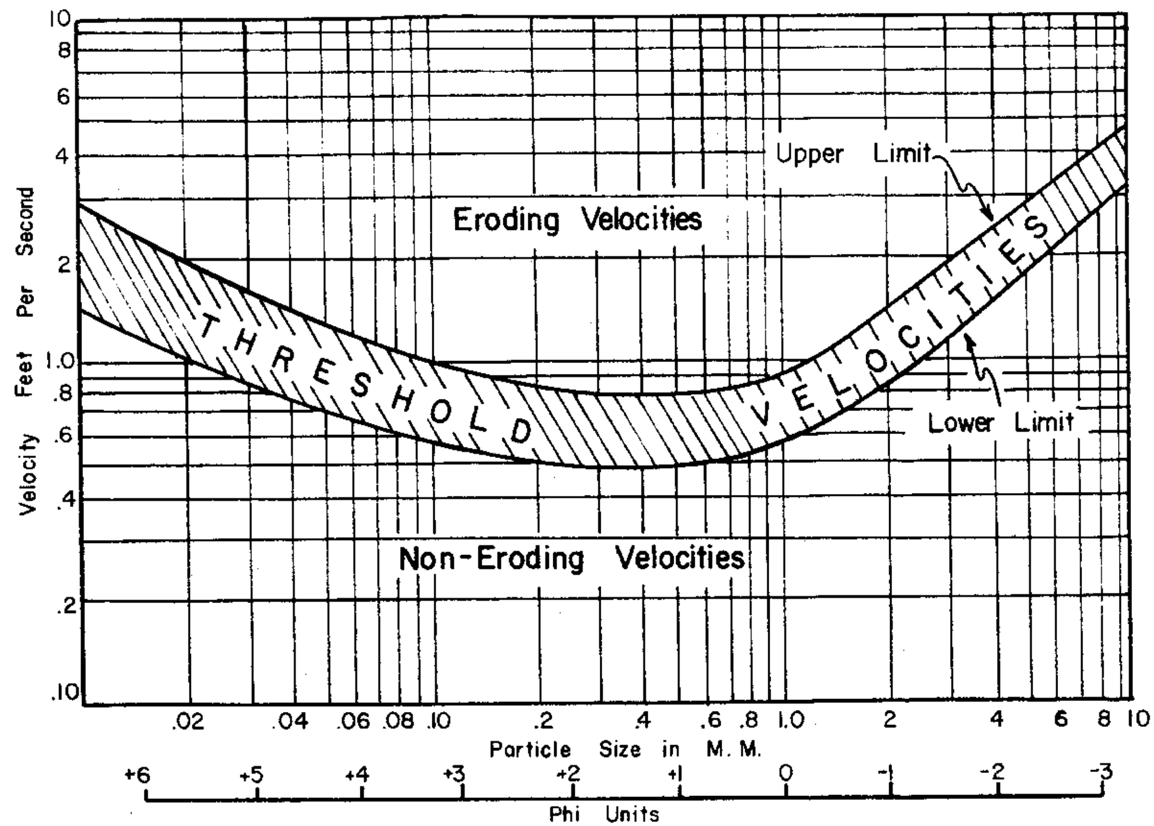


Fig. 4-1 **MEAN VELOCITIES REQUIRED TO ERODE SAND**

and less frequently than the more mobile material.

Attributing vast differences in sorting in the direction of transport to abrasion must be done with caution. Pettijohn (1957, p. 541) wrote:

> ... abrasion does not seem adequate to produce a size decrease of the magnitude commonly observed. Abrasion experiments with both gravel-sized and sand-sized debris failed to achieve a size reduction of the order of magnitude of that observed in natural streams for a given distance of travel ... Very probably in most deposits which are products of an aggrading current, the change of grain size in the downstream direction is largely a sorting effect.

While changes in mean shape will not be considered here, the change in mineralogical composition will be discussed later.

A more detailed discussion of the mean size and sorting parameters in relation to the medium of transport was written by Inman (1949), who elaborated on Russell's work. Inman, expanding on his own report that particles of size 0.18 mm are the most easily moved, wrote: "Since both coarse and fine materials are more difficult and since very fine material is readily carried into suspension, bottom sediments in the process of transportation tend to become progressively better sorted as its median diameter nears 0.18 mm." (Ibid, p. 61) He also stated: "Thus, when friction velocity does not greatly exceed the threshold velocity, fine sand marks the transition zone between transportation in suspension and transportation by surface creep." (Ibid, p. 61). However, Inman went on to point out that fine sediment, once in suspension will be carried to and be deposited in zones where the settling velocity is greater than the upward mixing forces in the water mass. Hence, these fine particles may also be well sorted. Also, as velocity levels exceed the threshold velocity of a wide range of particle sizes, the sorting will decrease. The same situation results when fluctuations in velocity occur, moving into an area a wide range of sizes at one time, only the most mobile sands at another, and depositing only fine suspended material during periods of quiescence.

While the meaning of the moment measures called mean and standard deviation (dispersion or sorting) are quite well understood, the third and fourth moment measures, the skewness and kurtosis, are somewhat less well understood. Skewness is a measure of the symmetry of the distribution curve while kurtosis compares the sorting in the central part of the curve to the sorting on the two ends. The relationship between these attributes of the grain size distribution and the sedimentary environment has not been defined. While these values are reported for the samples taken in this study, they will not be discussed.

The modal classes of a sediment, the size class which contains more than any other, can tell a great deal about the environment of deposition and/or the source. Considering the environment of deposition, the modal class is that size which is most easily and frequently moved into and deposited in the area. If a source is not contributing a full range of fragment sizes, a modal class may represent that size which is most abundantly weathered from the source.

The modal classes become particularly important if the texture is bimodal and the mean and median values become less descriptive. Pettijohn (1957, p. 45) pointed out: "In general, it is the coarse gravels that are bimodal." Typically these bimodal coarse gravels have one mode in the gravel class and the other falling in one of the sand classes.

There are several reasons for bimodal deposits. In some areas, the source supplies only a gravel mode and a sand mode. This is the situation of the Brazos River as described by Folk and Ward (1957). Alternatively, when the source does supply a wide range of particle sizes, the two size classes may have been deposited by fluctuating fluid velocities. In this case, the gravel would be moved into an area when the current velocity was high to be later infiltrated with sand as the velocity decreased. Finally, Pettijohn (1957, p. 46) discussed a third possible reason for bimodal distribution. "Incomplete mixing of two sizes of materials by natural agencies might also produce bimodal curves. Ice deposits, notably till, are most likely to show this character." The modes, particularly in a bi- or even tri-modal sediment can be indicative of the source material and the environment of deposition.

EFFECTS OF TRANSPORTATION ON MINERALOGY

Along with these influences on texture with transportation, alterations in the mineralogy of the detrital grains can occur. During transport, certain minerals are more resistant to abrasion than others, and some minerals, by nature of their higher densities, are acted upon by the processes of transport, in a different manner than lighter grains.

The relationship of source, transportive processes and the resulting mineralogy of the deposited material is summed up by Rittenhouse (1943, p. 1728):

> The mineral composition of a stream is dependent on the kind, the amount, and the size of minerals in the source rocks; on the way in which the source rocks are disintegrated; on the absolute and relative rates of mechanical and chemical disintegration during transport; on the absolute and relative rates of transportation of different minerals and different sizes of the same mineral; and on the hydraulic conditions that existed at the place and during the time of deposition.

A mineral-stability series in weathering was formulated by Goldich (1938) and is reproduced in Figure 4-2. Quartz is the most resistant mineral to alteration, with hornblende, augite, olivine, and the feldspars, less so. Within the feldspar group, the plagioclases have less stability than the potash feldspars. Given these relationships between the minerals, the idea of a mineralogical maturity index emerges. Pettijohn (1957, p. 508) wrote: "The maturity of a clastic sediment is the extent to which it approaches the ultimate end product to which it is driven by the formative processes that operate upon it." Quartz, being the most resistant mineral to abrasion, denotes mineralogic maturity when present as the predominate mineral in a sediment. The quartz and feldspar percentages are important because as quartz is commonly found in a source in conjunction with feldspars, the weathering away of the less resistant feldspars denotes maturity (Pettijohn, 1957). The source must be considered, however, for if it is low in feldspar, the maturity index notion can be deceiving.

The concept of maturity thus informs the sedimentologist about the history of the sedimentary material. As Pettijohn (1957, p. 510) stated, the maturity is "a combined record of the time through which such processes have operated and the intensity of their action." To have maturity, both of these functions must be strong. Given a source which contributes a spectrum of minerals, a mineralogically mature sediment emerges after being subjected for a long period of time

Olivine

Calcic plagioclase

Augite

Calci-alkalic plagioclase

Hornblende

Alkali-calcic plagioclase

Alkalic plagioclase

Biotite

Potash feldspar

Muscovite

Quartz

From Goldich, 1938.

Figure 4-2 Mineral Stability Series in Weathering to the processes of transportation and thus alteration.

Similarly, the minerals of high density, the so-called heavy minerals, are acted upon by the processes of erosion and transportation differently than are such minerals as quartz and the feldspars. It is their high density acting through Stokes Law to affect the settling velocity, which is important. Reviewing the terms of Stokes Law, it can be seen that, as the density of the mineral grain increases, so does the settling velocity, the diameter remaining the same. Or if the settling velocity is to remain the same as the density increases, the diameter of the heavier grains would have to be less. It is this concept which Rittenhouse (1943) used to define the hydraulic equivalent size. The hydraulic equivalent size is that size of a heavy mineral grain which will be deposited with a specific size of quartz or other light mineral. Hence, from Stokes Law, smaller, but heavier grains are deposited with larger but lighter grains.

As pointed out by Inman (1949), Stokes Law does not hold for grains larger than 0.18 mm. As reviewed previously, in the larger sizes, the settling velocity varies as the square root of the diameter. However, the hydraulic equivalent size for heavy mineral grains is still smaller than quartz grains. It is, in fact, much smaller than for the sizes following Stokes Law of Settling.

In terms of sediment transport, these concepts mean that a heavier grain will not be as easily eroded or transported as lighter grains. When particles of differing densities are moved and deposited together, the lighter grains will be larger than the denser grains. Thus, in a sediment, the heavy minerals will be concentrated in the smaller size classes (Rittenhouse, 1943).

To anyone who has walked along a sandy beach, the sight of patches or bands of dark sand are familiar. These dark sand grains are heavy minerals and the patches or bands are concentrations of grains with high densities. While these concentrations are more easily viewed on a beach, the very same type of deposit can occur in offshore sediments.

The formation of these concentrations is related to the hydraulic equivalence concept. Rittenhouse (1943, p. 1763) wrote: "Genetically, concentrates of heavy minerals may form in two ways. Some concentrates result from selective erosion, others from segregation during transport." If a slightly higher current velocity than the velocity under which deposition occurred erodes a sand bed, the lighter grains will be moved and carried away leaving the heavier material behind. In a similar manner, while undergoing movement such as rolling and sliding, the lighter minerals will travel further than the heavier grains. In these two ways, lag deposits of heavy minerals will be formed. Thus, the distribution of heavy minerals over an area can help to delineate the processes of erosion and deposition within the different zones.

One further use can be made of the distribution of heavy minerals within a sediment. Rather than the amount of heavy minerals, this use stresses the varieties which are present. In order to show that a sediment covering an area is homogeneous, both laterally and temporally and then to relate the sediment to a particular source, it is common to use the presence of a unique mineral or suite of minerals. Because quartz and the feldspars are so widely distributed in the geologic column and so commonly found in sediments, other mineral types must be used for this purpose. Often the heavy mineral assemblage or one unique such mineral can be used conveniently. The use of the technique of tracing a sediment to its source by using the identities of the heavy mineral suites is discussed by Rittenhouse (1943).

BATHYMETRY

Because the relationship between the processes of sediment transport, the character of a sediment, and the nature of the fluid regime has been demonstrated, it becomes necessary to identify the depth of the water column overlying the sediment surface and the topography of this surface.

Information regarding the topography of the sediment surface in the study area comes from three sources: 1. U.S. Department of Commerce (NOAA) Lake Survey Navigation Charts published with a series of depth soundings and contours to thirty feet; 2. Depth readings taken at each station during sampling operations; and 3. Recording depth profiles run during June, 1971, following the east-west sampling traverses. (Konel-Furono Recorder, Model F-863-S, 50 kHz).

Three facts concerning the U.S. Lake Survey navigation charts are important to remember when using the depth soundings. The most recent charts are based on smooth sheets prepared from the original soundings taken in 1913-1914 (U.S. Lake Survey, personal communication, 1973). Also, the depths are corrected to the low water datum for the lake, 576.8 feet. The mean monthly lake levels, Table 2-3, indicate that during the summers of 1971 and 1972, the actual lake level was about 580 feet or just greater than 3 feet above the datum. Finally, the Lake Survey uses the shallowest sounding in an area, because the charts are prepared for navigational purposes.

Reviewing the pattern of the depth soundings on navigation chart number 73 (Fig. 4-3) the topography of the inshore waters north of Point Beach Nuclear Power Plant is somewhat irregular with knolls of shallow water. Also of note are the several intrusions of shoaling water into the intermediate zones offshore in the area of the Kewaunee Nuclear Power Plant, Two Creeks, and Point Beach Nuclear Power Plant. Off Rawley Point, the slope of the bottom is considerably more regular, with an average slope of 25 feet in the first one-half mile offshore.

The results of the depth soundings from June, 1971 (Fig. 4-4) sampling survey show several differences as compared to the U.S. Lake Survey chart. During this survey, the lake was at 579.8 feet or about 3.0 feet above the datum. First, the hummocky nature of the bottom north of Point Beach Nuclear Power Plant was not detected, but was most probably due to the sampling interval. Of interest is the lobe of deep water northeast of Two Creeks. This is the very same area where a lobe of shallow water extended offshore in a generally hummocky topographical area, according to the U.S. Lake Survey Chart. Whereas depths of 20-32 feet are reported by the Lake Survey, this author found the depths to exceed 40 feet (Stations 099, 100, 170, and 171, Fig. 4-14). Similarly, off Rawley Point, where the Lake Survey showed 32 and 35 feet depths, this author found 44 and 45 feet depths (Stations 022 and 033). Conversely, at station 039, a depth of 90 feet was recorded whereas the Lake Survey showed a depth greater than 100 feet. At station 064, a depth of 51 feet was found during sampling where the Lake Survey showed depths exceeding 60 feet.

Results of the July, 1971 (Fig. 4-5) survey do not show appreciable differences

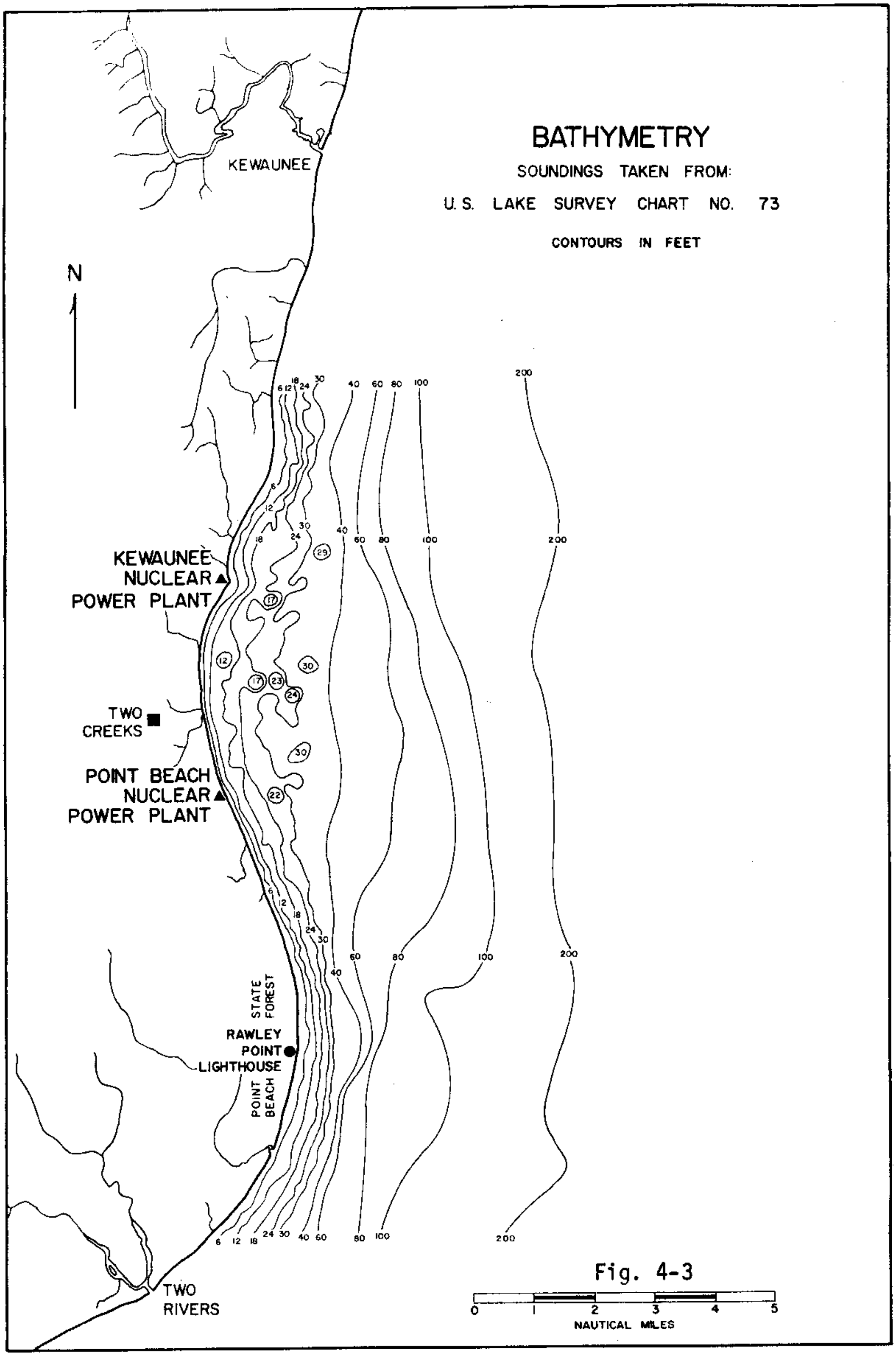
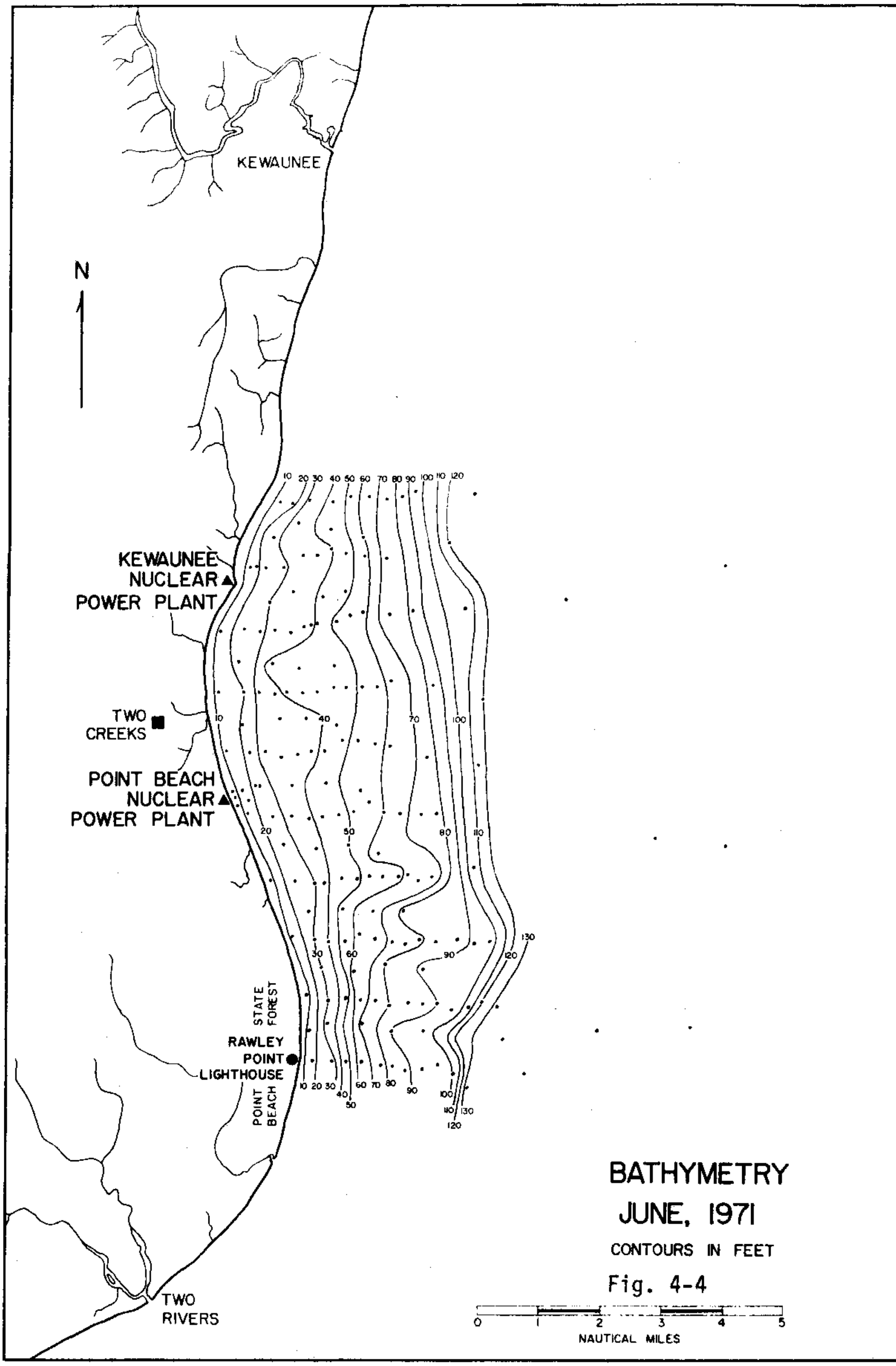

BATHYMETRY
SOUNDINGS TAKEN FROM:
U. S. LAKE SURVEY CHART NO. 73
CONTOURS IN FEET
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-3



BATHYMETRY
JUNE, 1971
CONTOURS IN FEET

Fig. 4-4

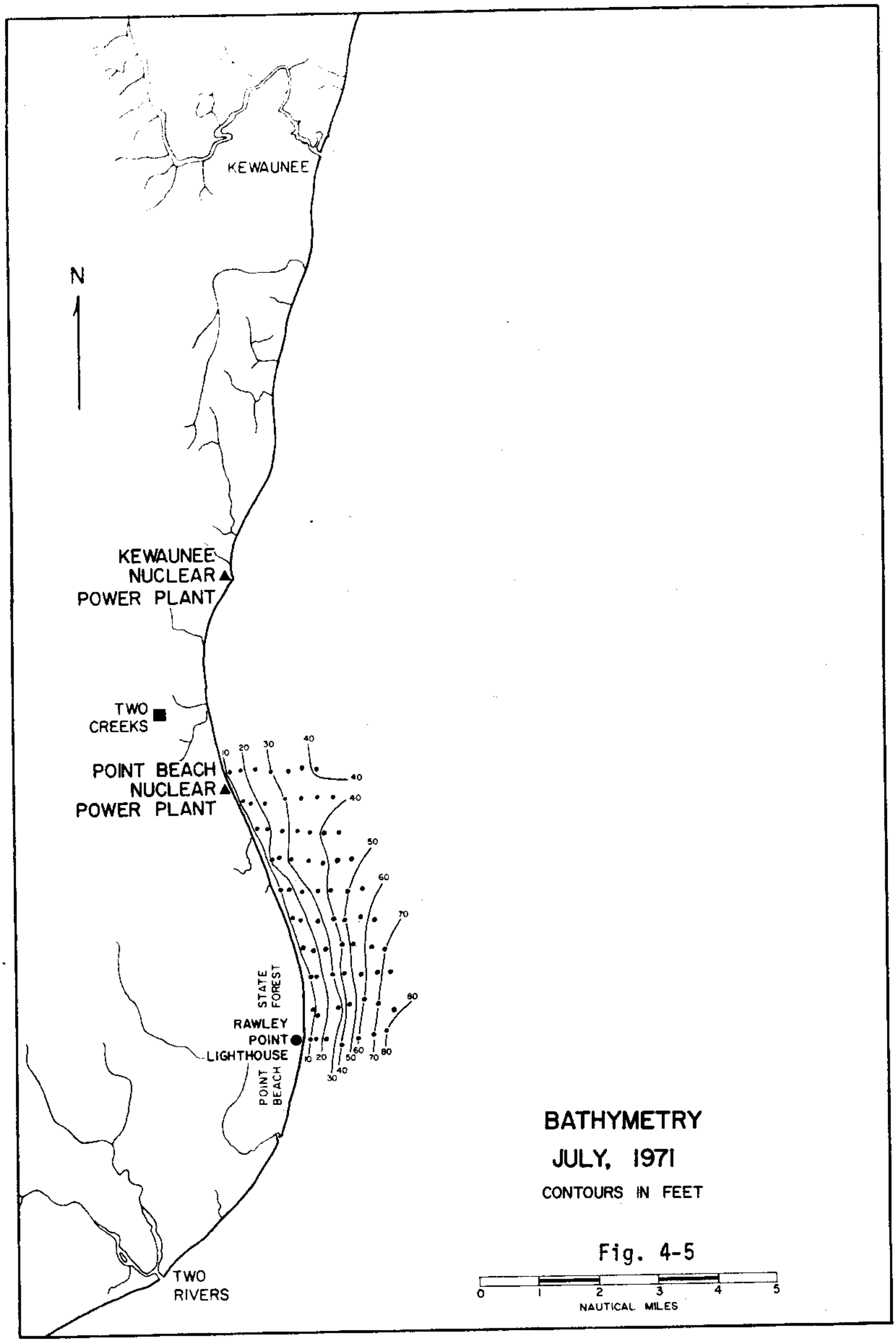

KEWAUNEE
N
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
10 20 30 40 50 60 70 80
BATHYMETRY
JULY, 1971
CONTOURS IN FEET
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-5

as compared to the June, 1971 survey, when slight variations in station position are taken into account. The same is true for the August, 1971 (Fig. 4-6) survey with one exception. The zone of deep water found in June, 1971 in the areas of stations 099, 100, 170, and 171 was not found at all during the August survey. Also, in the area of station 064 of the June, 1971 survey, no shallow readings were recorded. If this area is generally hummocky, as indicated by the U.S. Lake Survey, station spacing did not adequately delineate topographic highs and lows.

During the June, 1972 (Fig. 4-7) survey, shallow water was again measured in the northern part of the study area. During this survey, the lake level was only 0.01 foot higher than it was during the previous summer's work. Where a zone of deep water extended towards shore just north of Two Creeks (Stations 099, 100, 170, and 171) in June, 1971, and where shallow water was found in August, 1971, the same pattern of shallow water was seen during the June, 1972 survey. If one compares the June, 1972 survey to the U.S. Lake Survey Chart, one discovers that, first, the lobe of shallow water off Two Creeks indicated on the Lake Survey Chart was not found; and second, at station 1036 (see Fig. 4-21) a depth of 32 feet was reported whereas the Lake Survey shows a knoll, the shallowest area of which is 17 feet and the surrounding waters are no deeper than 24 feet. In the northern areas, the bottom slope is somewhat more gradual than offshore Rawley Point. An apparent trench (stations 928 and 929) found during this survey could have been overlooked previously due to station spacing.

Finally, in the area off Rawley Point surveyed in November, 1972, (Fig. 4-8) no change was noted shoreward of the 60 feet contour. At stations (Fig. 4-23) 1505, 1506, 1507, 1521, and 1522, major shoaling effects were observed.

The depth recordings taken in June, 1971 (Figs. 4-9 through 4-13) show a distinct difference between the bottom topography off Rawley Point and that further north. The three southern-most profiles display tow marked breaks in slope, resulting in a shelf feature lying between the two zones of steeper slope. Furthermore, these profiles appear to have a relatively smooth surface. The seven northern-most profiles record a more regular slope, with the slope becoming steeper further offshore. As opposed to the southern profiles, these records indicate a more irregular surface. Local topographic highs greater than 12 feet are apparent.

Both the depth contours from the readings taken during the sediment surveys and the depth profiles show the difference in the character of the offshore slope east of Rawley Point as compared to northeast of Point Beach Power Plant. Off Rawley Point, the slope has two marked breaks with a shelf feature in between. The surface of the slope is relatively smooth. North of Point Beach Power Plant the bottom slopes less steeply, but the area is marked by hummocky topography with local highs exceeding 12 feet. As a result, the surface of the slope appears rugged on the recorded profiles. It is this rugged topography which led to the apparent changes in depth east of Two Creeks during the study period. The station grid did not adequately delineate these surface expressions. Scattered depth measurements thus recorded anomalous highs and lows which are not really representative of the complex bottom topography.

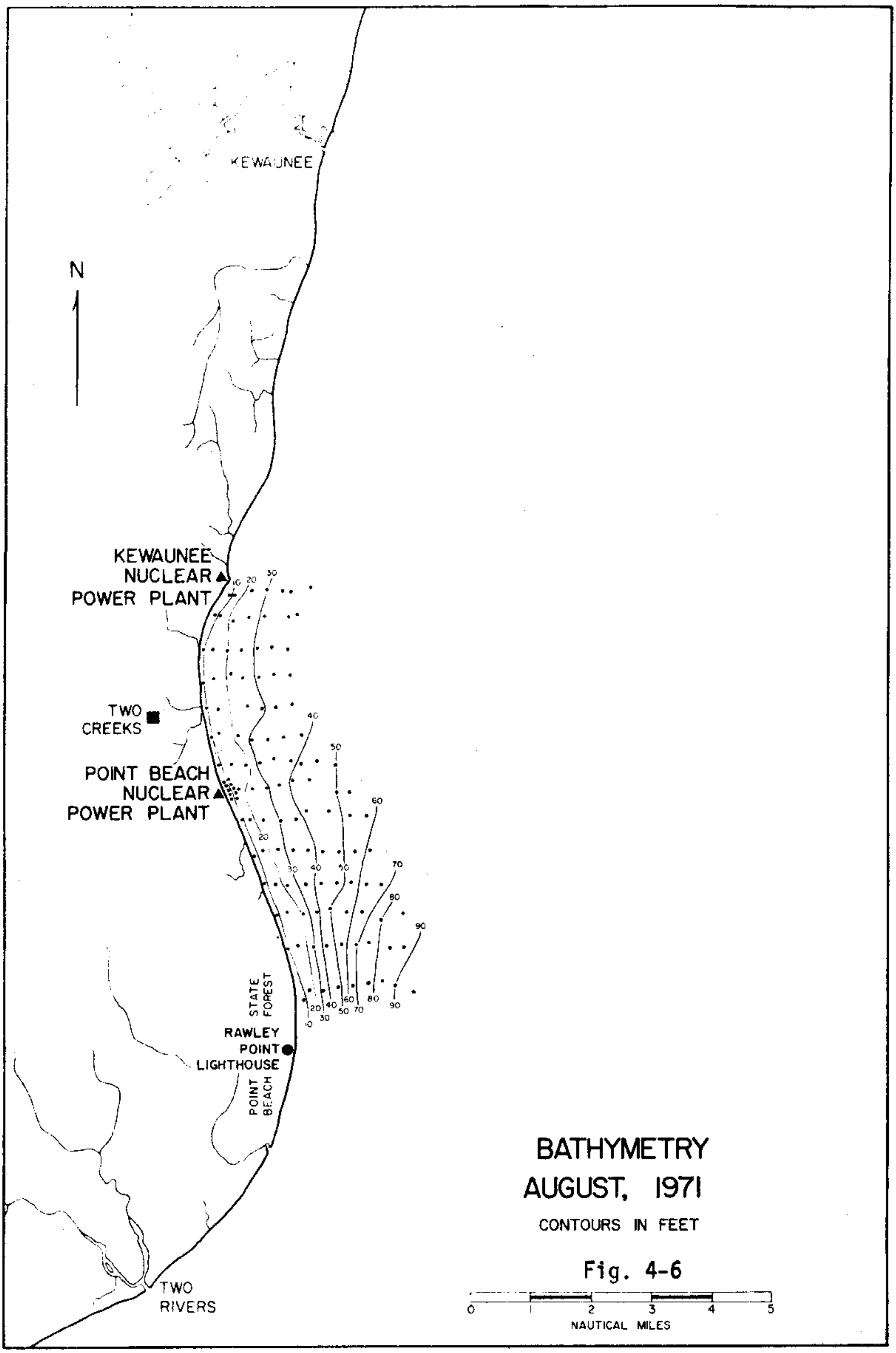

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
BATHYMETRY
AUGUST, 1971
CONTOURS IN FEET
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-6

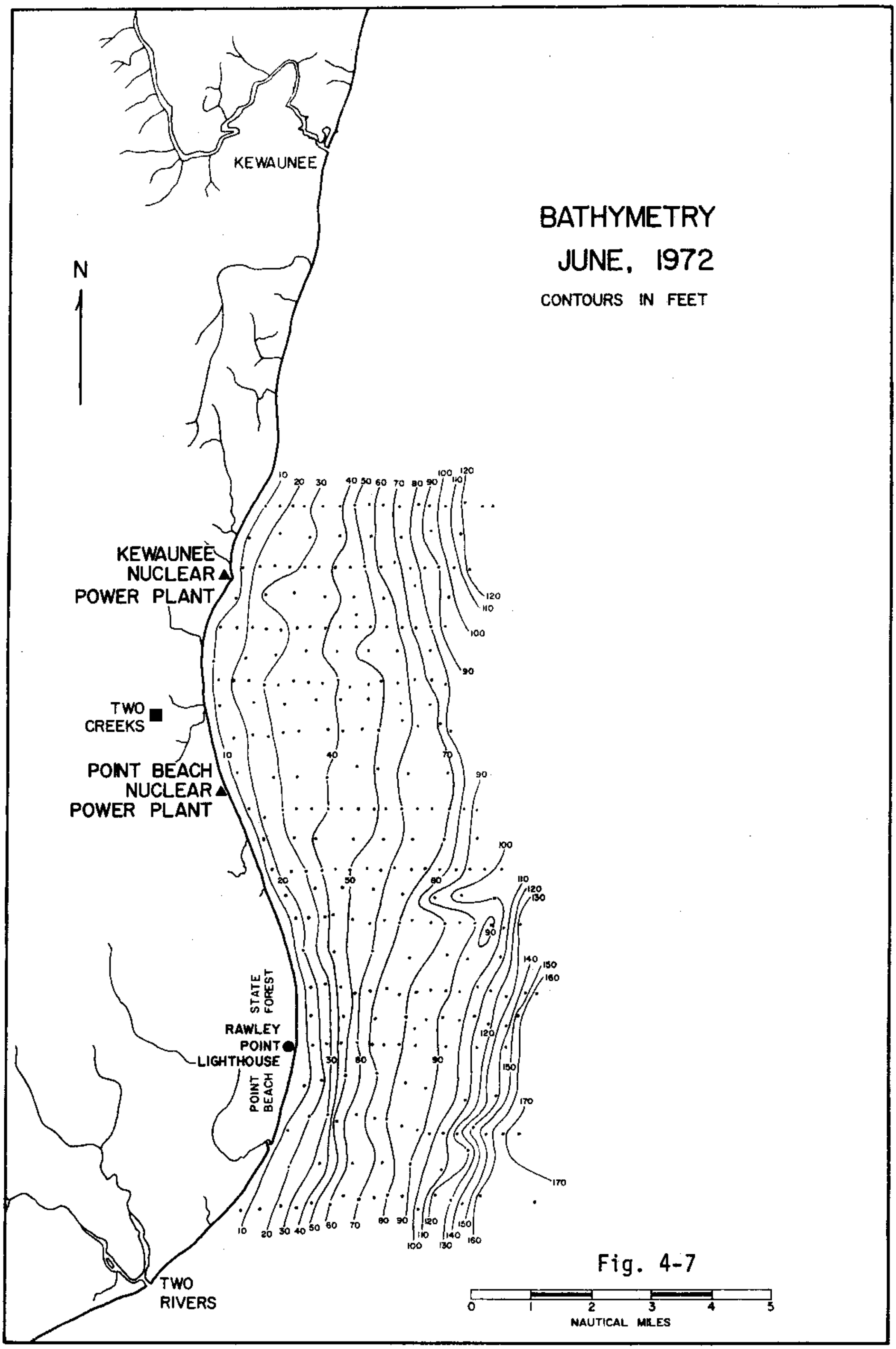
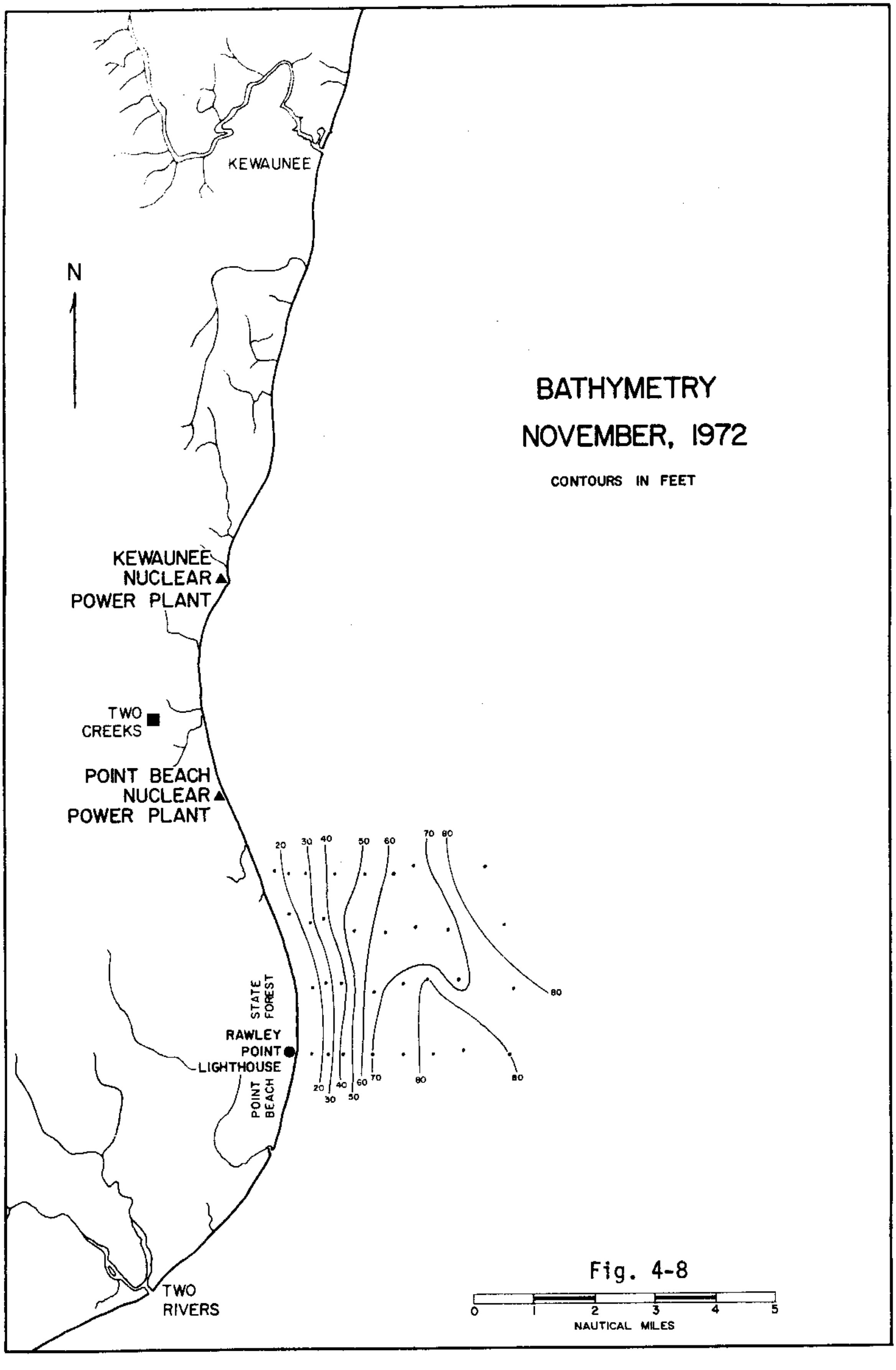

BATHYMETRY
JUNE, 1972
CONTOURS IN FEET
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-7



BATHYMETRY
NOVEMBER, 1972
CONTOURS IN FEET
KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
20 30 40 50 60 70 80
80
20 30 40 50 60 70 80 80
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-8

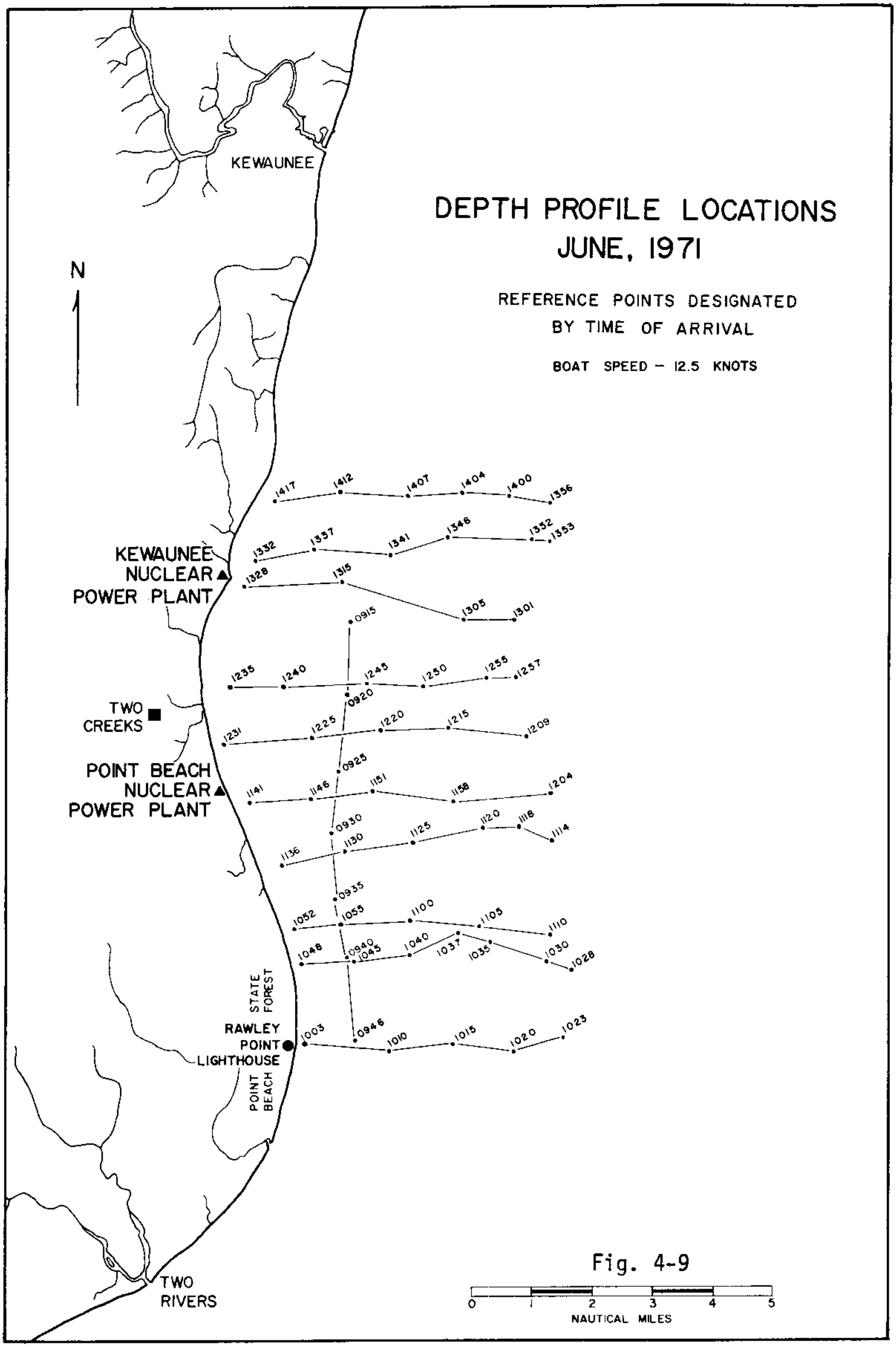

DEPTH PROFILE LOCATIONS
JUNE, 1971
REFERENCE POINTS DESIGNATED
BY TIME OF ARRIVAL
BOAT SPEED – 12.5 KNOTS
N
KEWAUNEE
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-9

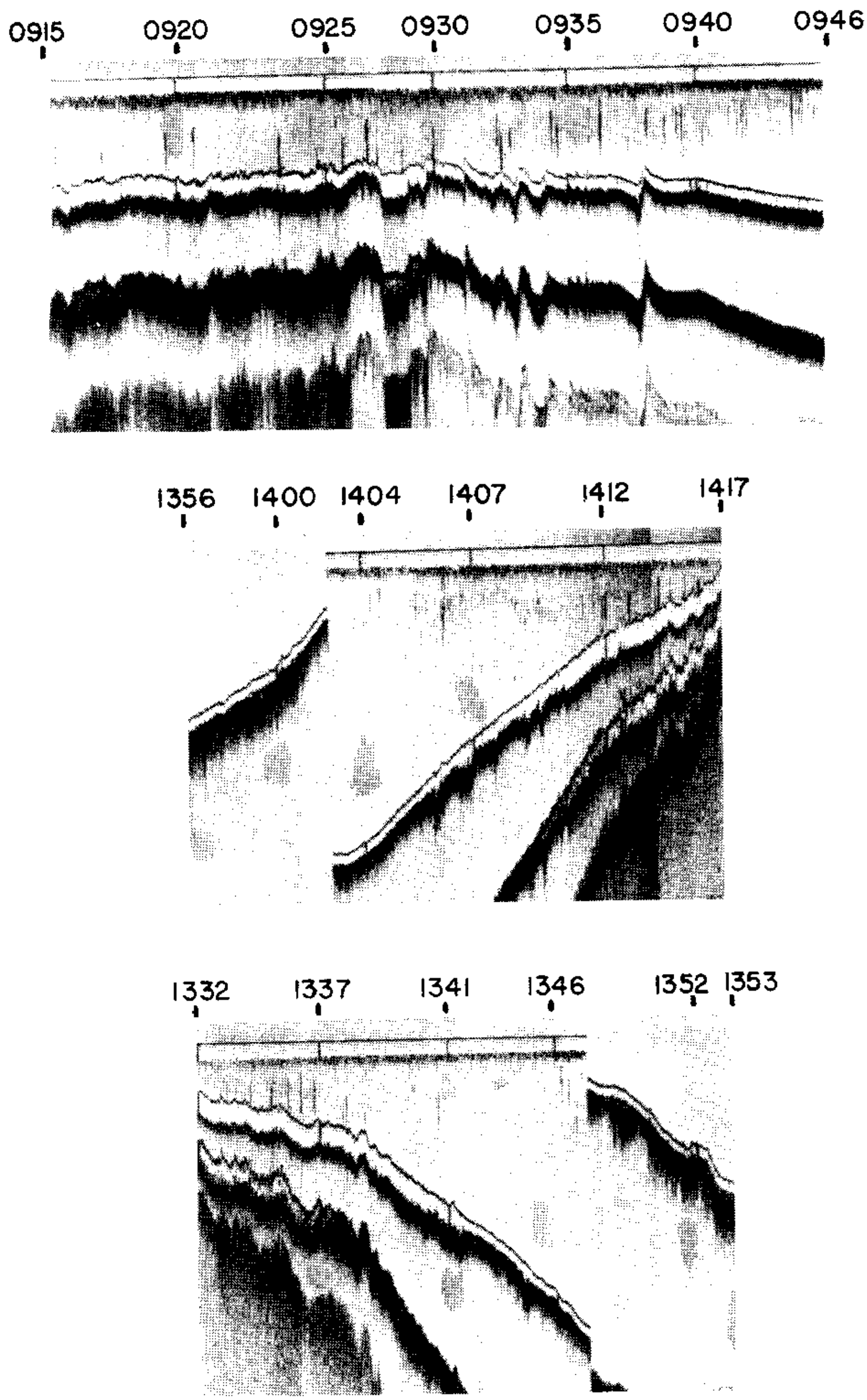


Fig. 4-10 Depth recordings. Vertical scale: 1 cm. = 40 Feet.

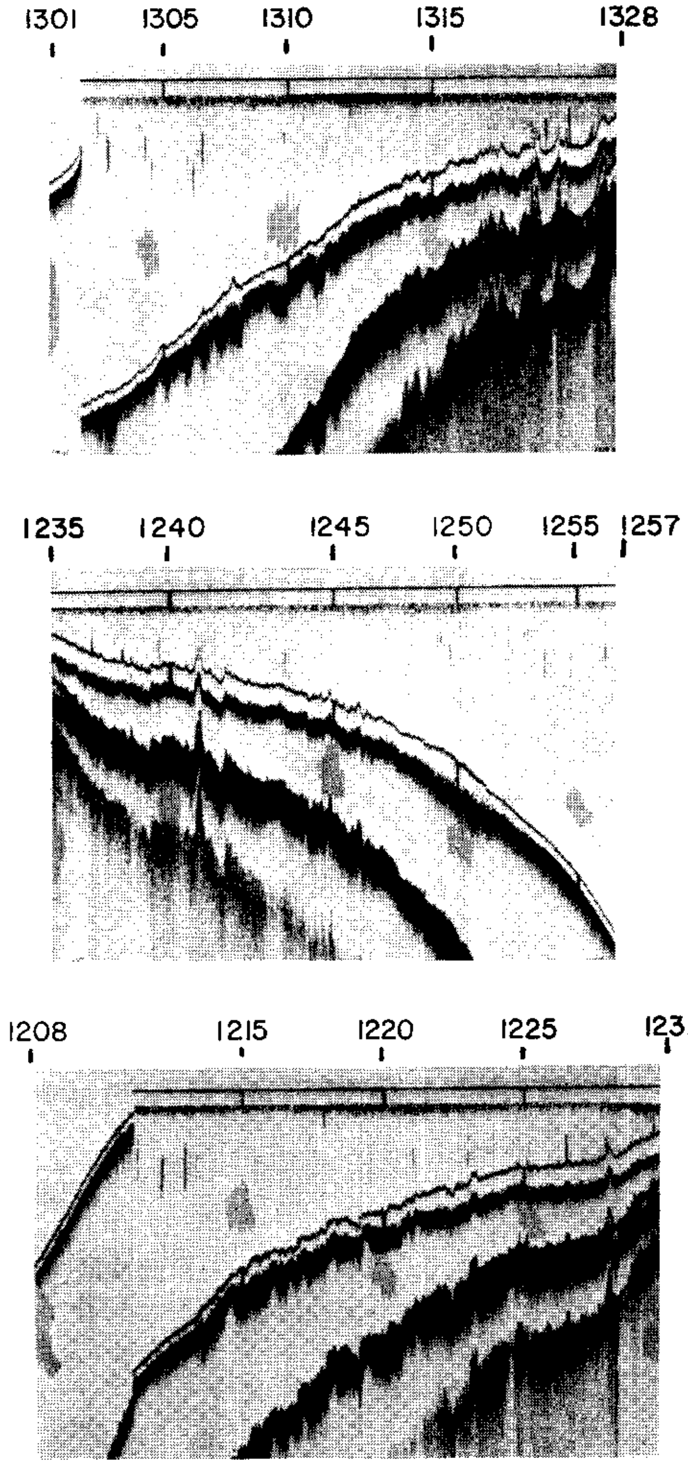


Fig. 4-11 Depth recordings. Vertical scale: 1 cm. = 40 Feet.

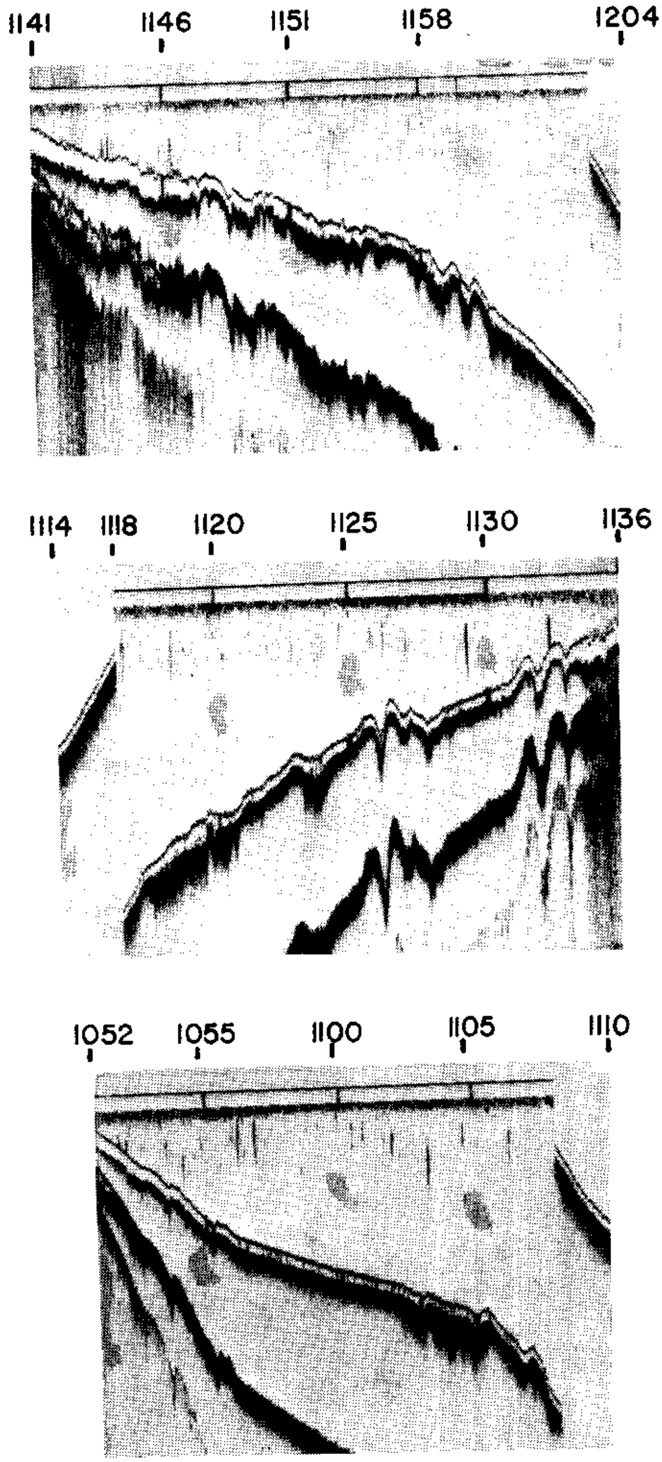


Fig. 4-12 Depth recordings. Vertical scale: 1 cm. = 40 feet.

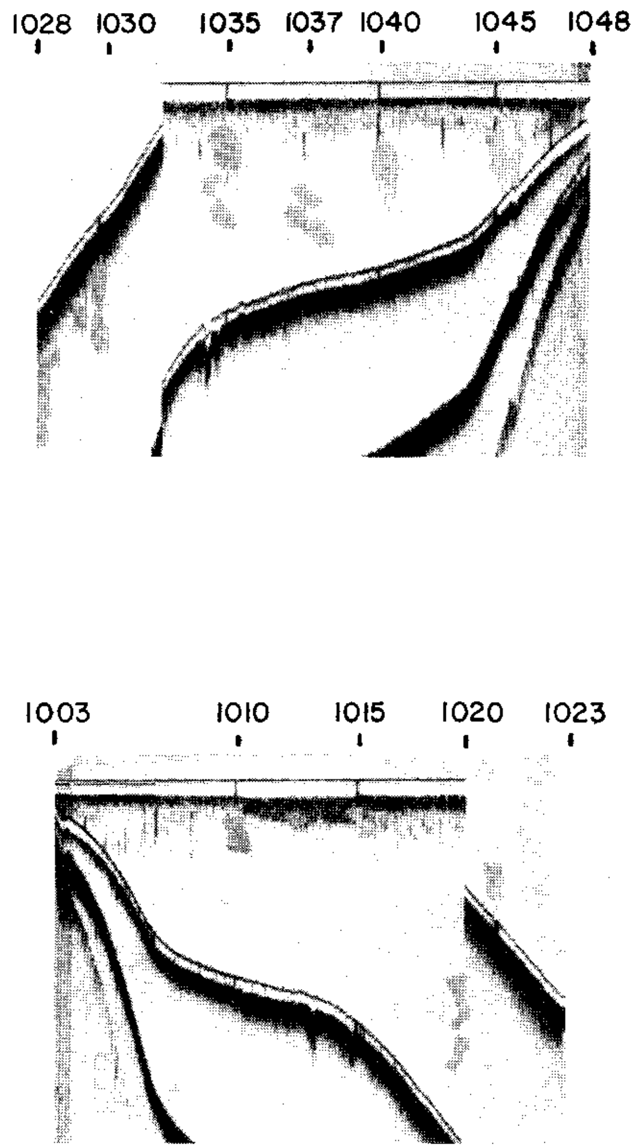


Fig. 4-13 Depth recordings. Scale: 1 cm. = 40 feet.

SURFICIAL SEDIMENTS

By the classification of the surficial sediment samples taken during the various sampling surveys into descriptive categories as described in Chapter Three, a characterization of the lateral distribution of these sediments has been obtained. Moreoever, the variation through time of the distribution of surficial sediments has been recognized.

It becomes apparent, by viewing the surficial sediment chart compiled from the samples taken during the first survey in June, 1971 (Figs. 4-14 and 4-15), that the sediments fall into four distinct groups. First, a portion of the bottom is made up of desiccated red clay with little or no unconsolidated material overlying it. This material occurs principally in the nearshore areas in the northern part of the study area paralleling the coast, but with lobes extending into the intermediate depths. Also, patches of the "clean" clay surface can be found interspersed among the other types of sediment offshore. At first sight, this clay appears to be the same desiccated red drift material which forms the bluffs lying at the back beach north of Point Beach Power Plant. The relationship between the materials sampled in these two locations is discussed later in this chapter.

A relationship observed during the sampling is worthy of note when describing this area of clay bottom. Frequently, a small amount of unconsolidated very fine to medium sand and/or granules and cobbles was found in the sampler along with a piece of hard red clay which had obviously been bitten out of the surface by the cutting edge of the Shipek bucket. This situation was noted most particularly during the first survey at sample stations 097, 098, 099, 100, 105, 128, 129, 133, 167, and 171. Because, at stations 097, 098, and 099, there was a sufficient amount of sand to lead this author to believe that the clay was covered with a thin veneer of sand, this area was so designated on the chart. At stations 100, 128, 129, 167, and 171, although some sand was present, it was a very small amount and these particular areas were classified as a clay bottom. At stations 105 and 133, a thin veneer of granules and sand occurred on a clay surface. There was sufficient unconsolidated material to allow classification as a gravelly sand surficial sediment. It is important to note that each of these ten stations lies near the boundary of a "clean" clay bottom and patches of thicker unconsolidated material. In fact, the samples themselves show this: at these stations, the patches of unconsolidated material are thinning out at their edges, exposing the underlying red clay.

The second group of surficial sediments is the rocky gravel and gravelly sand types. Patches of this sort of material occur in the northern part of the area, typically between the areas of "clean" clay bottom and sand. If one views the areas of rocky gravel and gravelly sand as related deposits, it can be seen that there is a lobe of this material in the northern part of the intermediate depth offshore area. Interspersed amongst this lobe are several sand patches.

Another observation gained during sampling was that large rocks recovered with some of the rocky gravel and gravelly sand samples had obviously been half buried in red clay. This was indicated by a sharp line of demarcation around the large rocks above which the surface was clean and well washed and below which clay still adhered. From this observation, it may be said that these patches of rocky gravel and gravelly sand overlie a surface of red clay and in some cases, the large rocks were originally embedded in and were a part of the

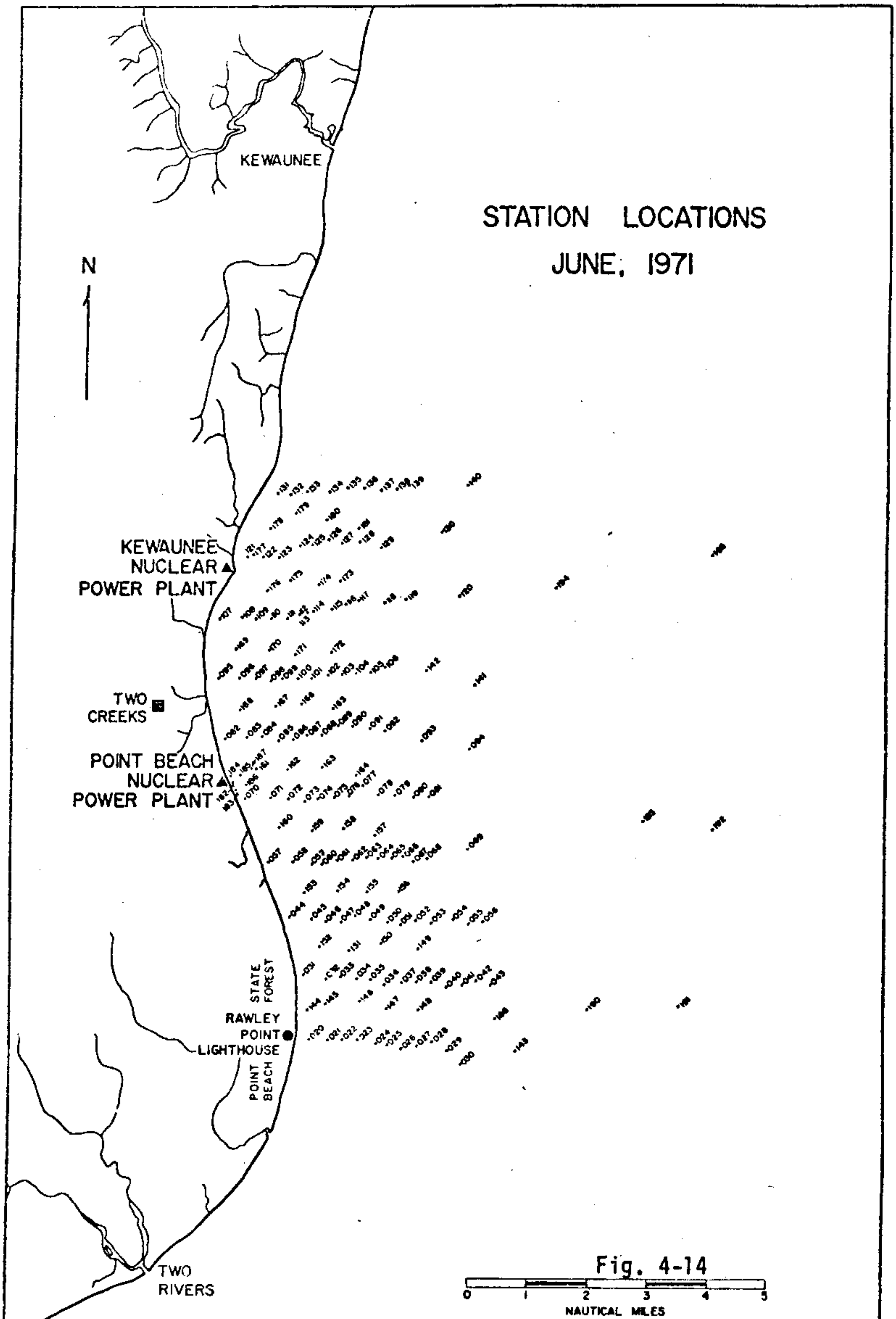

STATION LOCATIONS
JUNE, 1971
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-14

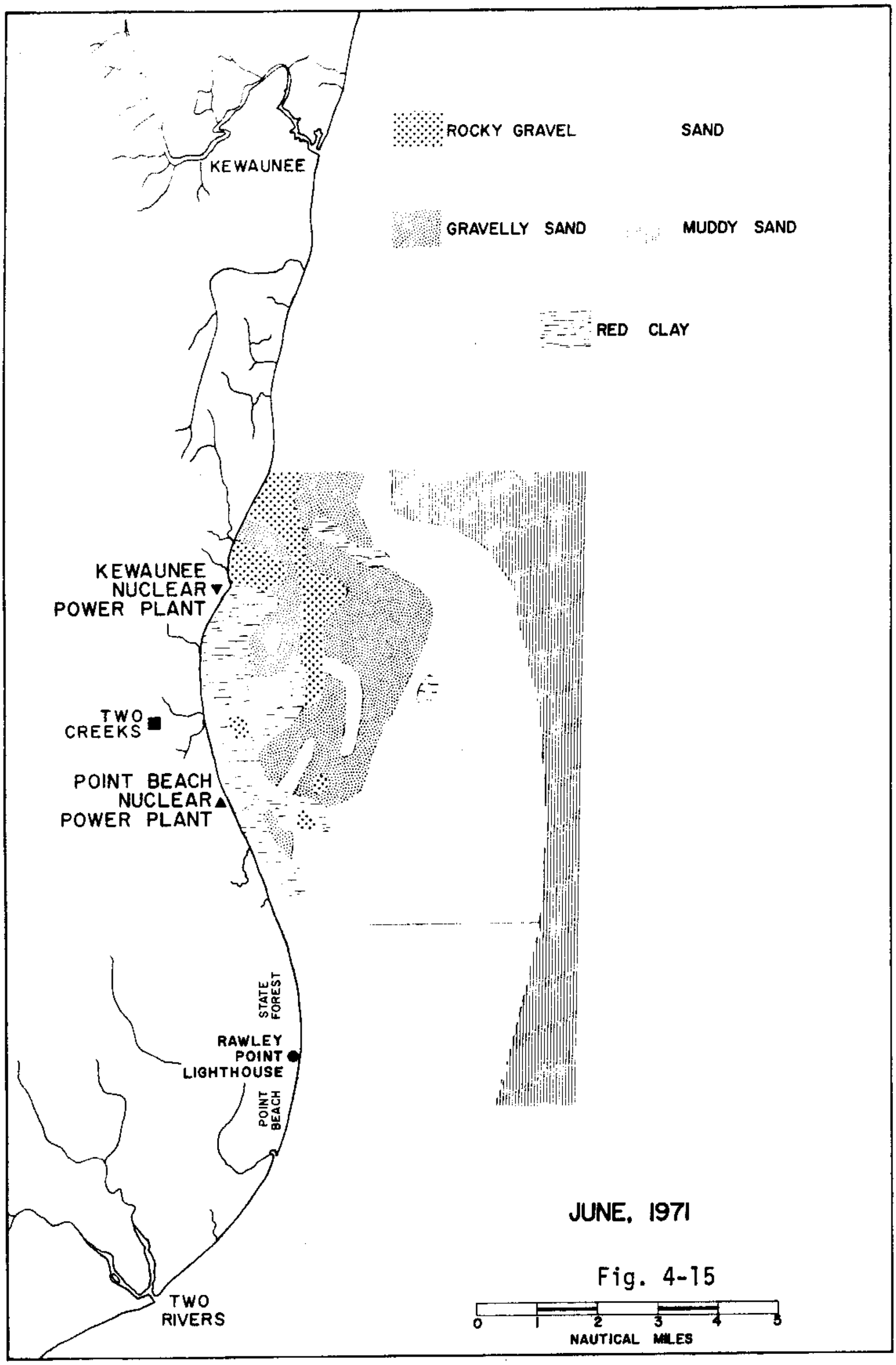

ROCKY GRAVEL
SAND
GRAVELLY SAND
MUDDY SAND
RED CLAY
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
JUNE, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-15

red drift material itself. Large rocks found in the surficial sediments in this manner are termed relict deposits, denoting that their presence in the area is due to conditions different from those found in the area at present (Swift, et al., 1971).

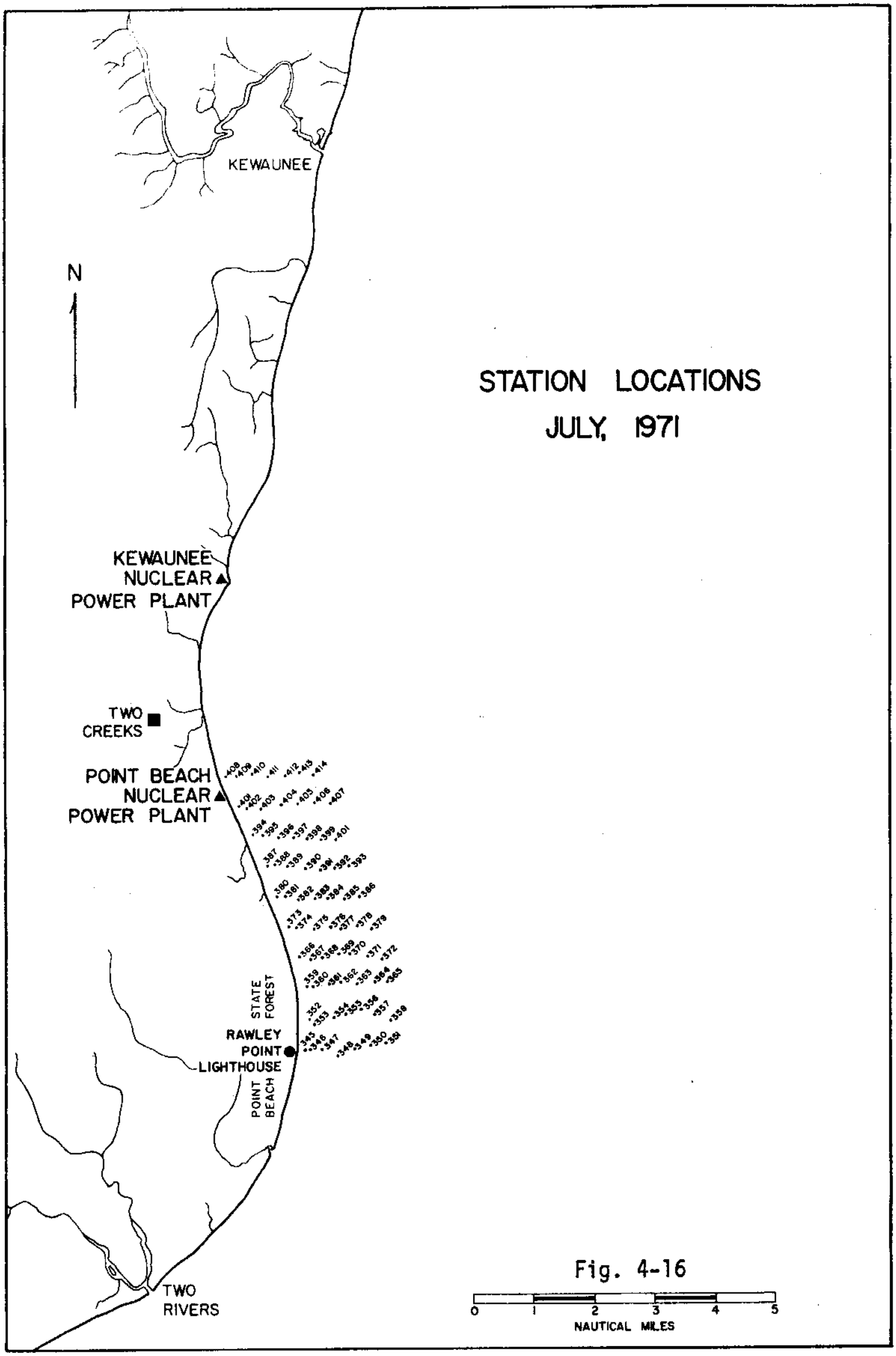
A third group of surficial sediments is the sand found primarily in the southern zone of the sampling area and bounding the lakeward edge of the rocky gravel and gravelly sand zones to the north. Sand patches are also interspersed amongst the coarser patches in the northern part of the area. In addition, a small patch of sand was found directly lakeward and to the south of the Unit I flume structure.

Finally, in the offshore and hence deeper, waters, muddy sand was found.

The surficial sediment pattern observed during the July, 1971 survey (Figs. 4-16 and 4-17) was similar to the previous one, although a somewhat smaller grid was covered. A striking similarity between the two surveys was the clay lobe south and offshore of Point Beach Power Plant, accompanied by a band of sand inshore, both north and south, but not directly in front of, the power plant. The offshore lobe has changed configuration somewhat with the areas of stations 389 and 406 (corresponding to stations 058 and 074 in the June, 1971 survey), being covered by sand and rocky gravel respectively, where previously these areas were part of the clay lobe. Sampling at station 397 (station 160 of the June, 1971 survey) showed that clay existed in July where unconsolidated material existed in June, 1971. A sand patch appeared in July, 1971, north of Point Beach Power Plant along the coast where clay was exposed previously. The most striking difference between the two surveys was the patch of sand which was found in July, 1971 in the intermediate depth waters off Rawley Point.

In August, 1971, the grid was resampled (Figs. 4-18 and 4-19). The surficial sediment pattern found was similar, but not precisely the same, as in the previous two surveys. A large area of "clean" clay bottom was again found in the nearshore and intermediate depths of the northern part of the study area. As in the previous two surveys, a lobe of this material was found to extend south of the power plant in the intermediate depths and in towards shore. The situation of sand and gravel lying in a thin veneer over the red clay was again observed during the sampling at stations 537, 540, 545, 548, 552, and 553 (corresponding to stations 083, 086, 167, 095, 097, and 099 of the June, 1971 survey). This veneer appeared to be quite sparse at stations 537, 545, 552, and 553 and the surficial sediment was designated as clay, rather than sand - material forming the veneer at these stations. In contrast, at station 540, a large amount of gravelly sand was found with small chips of clay, which appeared to have been freshly cut out of a clay surface. This area was thus described as having a surficial sediment of gravelly sand, but it should be remembered that this material seems to overlie a basement of desiccated red clay and in fact, lies near the boundary between the patch of gravelly sand and the "clean" clay.

By comparing the boundaries of the exposed clay and the unconsolidated material, it can be seen that in the area of stations 625, 552, and 553 (stations 071, 097, 098-099 of the June, 1971 survey) clay existed during this survey where unconsolidated material existed before. Areas where unconsolidated material existed in August, 1971 where clay was found before are at stations 606, 662, 554, 547, 563, and 557 (stations 058, 070, 171, 100, 107, and 169 of the June, 1971 survey) and over a large area directly in front of the Unit I flume struc-



STATION LOCATIONS
JULY, 1971

Fig. 4-16

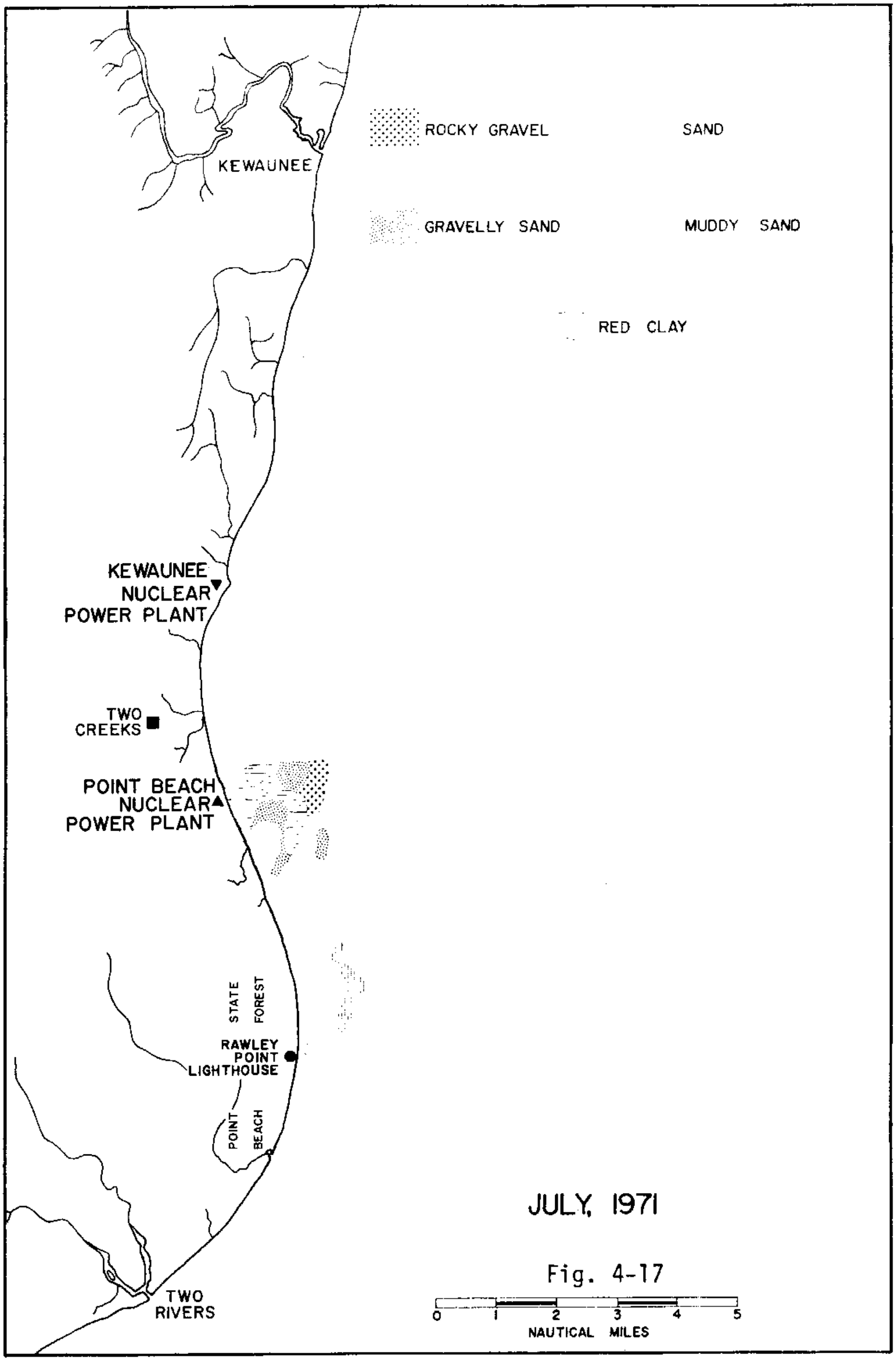
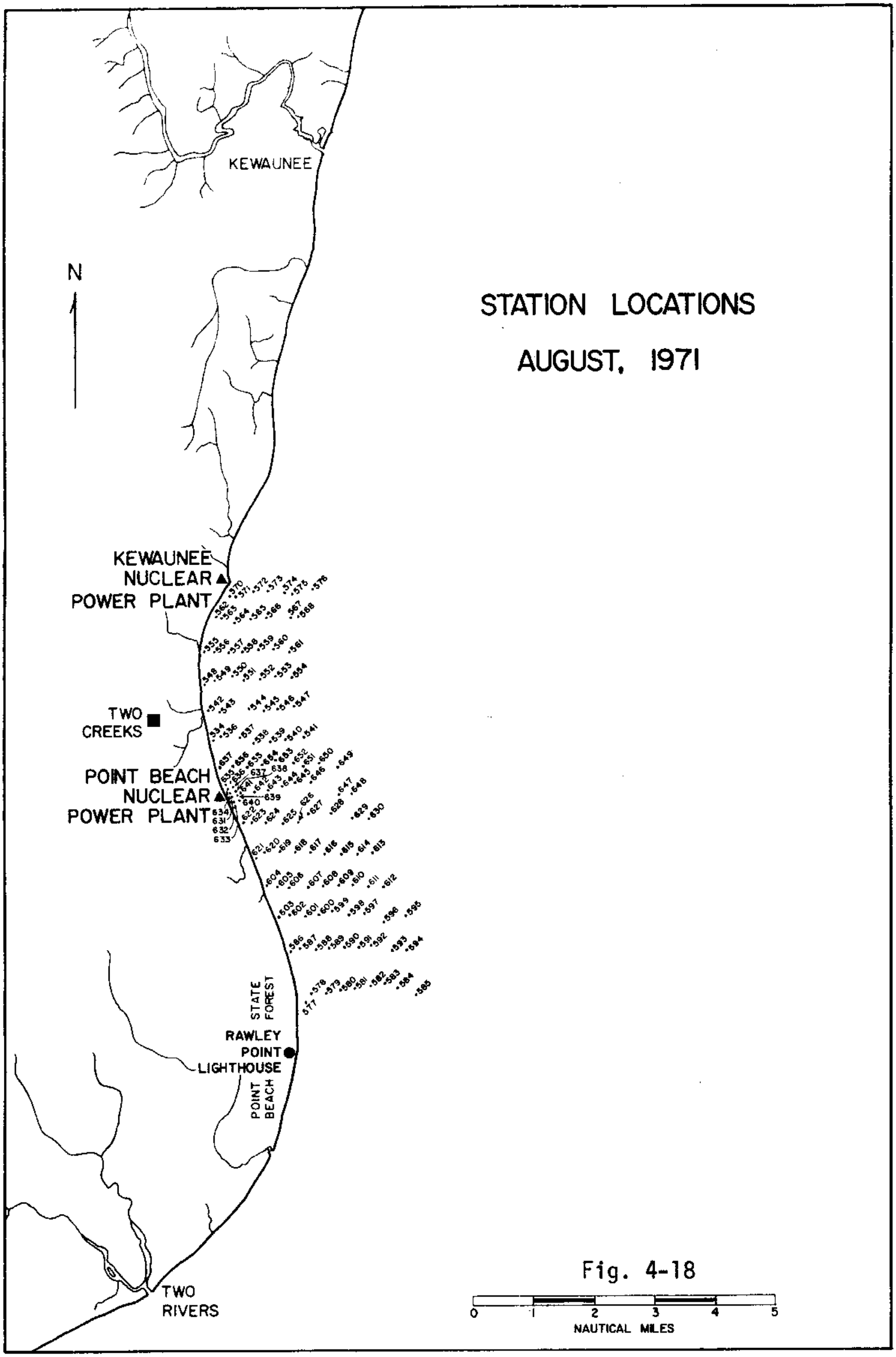
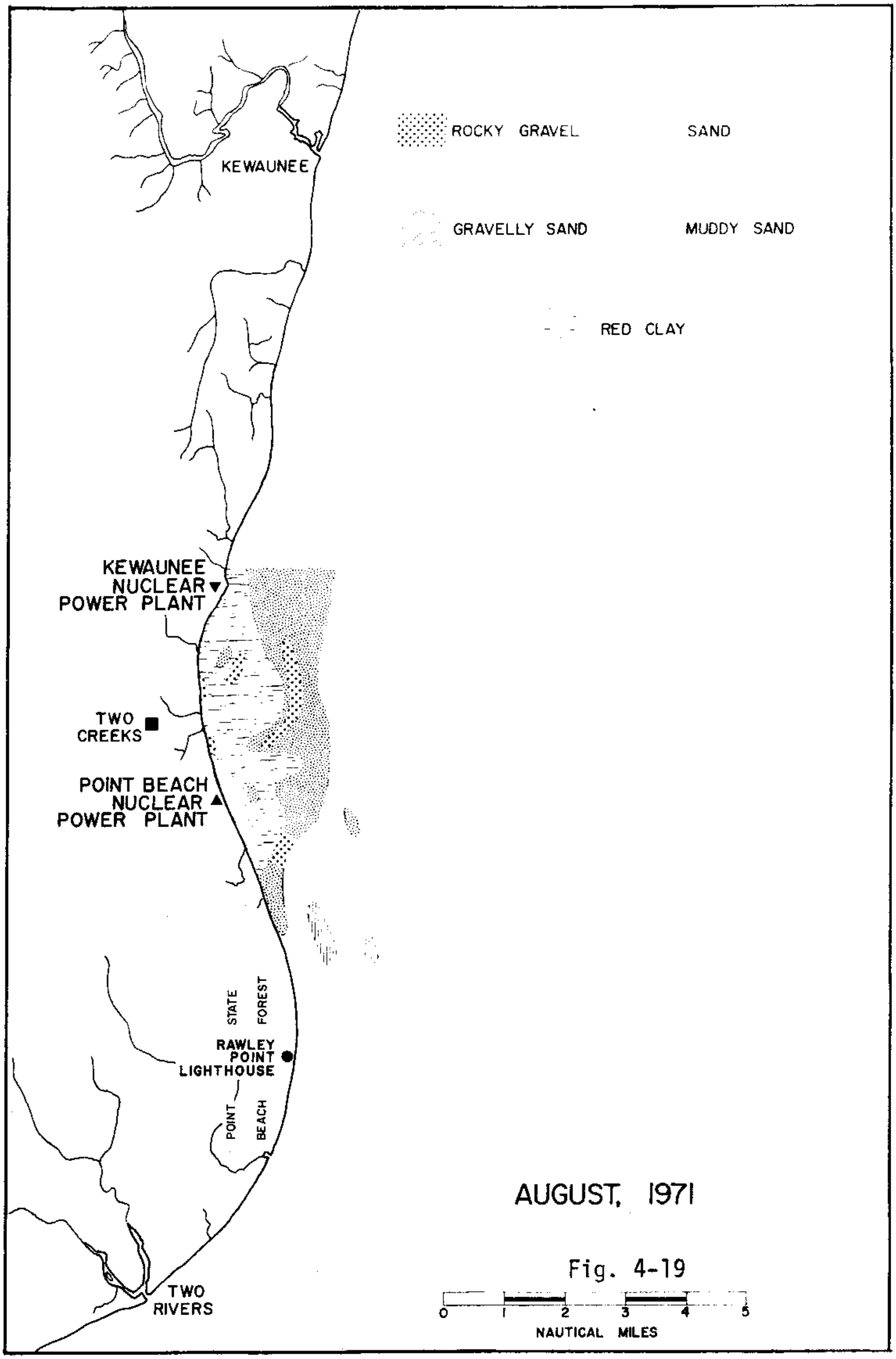

ROCKY GRAVEL
SAND
GRAVELLY SAND
MUDDY SAND
RED CLAY
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
JULY, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-17



STATION LOCATIONS
AUGUST, 1971

Fig. 4-18



ROCKY GRAVEL
SAND
GRAVELLY SAND
MUDDY SAND
RED CLAY
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
AUGUST, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-19

ture. It is important to note that stations 552 and 553 were two areas where a veneer of this material overlay the red clay, as observed during this and previous surveys. This reinforces the idea of intermittant patches of unconsolidated material overlying the red clay.

A large band of rocky gravel and gravelly sand was found in the intermediate depths of the northern zone, extending in towards shore south of Point Beach Power Plant. A difference in the surficial sediment pattern can be noted as compared with the two preceeding surveys. The recovery of gravelly sand at stations 603, 604, and 605 (station 604 corresponds to station 057 of the June, 1971 survey) appears to indicate a definite change in the surficial sediment pattern. During the first survey, a patch of gravelly sand was found in the intermediate depths southeast of Point Beach Power Plant. By July this material was found further in towards shore and by August it was found at the two most shoreward stations.

That several areas contained in the northern part of this rocky gravel and gravelly sand zone were covered by large diameter rocks (Fig. 4-20) was evidenced by samples recovered in the chain bag rock dredge. Table 4-1 lists the dimensions of the rocks recovered. It can be seen that most of these fall into somewhat the same size range with 6.0/4.0/3.5 inches being typical.

In addition to this main lobe of rocky gravel and gravelly sand, this type of surficial sediment occurs in several other patches. First, there are two scattered patches of rocks along the shore north of Point Beach Power Plant. While these two patches did not show up in the preceeding surveys, they may be very localized deposits which were not sampled in the two preceeding grids rather than being changes in the actual surficial sediment pattern. Two other local deposits occurred at stations 642, directly east of the Unit I flume structure, and at 629, found in an area of sand.

Sand was again found covering a large area in the southern part of the study area, from the nearshore zones out to the offshore areas. The zone of sand which was found in a local area directly in front of the flume structure during June, 1971, but only to the north and south of the flume structure during July, 1971, had become considerably larger. By August, 1971, sand covered a nearshore area about one and one-half miles in length paralleling the shore. One local sand patch was found south of the Kewaunee Power Plant.

Muddy sand deposits were found in the intermediate waters just north of Rawley Point, as they had been in July, 1971 and in the offshore waters.

Reviewing the surficial sediments encountered during the June, 1972 survey (Fig. 4-21 and 4-22), a similar pattern emerges to the three previous surveys. The desiccated red clay was exposed in the nearshore areas north of the Point Beach Power Plant with a lobe extending to the south in the intermediate depth waters. The situation of a veneer of unconsolidated material was again observed during sampling. At station 962, 1012, and 1036 (stations 162, no corresponding station, and 176 of the June, 1971 survey), a very small amount of unconsolidated sand was found along with large cuts of red clay. At stations 822, 996, 1000, and 1003 more abundant amounts of sand were recovered along with small cuts of clay. Similarly, at stations 947, 990, 1001, and 1011, gravelly sand was recovered as a veneer over the clay while at stations 979, 987, and 1057, rocks were found which appeared to have been embedded in clay.

Fig. 4-20 Large rocks recovered by dredge

TABLE 4-1

ROCK DREDGING RESULTS BY STATION

DIMENSIONS IN INCHES

PP680 - At Location of PP573

PP680	A	8.0	5.7	4.7
	B	9.0	8.5	3.7
	C	5.2	4.5	3.5
	D	6.0	4.2	4.2
	E	8.0	6.7	3.5
	F	6.0	5.5	5.0
	G	7.2	6.0	4.2
	H	5.2	4.0	3.5
	I	6.0	4.7	3.5
	J	7.0	4.5	4.5
	K	8.0	4.0	3.0
	L	5.7	3.2	2.5
	M	6.2	5.0	4.2
	N	14.0	12.0	5.7
	O	5.0	2.7	2.5
	P	5.2	3.5	2.0
	Q	6.2	4.5	3.5
	R	4.7	2.2	2.0
	S	4.7	4.2	2.5
	T	3.2	3.0	2.0
	U	3.2	3.0	2.0
	V	6.7	5.2	4.5
	W	3.5	2.5	2.5
	X	4.7	3.2	2.7
	Y	3.7	3.5	2.2
	Z	3.2	3.0	1.7
	AA	3.7	3.2	2.0
	BB	4.0	3.7	1.2
	CC	4.0	3.7	2.7
	DD	4.7	3.7	3.5
	EE	4.5	3.0	2.5
	FF	3.5	3.0	1.7
	GG	3.2	3.0	2.5
	HH	6.5	4.5	4.5
	II	5.0	5.0	2.5
	JJ	6.0	5.5	4.7
	KK	6.7	6.0	3.5
	LL	5.0	3.0	2.2
	MM	8.0	5.2	3.7
	NN	10.0	9.0	4.0

ROCK DREDGING RESULTS

PP681 - At Location of PP576

PP681	A	3.7	3.2	2.5
	B	6.0	4.0	3.0
	C	5.7	5.0	3.0
	D	5.0	4.0	2.2
	E	3.5	3.2	2.0
	F	5.0	4.2	4.0
	G	4.0	3.5	1.7
	H	5.7	3.0	3.0
	I	4.7	4.2	2.5
	J	3.5	2.7	2.0
	K	4.5	3.2	1.5
	L	5.2	4.5	3.0
	M	7.5	6.0	3.2

PP682 - At Location of PP567

PP682	A	6.5	5.7	5.7
	B	6.7	5.0	4.0
	C	6.2	5.5	1.5
	D	5.2	4.5	2.2
	E	6.2	4.7	3.0
	F	7.7	6.2	5.2
	G	7.2	4.2	3.5
	H	10.7	9.0	5.5

PP683 - At Location of PP569

PP683	A	9.0	6.5	5.5
	B	9.7	5.5	4.5
	C	9.2	7.2	3.0
	D	7.2	5.7	2.0
	E	5.0	4.0	3.2
	F	6.2	3.2	1.2
	G	4.2	2.5	2.5
	H	3.7	2.7	1.7
	I	4.0	3.5	2.0
	J	6.0	4.7	3.5
	K	5.2	5.7	3.2
	L	4.5	3.5	2.5
	M	4.5	4.2	2.7
	N	5.2	3.5	2.0
	O	3.7	3.2	2.5
	P	3.0	2.7	1.7
	Q	3.7	2.5	2.2
	R	17.5	8.5	7.0

ROCK DREDGING RESULTS

PP1095 - At Location of PP1015

PP1095	A	3.0	1.5	2.5
	B	5.0	3.0	2.5
	C	4.5	2.0	2.5
	D	3.5	1.5	2.5
	E	5.0	1.75	4.0
	F	3.0	2.75	1.5
	G	4.0	3.75	2.5
	H	5.5	2.0	3.5
	I	9.5	7.5	4.0

Also chunks of Red Clay

PP1096 - At Location of PP1016

PP1096	A	5.5	3.0	3.0
	B	3.5	2.0	3.0
	C	5.0	2.5	1.5
	D	4.0	2.0	3.0
	E	7.0	4.0	4.0
	F	3.0	1.5	2.5
	G	6.0	3.0	3.0
	H	10.0	8.0	6.5
	I	14.0	13.0	7.0
	J	3.5	2.5	3.0

PP1097 - At Location of PP1017

PP1097	A	6.5	4.5	3.0
	B	7.0	8.0	6.0
	C	6.0	5.0	2.0

Also chunks of Red Clay

PP1098 - At Location of PP1022

PP1098	A	4.5	2.0	3.0
	B	2.0	1.5	1.75
	C	3.5	3.0	3.5
	D	3.75	2.0	3.0
	E	2.75	2.0	2.5
	F	2.5	2.0	2.0
	G	3.5	2.5	2.0
	H	2.75	2.0	2.5
	I	3.5	2.5	2.0
	J	3.0	2.0	2.5
	K	6.5	3.0	3.5
	L	3.0	1.75	2.5

ROCK DREDGING RESULTS

PP1098	M	3.5	1.0	2.0
	N	3.5	2.0	2.75
	O	3.0	1.5	3.5
	P	4.0	2.0	2.5
	Q	3.75	1.5	2.5
	R	3.0	1.5	2.0
	S	4.0	1.5	2.5
	T	4.25	1.75	2.5
	U	3.75	2.5	2.5
	V	3.25	2.5	1.75
	W	2.25	1.5	2.0

PP1099 - At Location of PP1043

PP1099	A	3.5	2.5	4.0
	B	6.5	4.0	2.0
	C	6.0	3.5	4.0
	D	3.5	4.0	2.5
	E	4.5	2.0	4.0
	F	6.0	5.0	4.5
	G	11.0	7.5	5.0
	H	17.0	13.0	4.5
	I	6.5	7.0	6.0

PP1100 - At Location of PP1056

PP1100	A	6.5	6.0	3.5
	B	8.0	4.0	4.0
	C	12.0	8.0	5.0
	D	6.0	4.0	3.0

PP1101 - At Location of PP1057

PP1101	A	5.0	3.0	2.0
	B	6.0	4.0	3.5
	C	3.0	2.5	2.0
	D	2.5	4.0	2.0
	E	6.0	4.0	3.0
	F	2.5	3.5	3.0
	G	2.5	3.0	2.0
	H	9.0	8.0	5.0
	I	9.0	6.5	4.0
	J	12.0	6.0	10.0

Also chunks of Red Clay

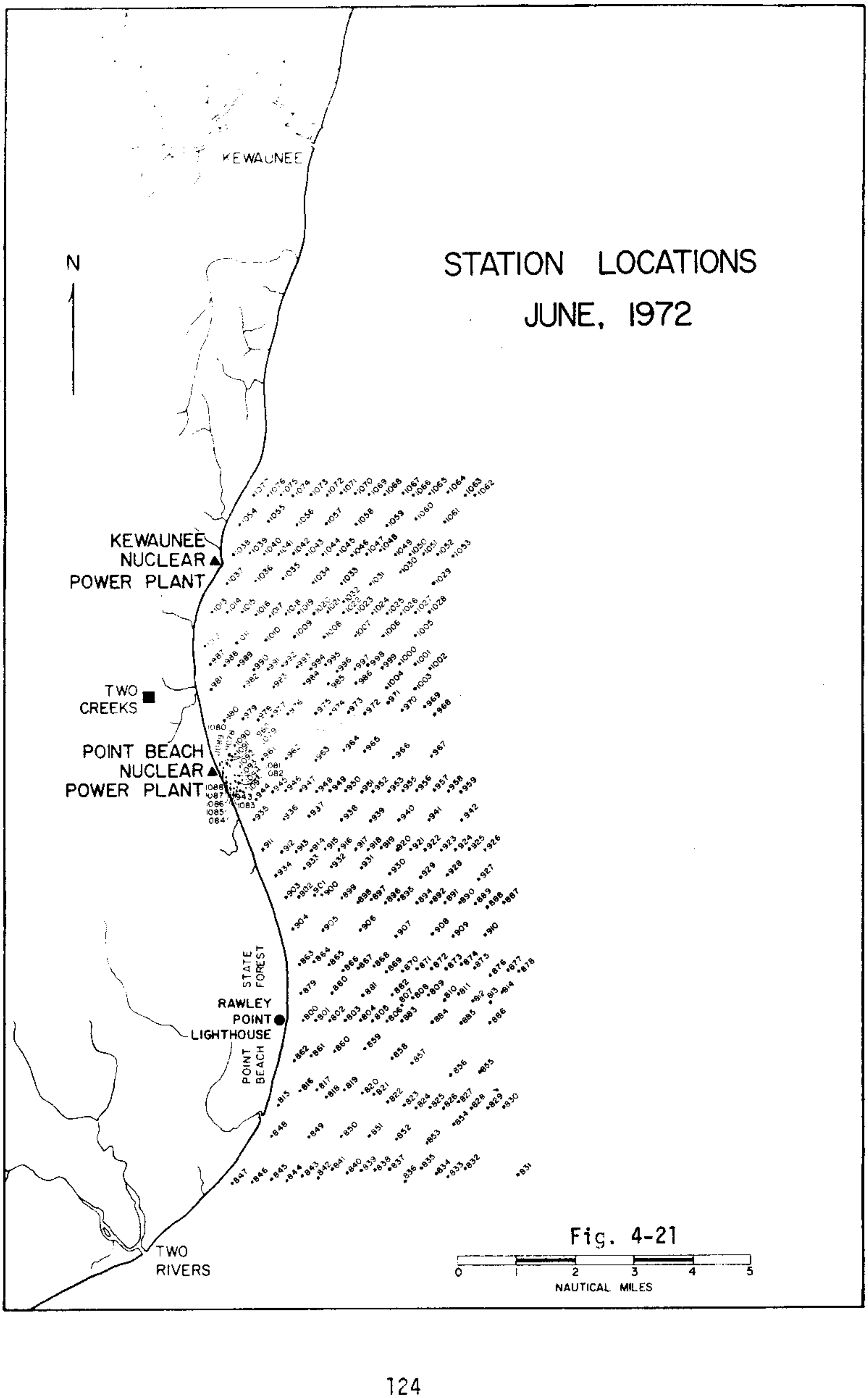

STATION LOCATIONS
JUNE, 1972
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-21

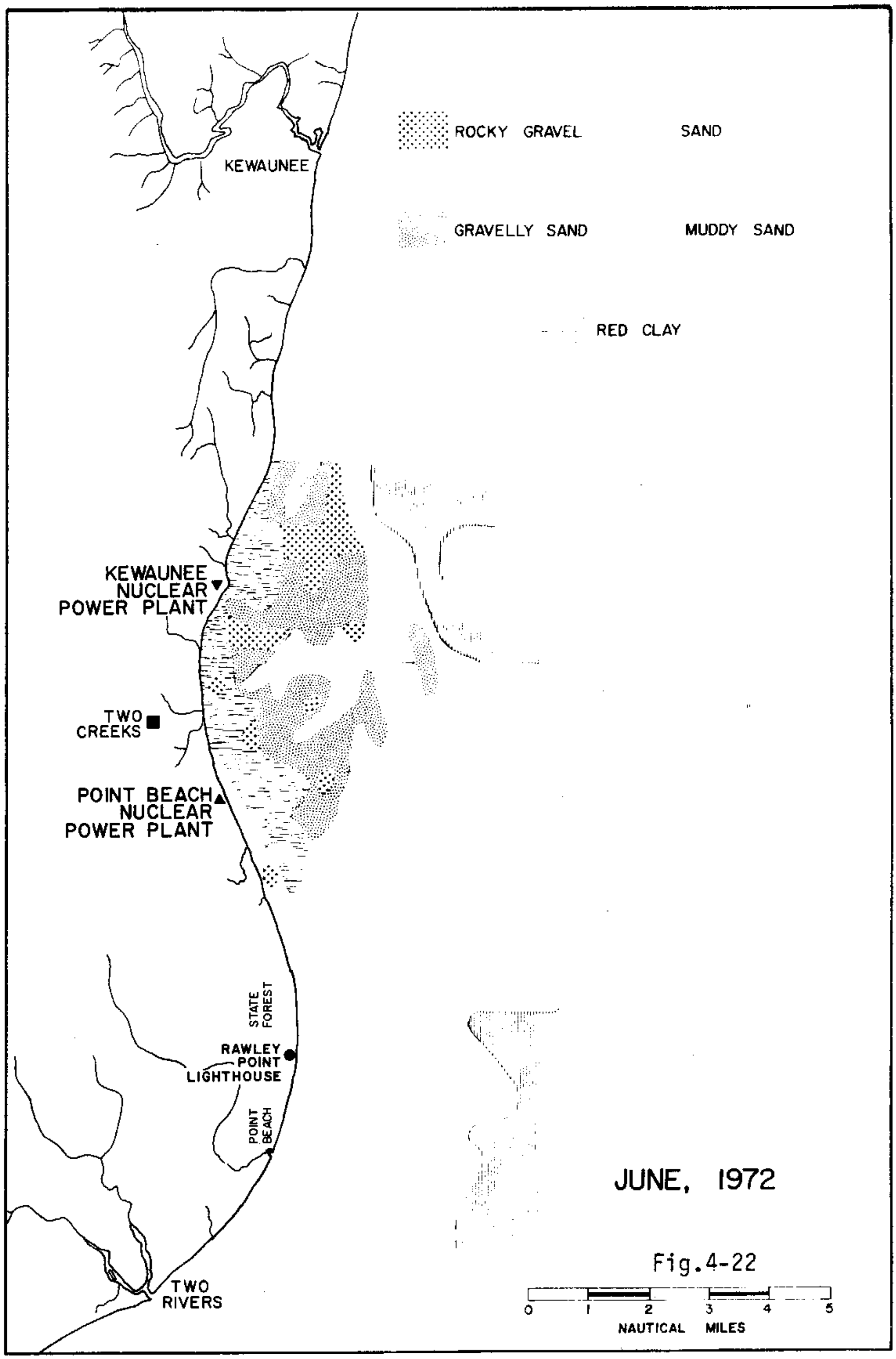

ROCKY GRAVEL
SAND
GRAVELLY SAND
MUDDY SAND
RED CLAY
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
JUNE, 1972
0 1 2 3 4 5
NAUTICAL MILES

Fig.4-22

The extent of the exposed red clay changed somewhat since the three previous surveys. Comparing the results of the June, 1972 survey to those of the June, 1971 survey, it can be seen that the lobe of clay in the intermediate depths has changed form somewhat. At stations 944 and 962 (stations 071 and 162 of the June, 1971 survey), clay was exposed whereas gravelly sand and sand was found there in June, 1971. The converse was true at station 947 (station 073 of the June, 1971 survey) where clay was found one year before. It should be remembered that this was a station where in June, 1972 the gravelly sand appeared as a veneer on the clay. Further, a smaller area of clay was exposed in June, 1972 directly in front of Point Beach Power Plant than in June, 1971.

To the north in the areas offshore of the Kewaunee Power Plant and Two Creeks, the clay area exposed became narrower. The rocky gravel found just north of the Kewaunee Power Plant in June, 1971 was not found during June, 1972.

Comparing the area of exposed clay in the July, 1971 and June, 1972 surveys, it is apparent that the southward extending lobe of "clean" clay had become slightly larger by June, 1972, but that areas directly in front of the flume structure which were previously exposed clay had become sand covered. This same trend can be seen when comparing the August, 1971 survey to the June, 1972 survey in regard to the exposed clay. By June, 1972, the clay lobe had increased its dimension offshore but clay which had been exposed near the flume structure in front of Point Beach Power Plant was, by June, 1972, covered with sand. To the north, the exposed clay zone narrowed, as unconsolidated material had moved closer to shore.

The rocky gravel and gravelly sand, then, had quite obviously moved in towards shore in the study area north of Point Beach Power Plant as compared to the June, 1971 and August, 1971 surveys with the exception of inshore waters at the northernmost section, where clay was exposed in June, 1972, but was not in June, 1971. Similarly, a lobe of sand had moved in towards shore between the Kewaunee and Point Beach Power Plants by June, 1972. This feature was not found in any of the three previous surveys. This sand may have, in fact, covered over the rocky gravel and gravelly sand found in the area before.

Results of chain bag dredging, as shown in Table 4-1 showed that rocks of a similar size to those recovered in August, 1971 were found in June, 1972.

It is important to note the sand patch along the shoreline lakeward of the flume structure which developed during the period of this study. Where there was a small sand patch surrounded by clay in June, 1971, and where in July, 1971, clay was exposed with sand patches to either side, a large sand patch was formed by August, 1971; and by June, 1972, this sand patch had become a northerly extending lobe of the large sand area covering the southern zone of the study area.

As in the three previous surveys, the southern part of the sampling grid was dominated by sand. The recovery, at station 822, of desiccated red clay along with the sand would seem to indicate that the sand is underlain in this area by clay material.

Finally, muddy sand was found offshore, as it had been previously. The patches of muddy sand found in the intermediate depth waters off Rawley Point during July and August, 1971, were not found in June, 1972.

Although it was only possible to sample a very small section of the survey area in November, 1972 (Figs. 4-23 and 4-24), two important points stand out. First, an area of gravelly sand was found south of Point Beach Power Plant at station 1530 (station 058 of the June, 1971 survey). In this area, clay was found during the June, 1971 and June, 1972 surveys while sand was recovered during the July and August, 1971 surveys.

Also, three patches of muddy sand were found. The largest was off Rawley Point while another was nearshore midway between Point Beach Power Plant and Rawley Point. The third area was a station at the lakeward edge of the grid, in deeper water. The remainder of the study area was sand.

In summary, four surficial sediment types were found. Desiccated red clay was found predominately in the nearshore and intermediate depth waters north of Point Beach Power Plant but with a lobe of changing proportions south of the power plant. A zone of rocky gravel and gravelly sand, including large rocks, was found in the intermediate depths lakeward of the clay exposures. Patches of this material were also found in the nearshore and intermediate depths south of Point Beach Power Plant. While, during the summer of 1971, the exposure of material south of Point Beach Power Plant became more extensive, by June, 1972, at only one station (911) was this sort of material recovered. Similarly, in November, 1972, one station showed a gravelly sand surficial sediment. The sand in the southern zone of the sampling grid was extensive during each of the surveys. By June, 1972, a large lobe of sand had moved in towards shore north of Point Beach Power Plant.

Directly lakeward of the outfall, where a small sand patch existed during June, 1971, and where clay was found in July, 1971, a sand patch was found to be growing by August, 1971. This trend continued through June, 1972 when the sand patch extended southward along the shore, connecting with the extensive sand area to the south.

Muddy sand was found offshore, but during the mid and late summer of 1971, and in November, 1972, patches of this material were found off Rawley Point.

It is believed by this author that the desiccated red clay is a relict sediment, as are most of the large rocks found within the sampling grid. Swift, et al. (1971, p. 324) wrote: "... sediments are defined as relict because they are where they are today, having been transported to the site and deposited there when the environment was different." As mentioned previously, this red clay was strikingly similar to the Valders till forming the back beach. While the mineralogical relationship of these materials will be discussed later in this chapter, it appears that these same glacial deposits found onshore underlie the recent sediments in the lake. The many stations where a veneer of unconsolidated material was found to overlie the red clay bears this out. Large rocks are known to exist in these glacial deposits onshore (Thwaites and Bertrand, 1957) and may well have been contained within the red clay offshore at one time. If the red clay is slowly being worn down, the rocks may have been exposed at the surface during this process. A few of these large rocks may have been rafted into the area by ice, but it does not seem possible that this origin can be ascribed to the large number of rocks found in the area. Also, this would not explain why these large rocks were found in certain local patches of the northern part of the study area, but not in others.

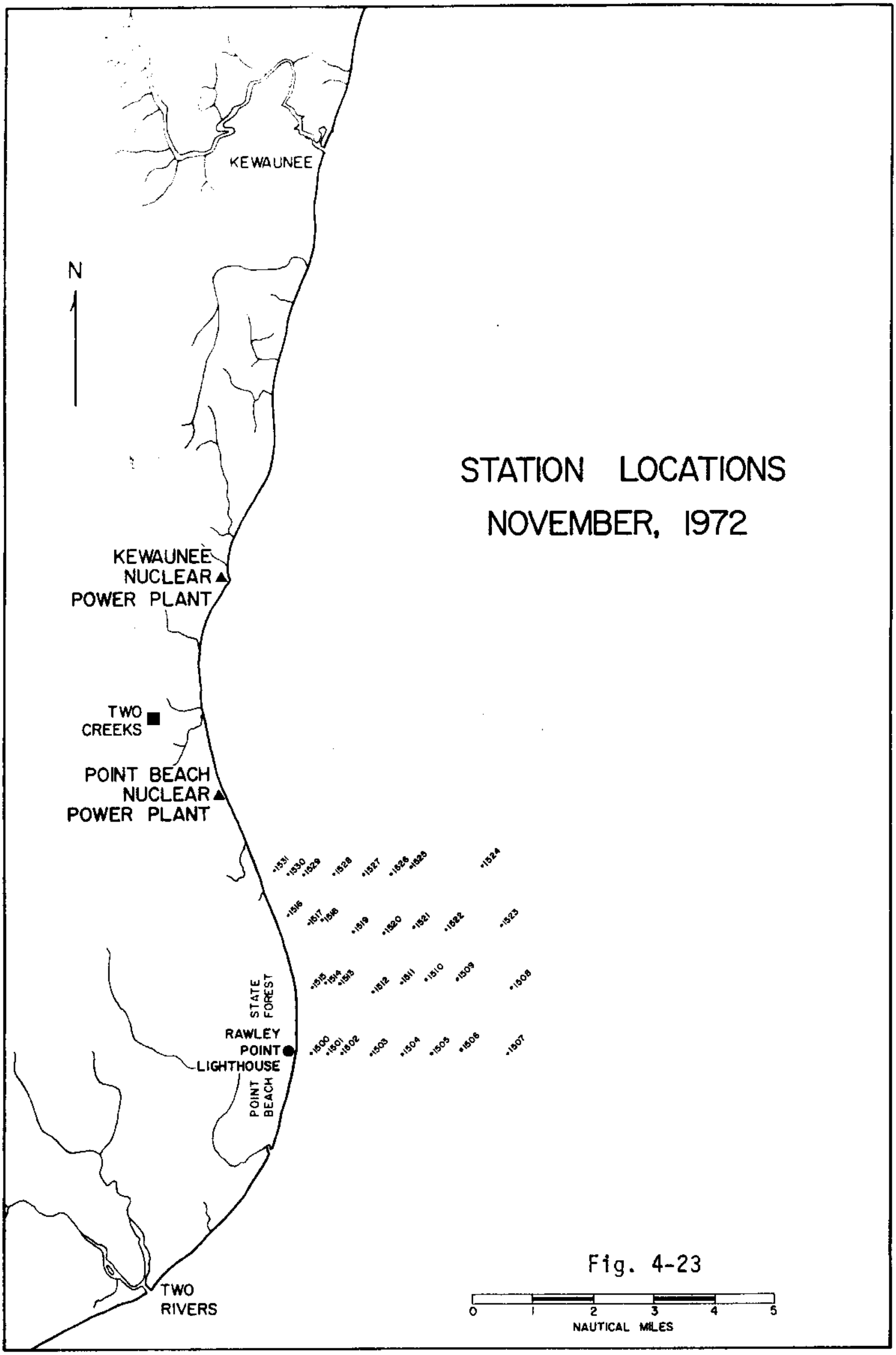

KEWAUNEE
N
STATION LOCATIONS
NOVEMBER, 1972
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
1531
1530
1529
1528
1527
1526
1525
1524
1516
1517
1518
1519
1520
1521
1522
1523
1515
1514
1513
1512
1511
1510
1509
1508
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
1500
1501
1502
1503
1504
1505
1506
1507
POINT
BEACH
TWO
RIVERS
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-23

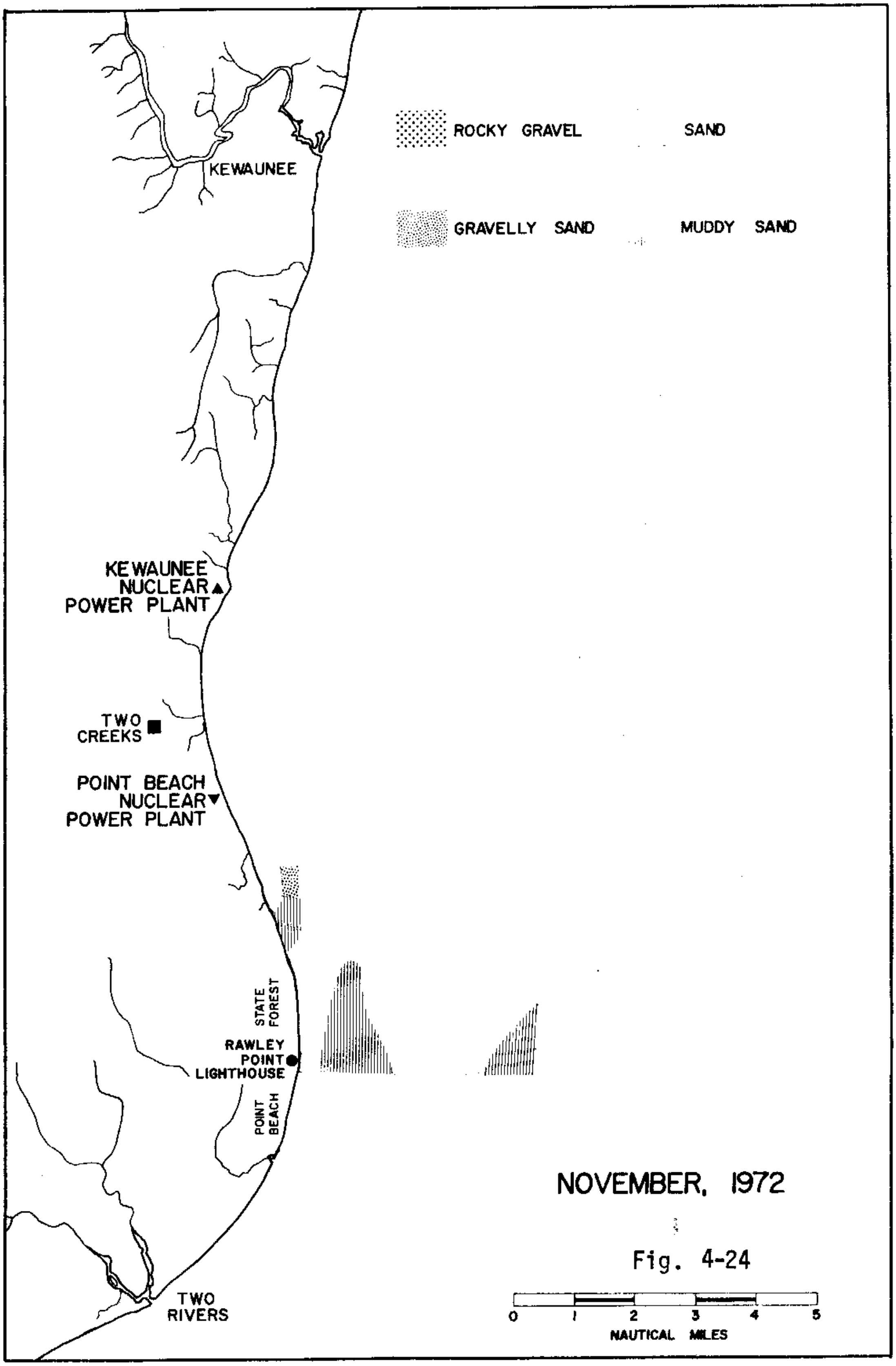

ROCKY GRAVEL
SAND
GRAVELLY SAND
MUDDY SAND
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
NOVEMBER, 1972
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-24

The study area can be characterized, then, by a combination of relict sediments and recent unconsolidated materials. There is considerable difference in the nature of the unconsolidated material, with patchy rocky gravel and gravelly sand dominating the northern zone and sand dominating the southern zone.

TEXTURAL PARAMETERS

Patterns formed by the statistical parameters compiled from texture-weight analyses of the surficial sediments can aid in characterizing the patterns of transport and depositional environments of the area. First to be reviewed are the patterns revealed during each survey, followed by a comparison and delineation of trends during the study period.

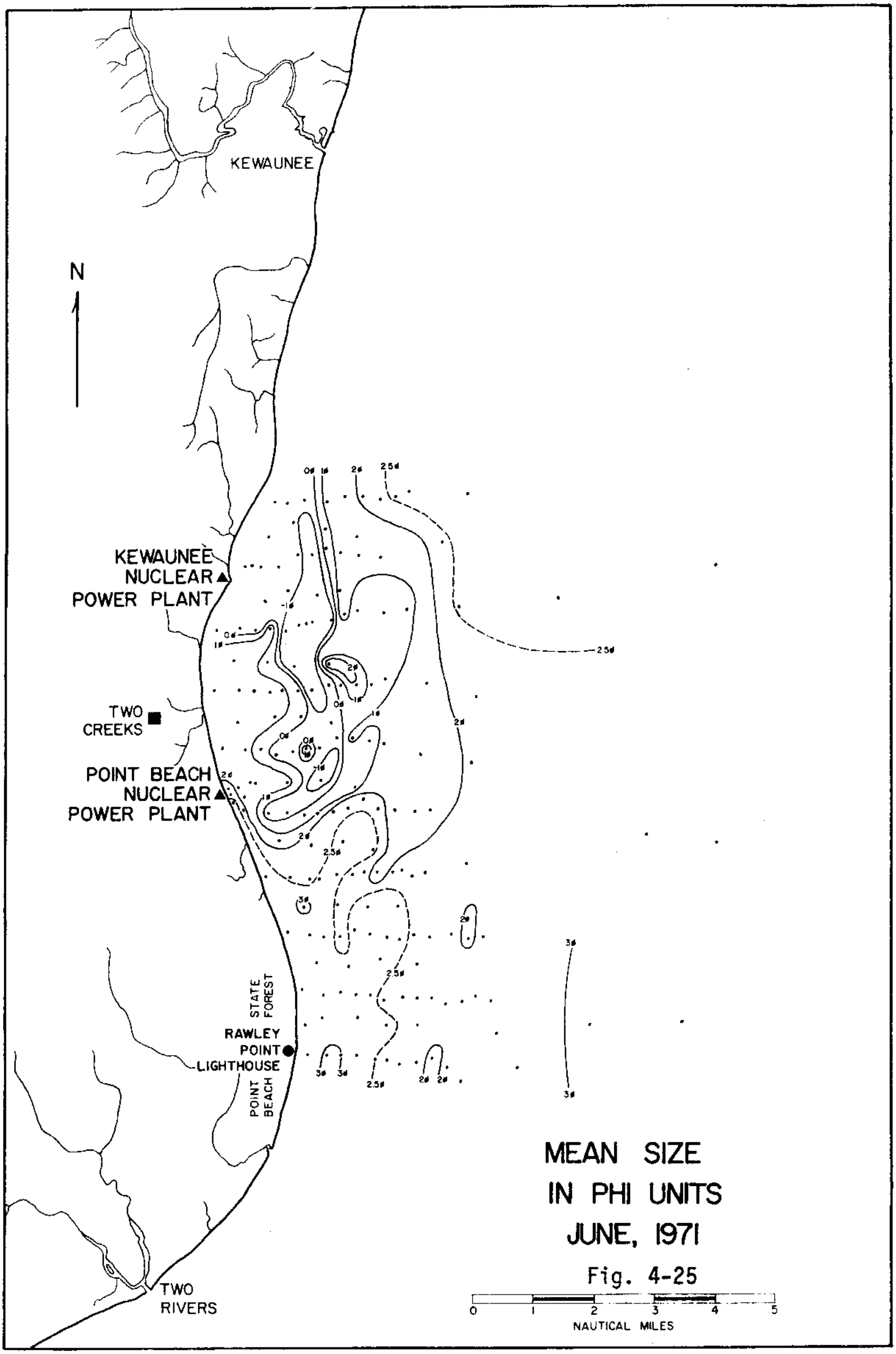
Considering the June, 1971 parameters, the mean size (Fig. 4-25) indicates, in the intermediate and nearshore waters, a trend of larger sizes to the north, decreasing to the south. There was, in fact, a north-south trending lobe of coarse material (coarser than 0ø) off the Kewaunee Power Plant, surrounded by a large lobe of material of decreasing distance from the center. To the south, a large zone of fine sand was found, with the slightly finer textures in this size class lying nearshore. The limits of this sand area were affected by the coarser component to the north, as evidenced by the lobes of coarser material extending southward into the fine sand. Lakeward of Rawley Point, two stations with very fine sand were found. Offshore, near the limits of the study area, a gradation existed to fine and very fine sand as a mean size.

Much the same pattern is shown by the median diameter (Fig. 4-26) contours. A large north-south trending lobe of coarse textures appears on the chart, with the coarsest material at its center and decreasing sizes towards the edges. Again fine sand dominated the southern and offshore zones.

By contouring the phi diameter at which the cumulative curve of the texture reaches 84% and 95% of the total weight, a distribution of the finer fractions can be seen. The ø84 (Fig. 4-27) and ø95 (Fig. 4-28) contours of the June, 1971 survey further su stantiates the gradation of coarser to finer material along the north-south trend and the occurrence of finer material offshore. Shoreward of Point Beach State Forest the area of finer sand indicated on the mean size chart is also apparent on the ø84 and ø95 charts.

Considering the sorting parameter (Fig. 4-29), the sediments to the north of Point Beach Power Plant were less well sorted (See Table 4-2) than those further south. This is in general agreement with the theory reviewed earlier which showed that sorting increases as a diameter of 0.18 mm. (2.5ø) is approached. The lobe of coarser bimodal material in the northern area is reflected in the lobe of sorting values greater than 1ø. Sorting values below 1ø, both offshore and in the southern zone, reflect the fine sand nature of the surficial sediment. Lying along the shoreline between Point Beach Power Plant and Rawley Point were well and very well sorted fine-very fine sands.

By reviewing the parameters from the July, 1971 survey similar trends are observed. Mean size (Fig. 4-30) decreased from north to south in the intermediate zones between Point Beach Power Plant and Rawley Point. A lobe of material coarser than 2ø mean size extended about 1-1/3 miles south of the power plant in the intermediate depths. A fine sand area again dominated the south with the



MEAN SIZE
IN PHI UNITS
JUNE, 1971

Fig. 4-25

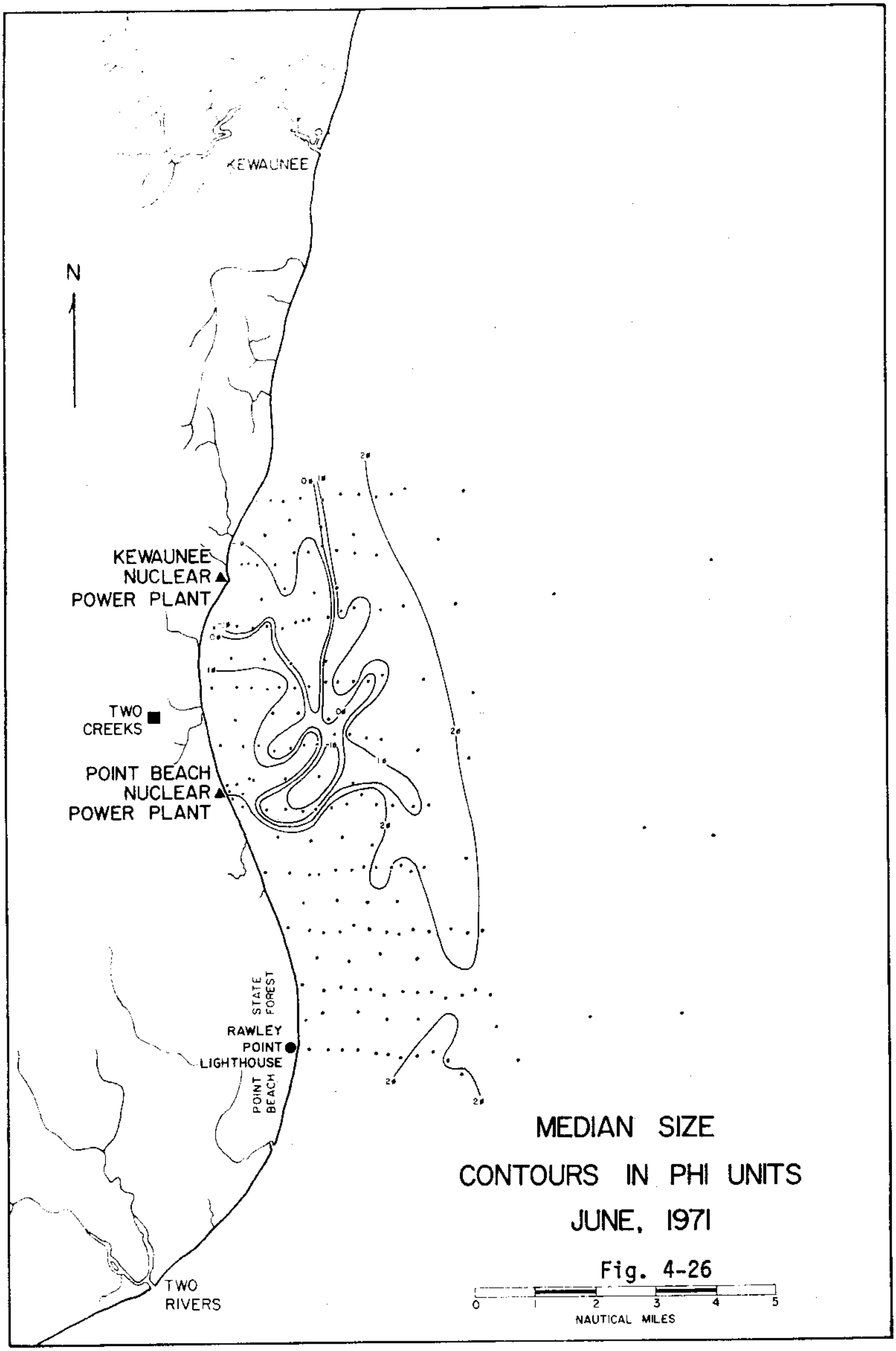
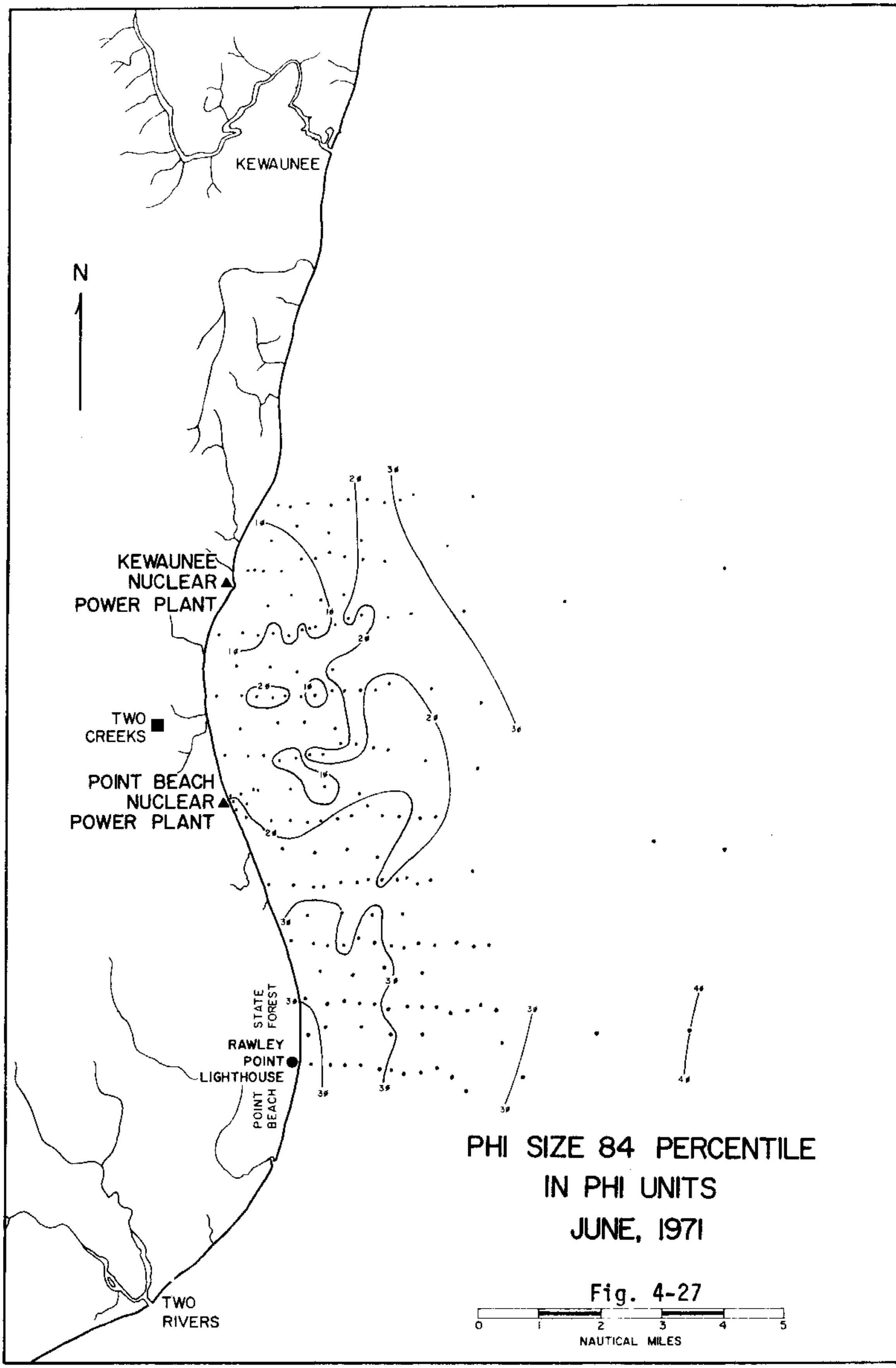
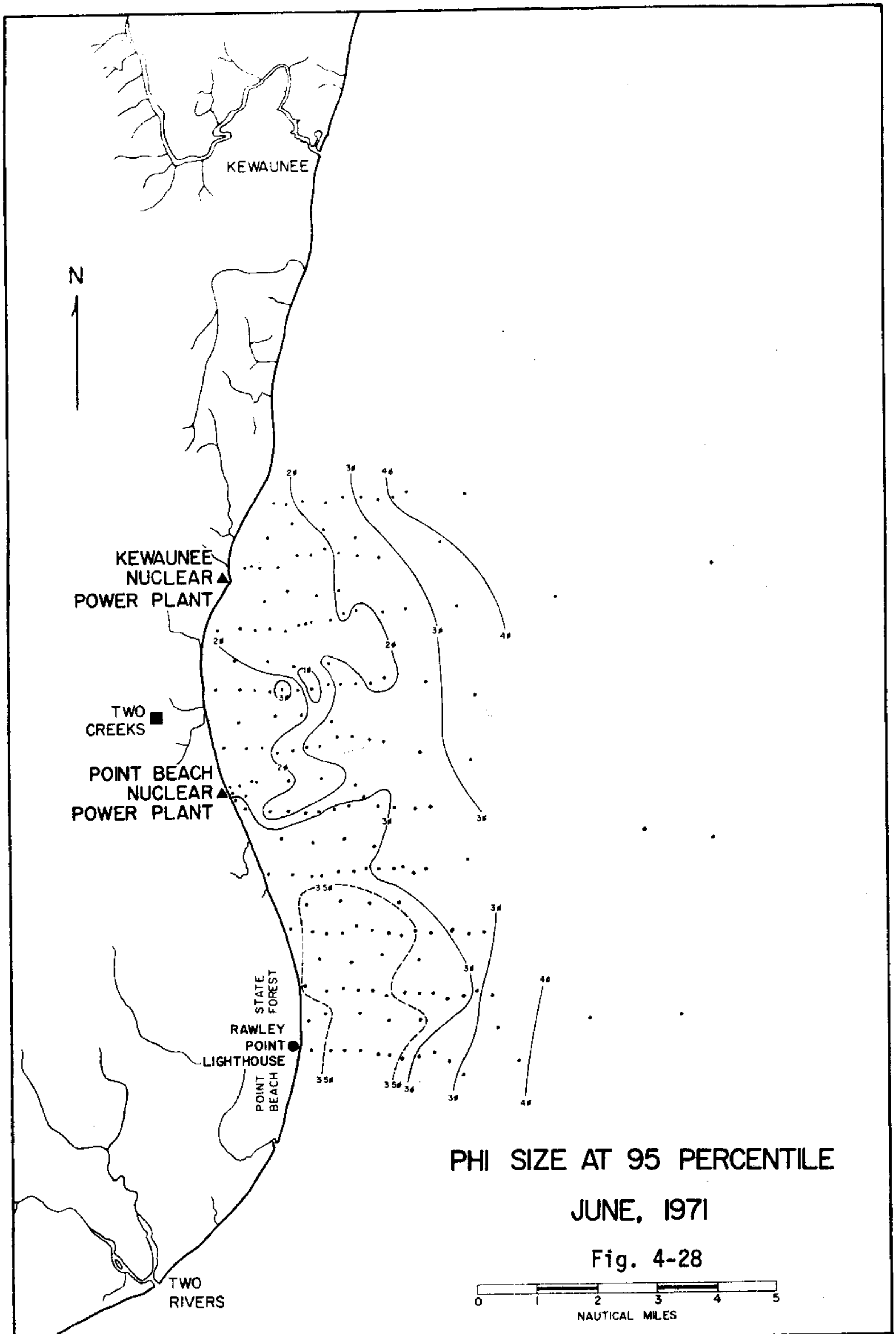

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
MEDIAN SIZE
CONTOURS IN PHI UNITS
JUNE, 1971
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-26



PHI SIZE 84 PERCENTILE
IN PHI UNITS
JUNE, 1971

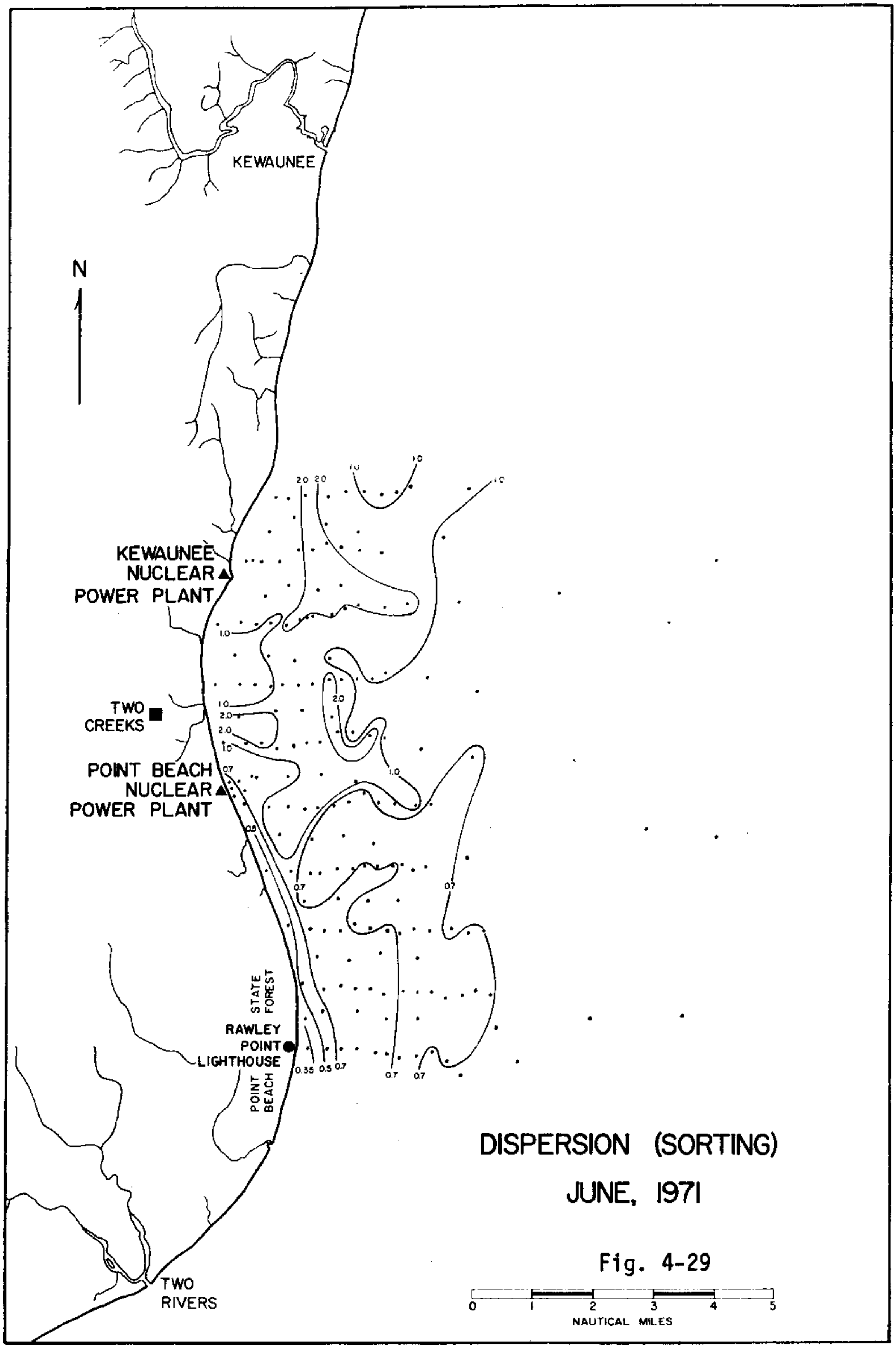
Fig. 4-27



PHI SIZE AT 95 PERCENTILE

JUNE, 1971

Fig. 4-28



DISPERSION (SORTING)
JUNE, 1971

Fig. 4-29

TABLE 4-2

Interpretation of the Sorting Parameter

Sorting Values	Verbal Classification
Less than 0.35ø	Very Well Sorted
0.35 - 0.50ø	Well Sorted
0.50 - 0.71ø	Moderately Well Sorted
0.71 - 1.0ø	Moderately Sorted
1.2 - 2.0ø	Poorly Sorted
2.0 - 4.0ø	Very Poorly Sorted

From: Folk, 1968

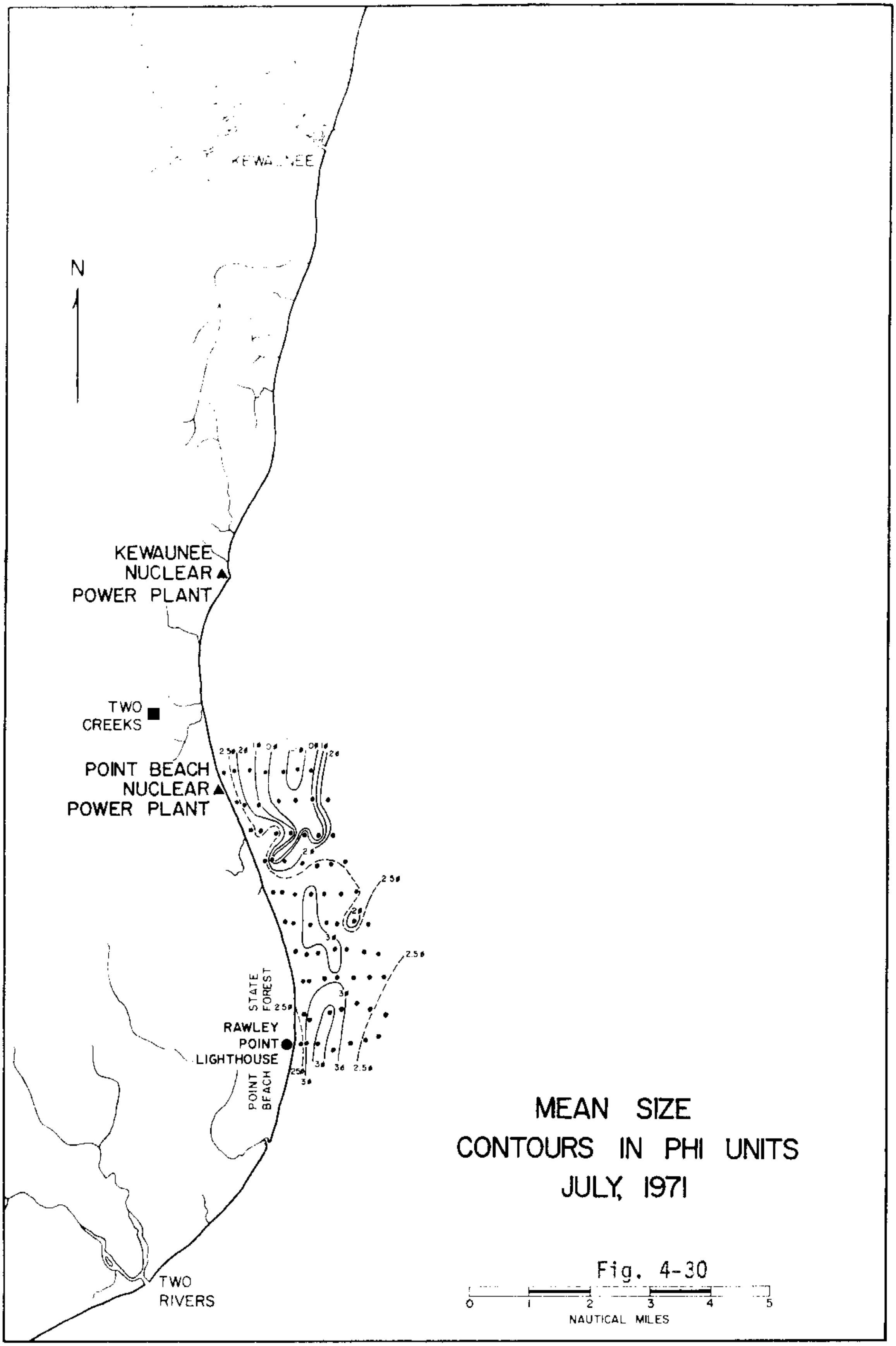

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
MEAN SIZE
CONTOURS IN PHI UNITS
JULY, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-30

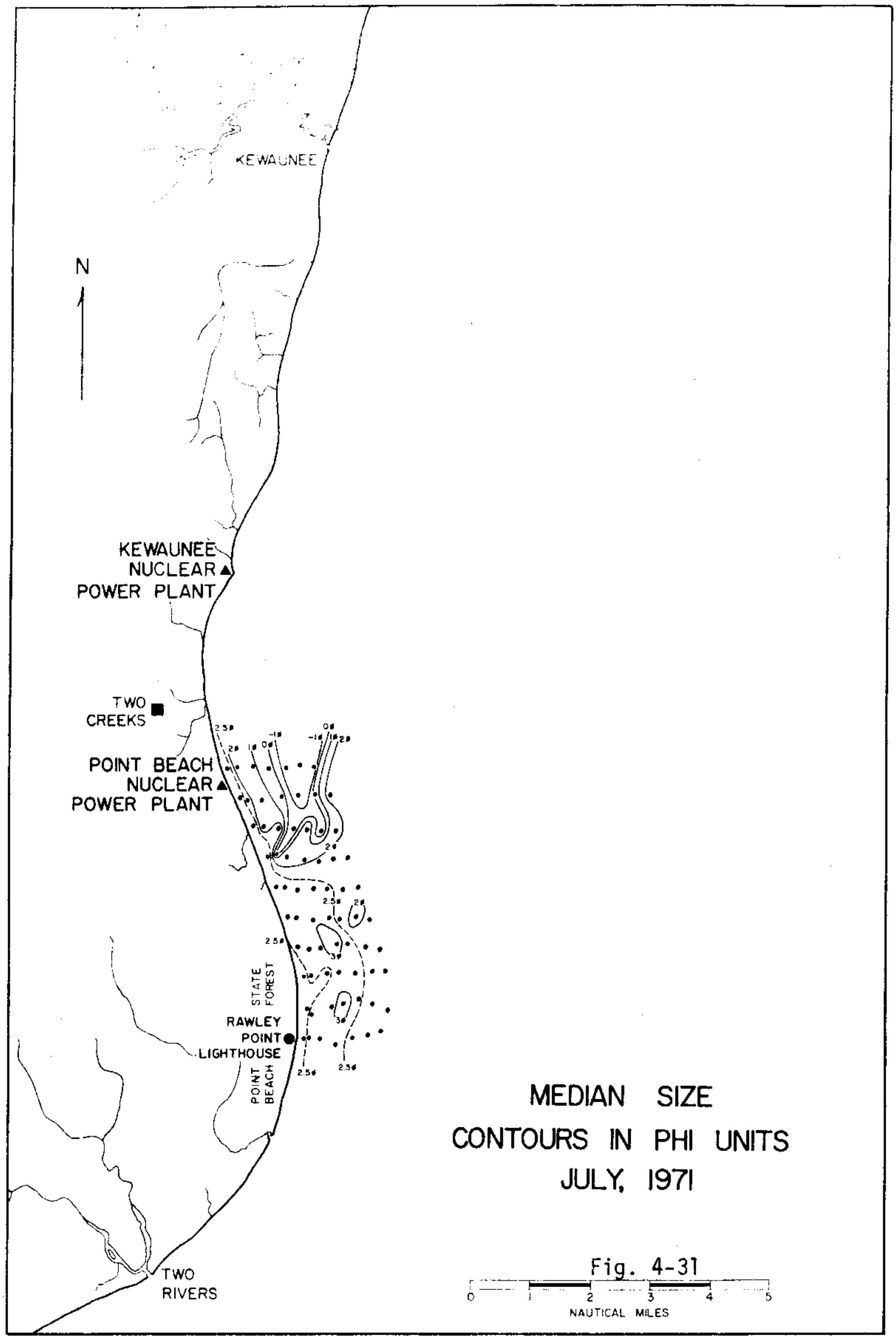
finer textures in that size class occurring along the shore with the exception of the one station nearest Rawley Point. Two areas of surficial sediment with mean sizes in the very fine sand range occurred admidst the fine sand patch.

The median diameter (Fig. 4-31) contours indicate an almost identical pattern. A lobe of sediment with a median diameter coarser than 2ø dominated the northern section of the sampling grid, extending at its southernmost point about 1-1/3 miles south of Point Beach Power Plant. Lying admidst the fine sand in the south, two areas of very fine sand again appeared. Whereas only one station along the shoreline had a mean size greater than 2.5ø, four stations had a median size less than 2.5ø.

Patterns established by the ø84 (Fig. 4-32) and ø95 (Fig. 4-33) parameters are markedly similar to the mean and median sizes. The ø84 size decreased from north to south, with a band of material with slightly larger ø84 values bordering the shore north of Rawley Point. This indicates that this nearshore area had been swept clean of very fine particles. The sorting parameter (Fig. 4-34) again followed the trends indicated by the size parameters. The northern coarser material was more poorly sorted than the sand to the south, whose mean size approached 2.5ø.

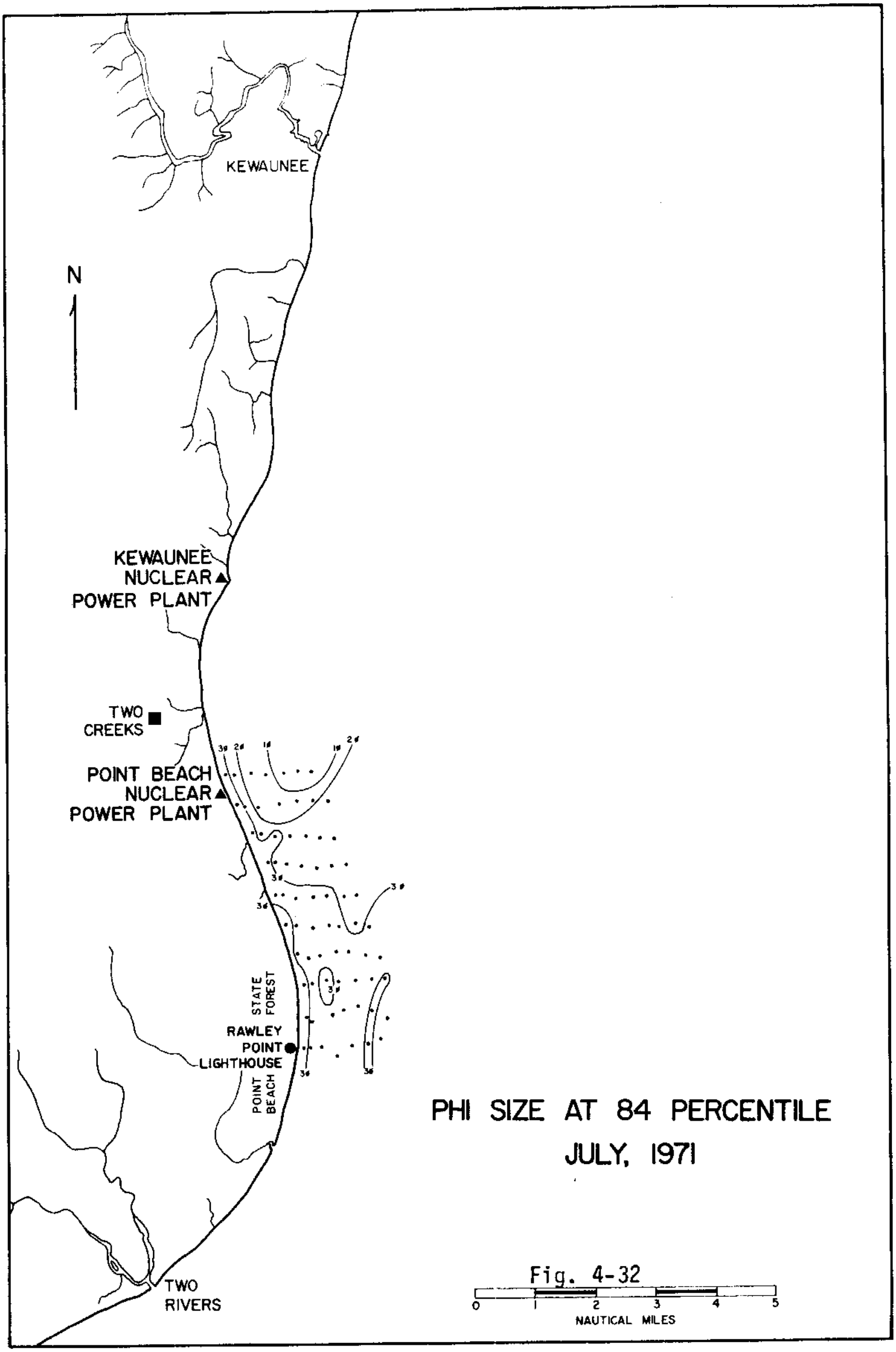
While the major trends exhibited by the statistical parameters from the previous two surveys were also apparent in the August, 1971 survey, several anomalies did occur. Patches of material of mean size above 2ø appeared along the shore north of Point Beach Power Plant and immediately in front of the Power Plant (Fig. 4-35). Of particular interest is the material of mean size less than 2ø directly shoreward of the Unit I discharge outfall. One area of mean size finer than 3ø was found in the intermediate waters north of Rawley Point. While each of these features is also demonstrated by the median size contours, one more feature is indicated by this parameter (Fig. 4-36). The four stations along the shore north of Rawley Point had a median diameter slightly larger than the more lakeward stations in the area. Considering the ø84 (Fig. 4-37) and ø95 (Fig. 4-38) charts of this survey, this band of coarser material is obvious. As far as the patches of sand along the coast north and in front of the power plant are concerned, they too are reflected in the ø84 and ø95 values. The sorting values (Fig. 4-39) from the August, 1971 survey exhibit a somewhat more complicated pattern. First, the more poorly sorted sediments did occur in the northern section, reflecting the coarser bimodal material. Also, the sand patches bordering the shoreline directly in front of and north of the power plant were better sorted than the surrounding sediments, with the exception of the material at station 632. It was this station, directly in front of the Unit I flume, which had a coarser mean and median size than the associated sand. In the intermediate depths south of Point Beach Power Plant, the relationship between mean size and sorting broke down. The area of poorly sorted material extended into the zones of material with mean diameters in the fine and very fine sand classes. This occurred at stations 589 and 600.

The mean diameter values (Fig. 4-40) from the June, 1972 survey show that sand dominated most of the study area. To the south of Point Beach Power Plant, mean diameter values corresponding to fine sand occurred with the slightly finer values in this size class predominating along the shoreline and extending into the intermediate depths. One large patch of sand with mean diameters in the very fine sand category was revealed south of Rawley Point along with another patch



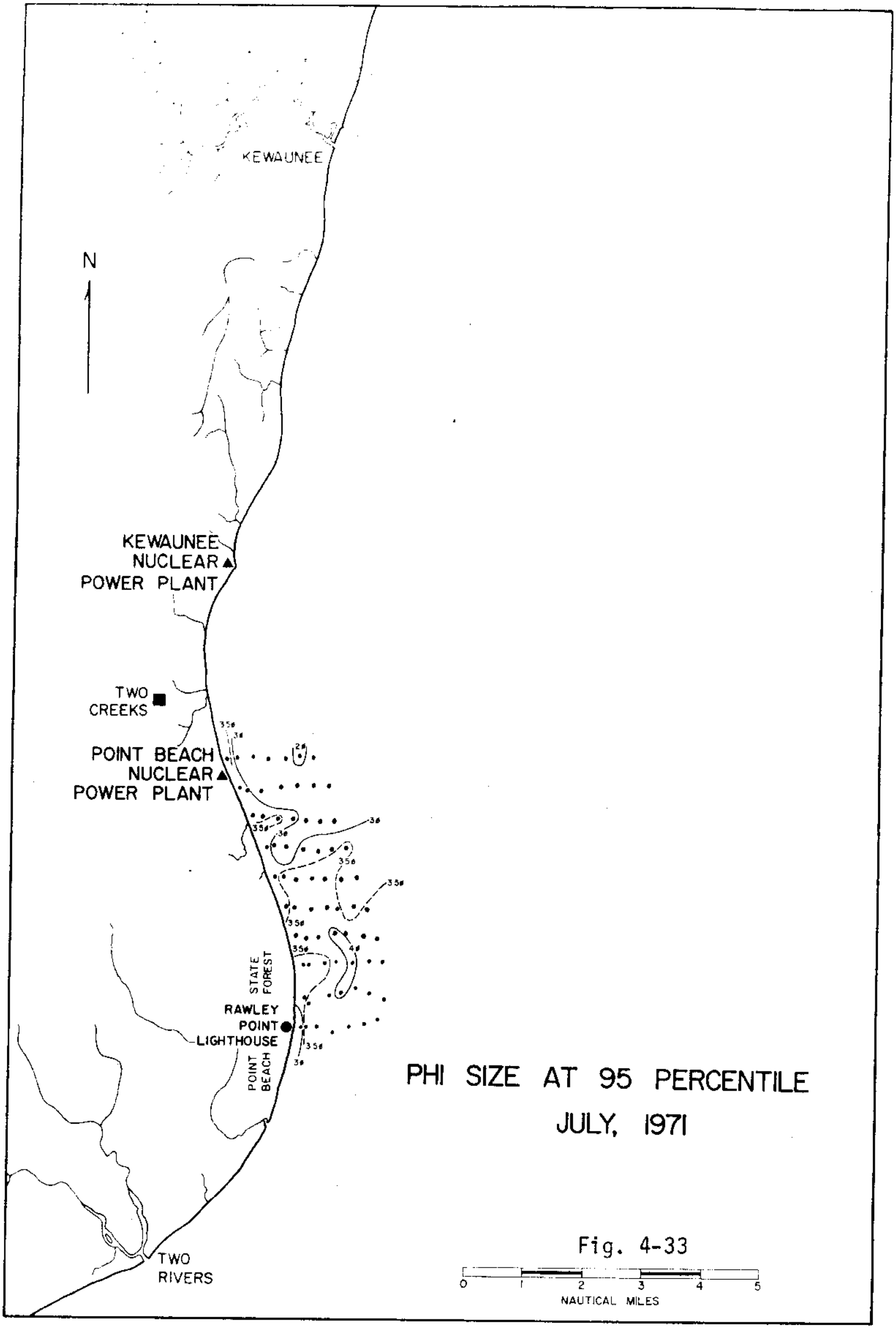
MEDIAN SIZE
CONTOURS IN PHI UNITS
JULY, 1971

Fig. 4-31



PHI SIZE AT 84 PERCENTILE
JULY, 1971

Fig. 4-32



PHI SIZE AT 95 PERCENTILE
JULY, 1971

Fig. 4-33

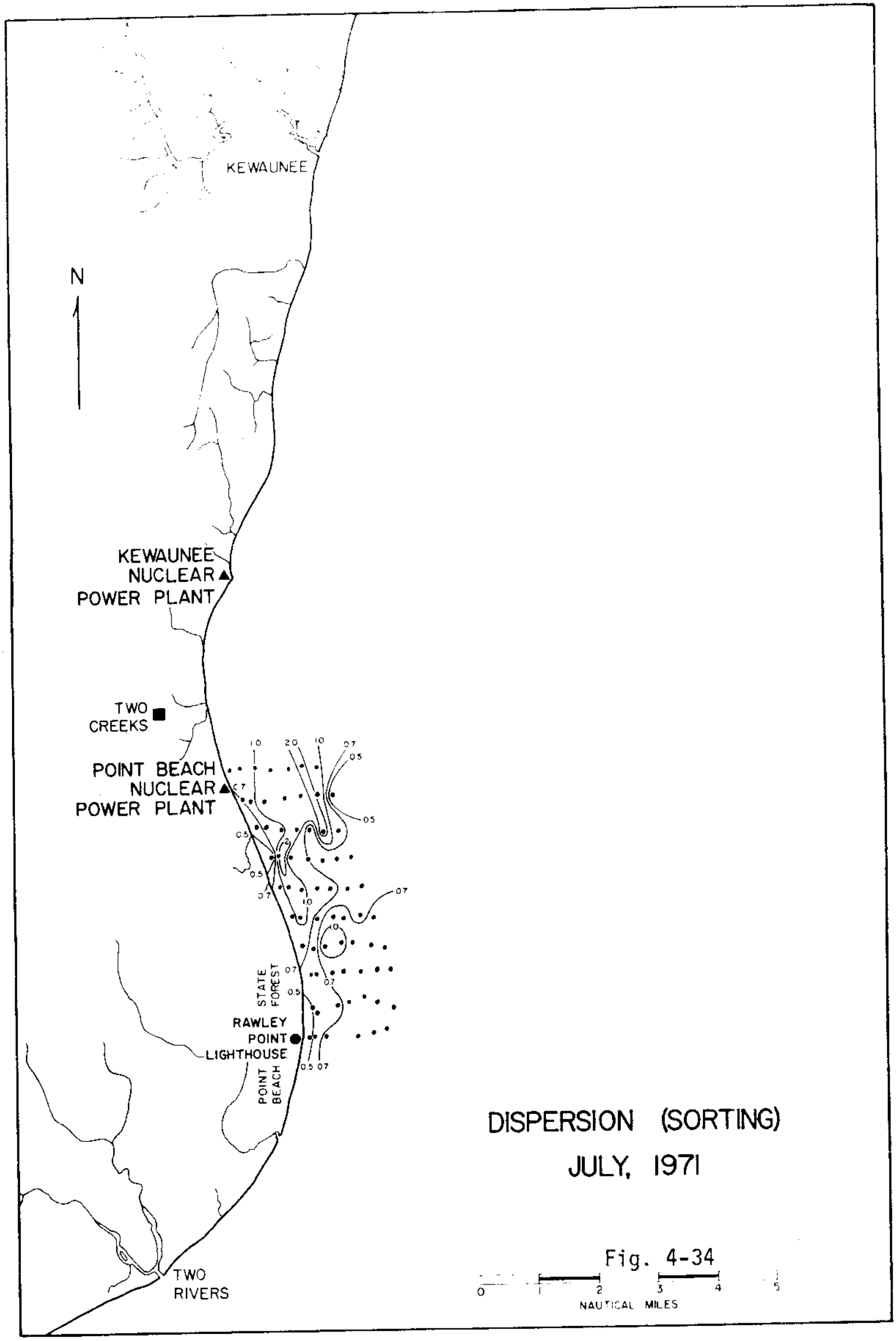
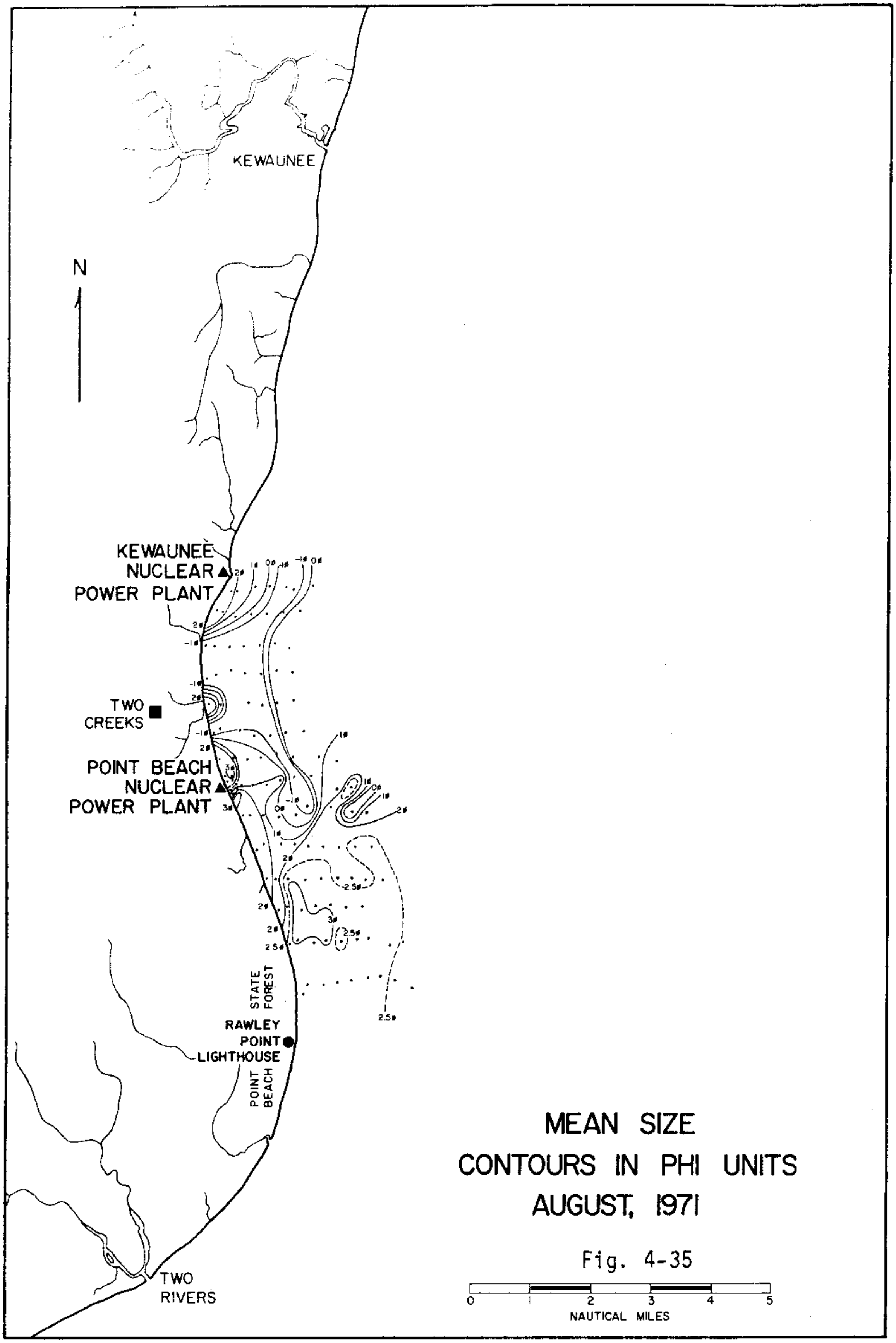
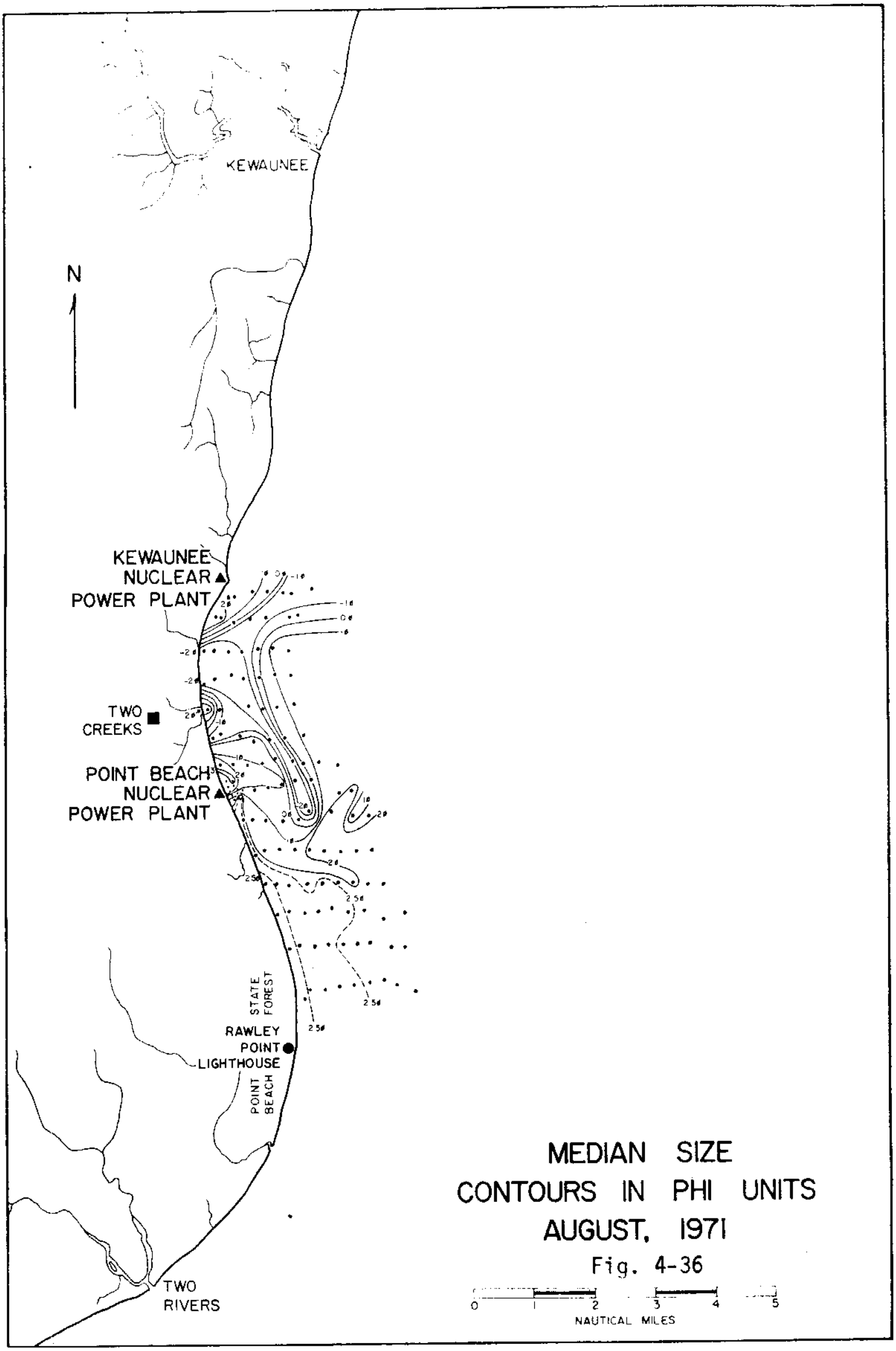

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
DISPERSION (SORTING)
JULY, 1971
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-34



KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
MEAN SIZE
CONTOURS IN PHI UNITS
AUGUST, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-35



MEDIAN SIZE
CONTOURS IN PHI UNITS
AUGUST, 1971

Fig. 4-36

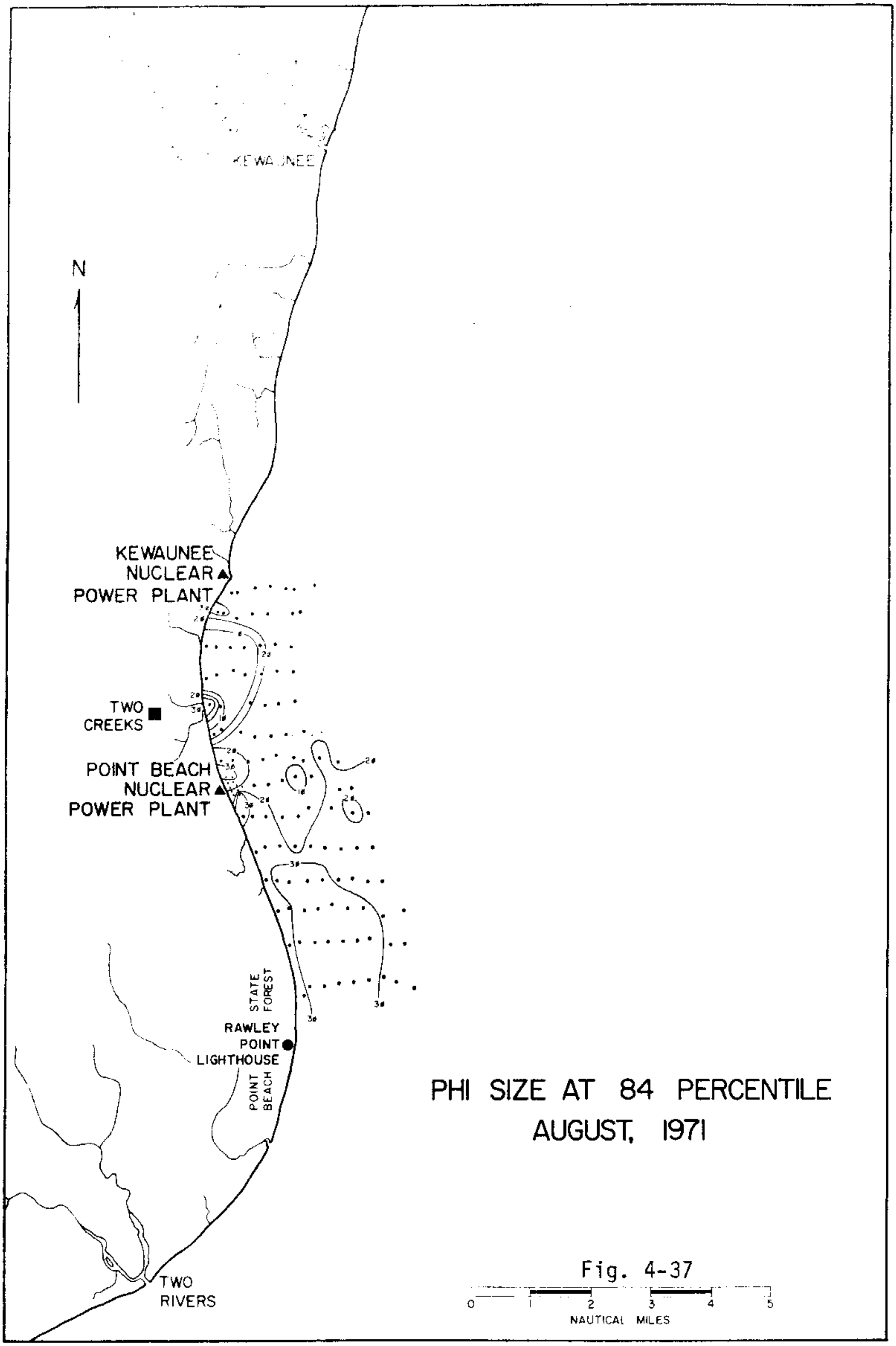

N
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
PHI SIZE AT 84 PERCENTILE
AUGUST, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-37

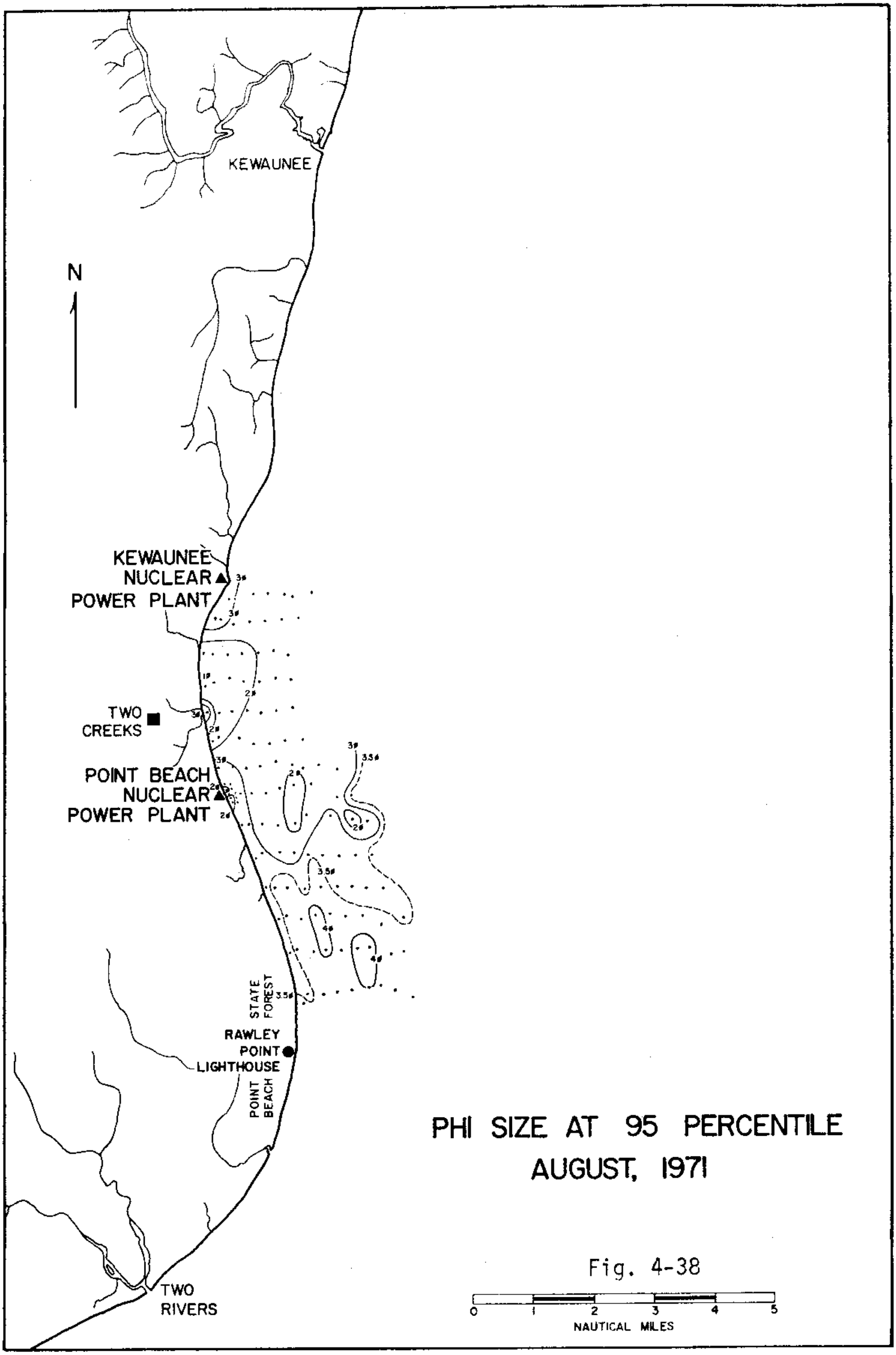

KEWAUNEE
N
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
PHI SIZE AT 95 PERCENTILE
AUGUST, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-38

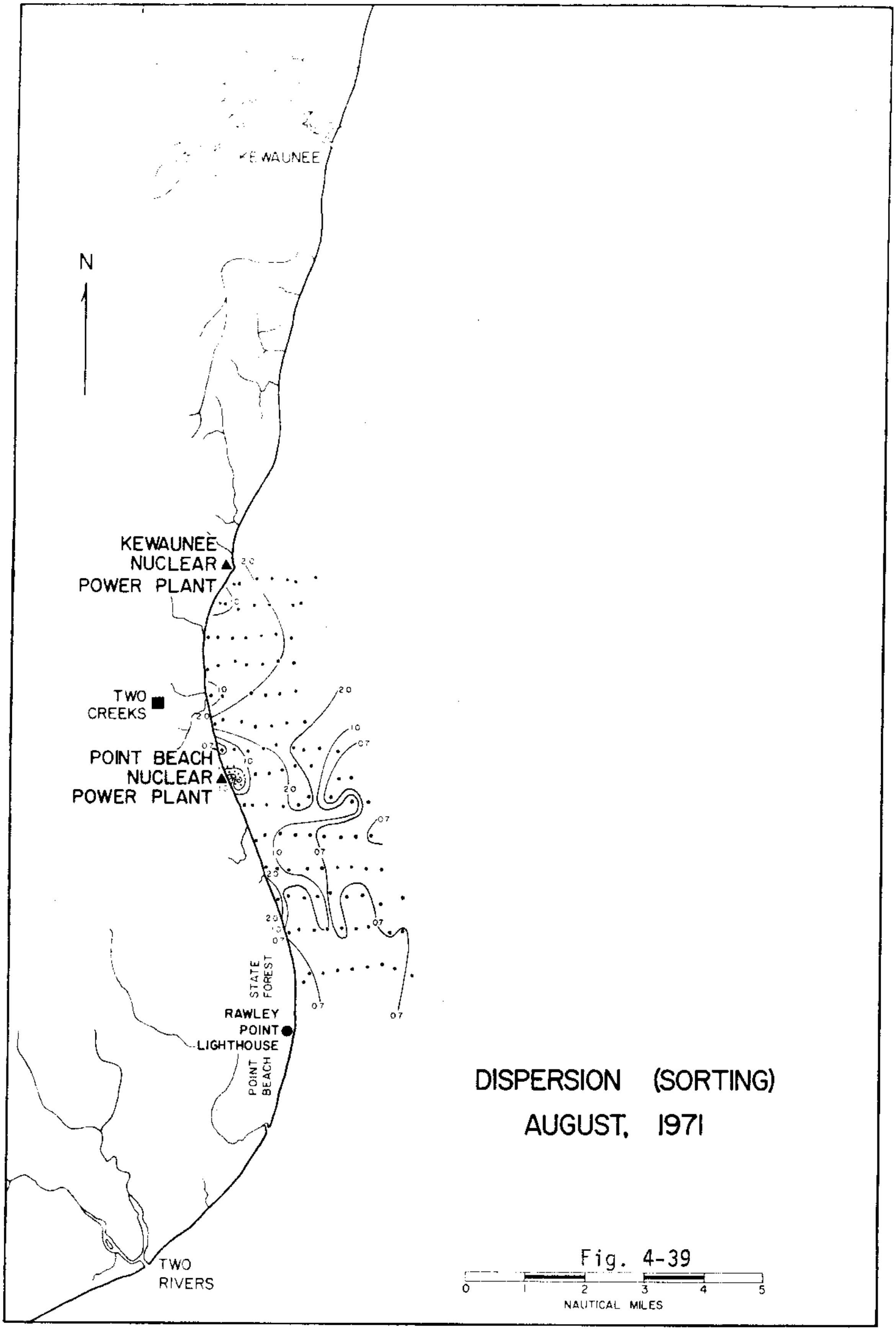
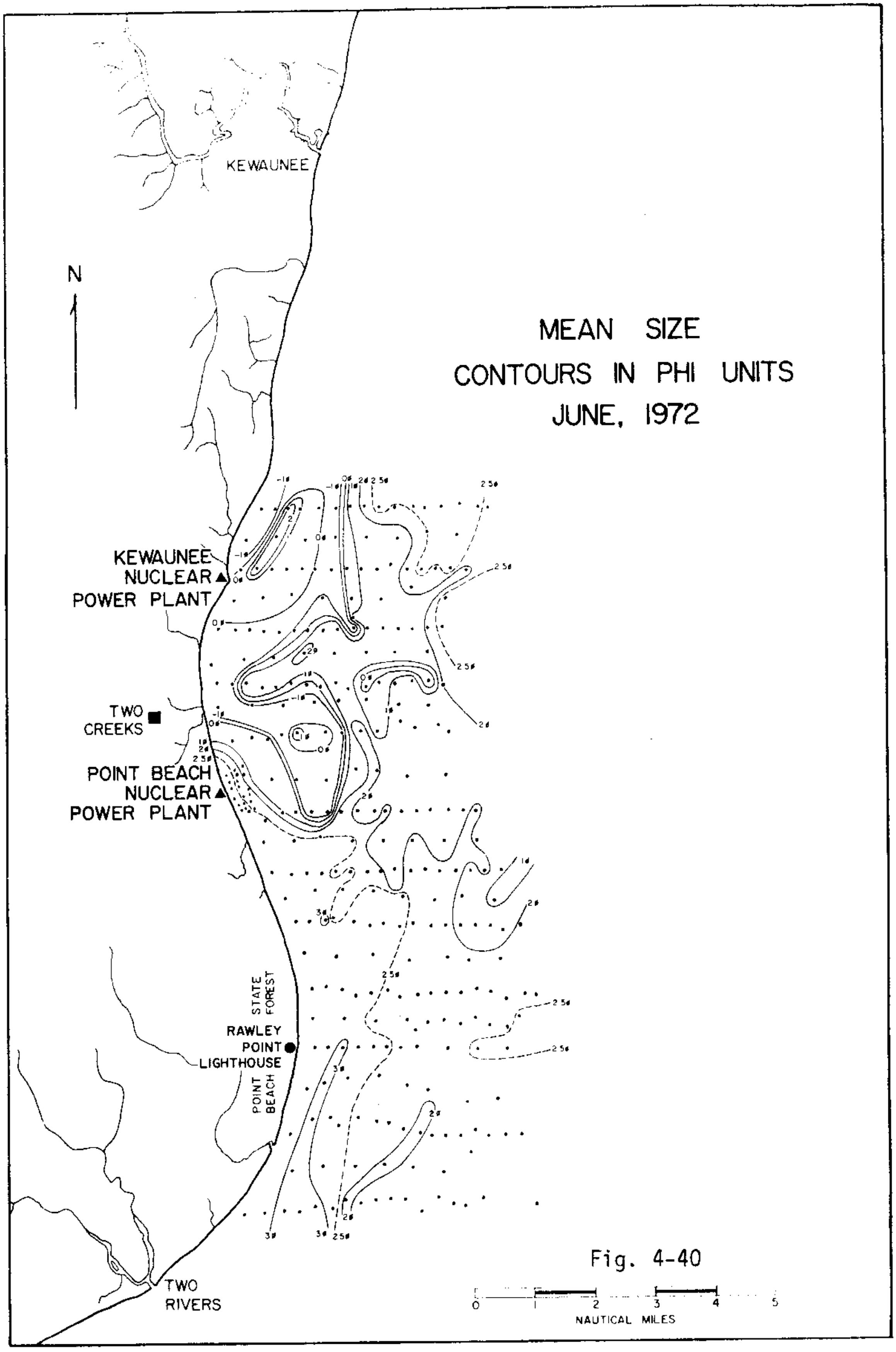

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
DISPERSION (SORTING)
AUGUST, 1971
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-39



MEAN SIZE
CONTOURS IN PHI UNITS
JUNE, 1972
N
KEWAUNEE
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-40

of medium sand further offshore. The zone of fine sand extended northward without interruption along the coast covering the very nearshore waters in front of Point Beach Power Plant.

In the northern reaches of the sampling grid, patches of a variety of materials become apparent. A lobe of sediments of mean diameter coarser than 0ø dominated the inshore and intermediate waters, extending southward to just south of Point Beach Power Plant. Further offshore, a large portion of the bottom was covered with sand having a mean diameter in the medium sand range. This material continued westward near Two Creeks almost reaching shore. Interspersed throughout the northern section were local concentrations of finer and coarser material. Near the lakeward edges gradations to finer sands occurred.

Similar patterns are reproduced by the median diameter values (Fig. 4-41). As in the mean diameter parameter, to the south of Point Beach Power Plant, fine sand was the rule, with the finer values occurring along the shoreline but with a band of slightly coarser fine sand abutting the coast. Patches of medium sand values were interspersed admidst the intermediate and offshore areas. Again, the sand body extended without interruption northwards along the shoreline past Point Beach Power Plant. Irregular areas of coarser sands and intermittant gravels appeared. Of particular interest is the extension of the sands in towards shore.

The distributions of the ø84 (Fig. 4-42) and ø95 (Fig. 4-43) values lie in much the same patterns as the mean and median parameters. In the southern section, both of these parameters reveal a band of slightly finer sands in the intermediate waters past Rawley Point and at the lakeward reaches of the sampling grid. In the northern sector, patches of various size material are again demonstrated as is the influx of fine and medium sands.

Finally, the sorting values (Fig. 4-44) display a very irregular pattern, particularly in the north. In the south, the sorting values were generally lowest where the mean diameter was near 2.5 or slightly less. The very well sorted zone near shore at Rawley Point was an exception to this generalization. It is important to note that, directly in front of the Unit I flume there was poorly sorted material, grading to better sorted sediments on either side. To the north of Point Beach Power Plant, the irregular pattern of the sorting values reflects the patchiness of the surficial sediments, as indicated by the four other parameters. The areas covered by material of mean diameter in the medium sand class were moderately well sorted as opposed to the coarser mean diameter material which, as one would expect, was considerably more poorly sorted. Where on the mean diameter chart a lobe of medium sand reaches toward shore, there was a local well sorted zone.

During November, 1972, a final survey was attempted. This sampling period was the only one which could be classified as a winter survey. From the contours of the mean diameter values (Fig. 4-45), the fine sand dominating the southern sector of the study area was again found. The finer textures in this size class lay close to shore, surrounding two stations at which mean diameters in the very fine sand class were found. Also found were two patches of coarser material. The median diameters (Fig. 4-46) followed much the same pattern, although the very fine sand classes were not obvious. That finer components existed in the nearshore sediments is again illustrated by the ø84 values (Fig. 4-47). It is this parameter, together with the ø95 values (Fig. 4-48), which are also indicative of a finer fraction in the very lakeward stations. The

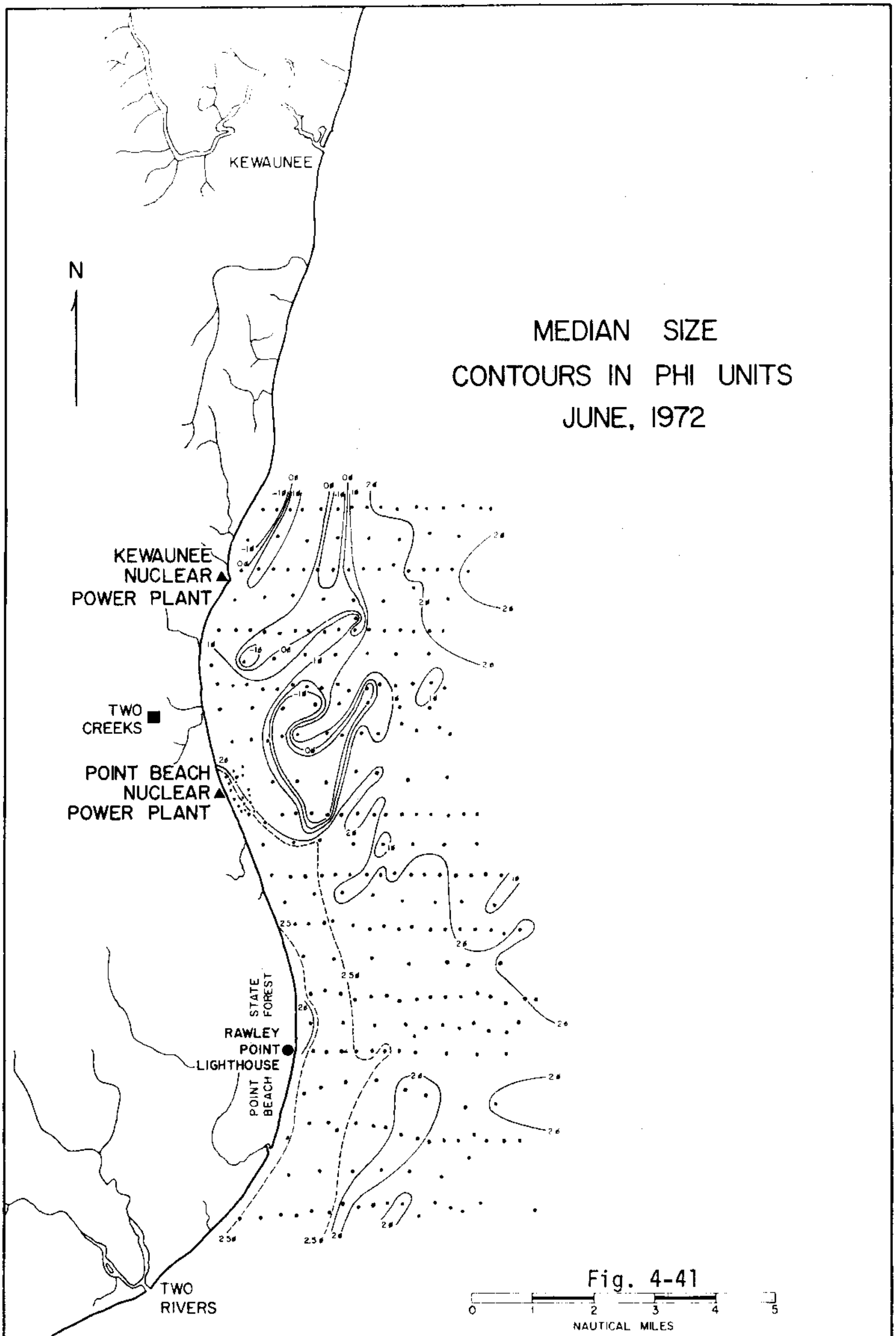

MEDIAN SIZE
CONTOURS IN PHI UNITS
JUNE, 1972
KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-41

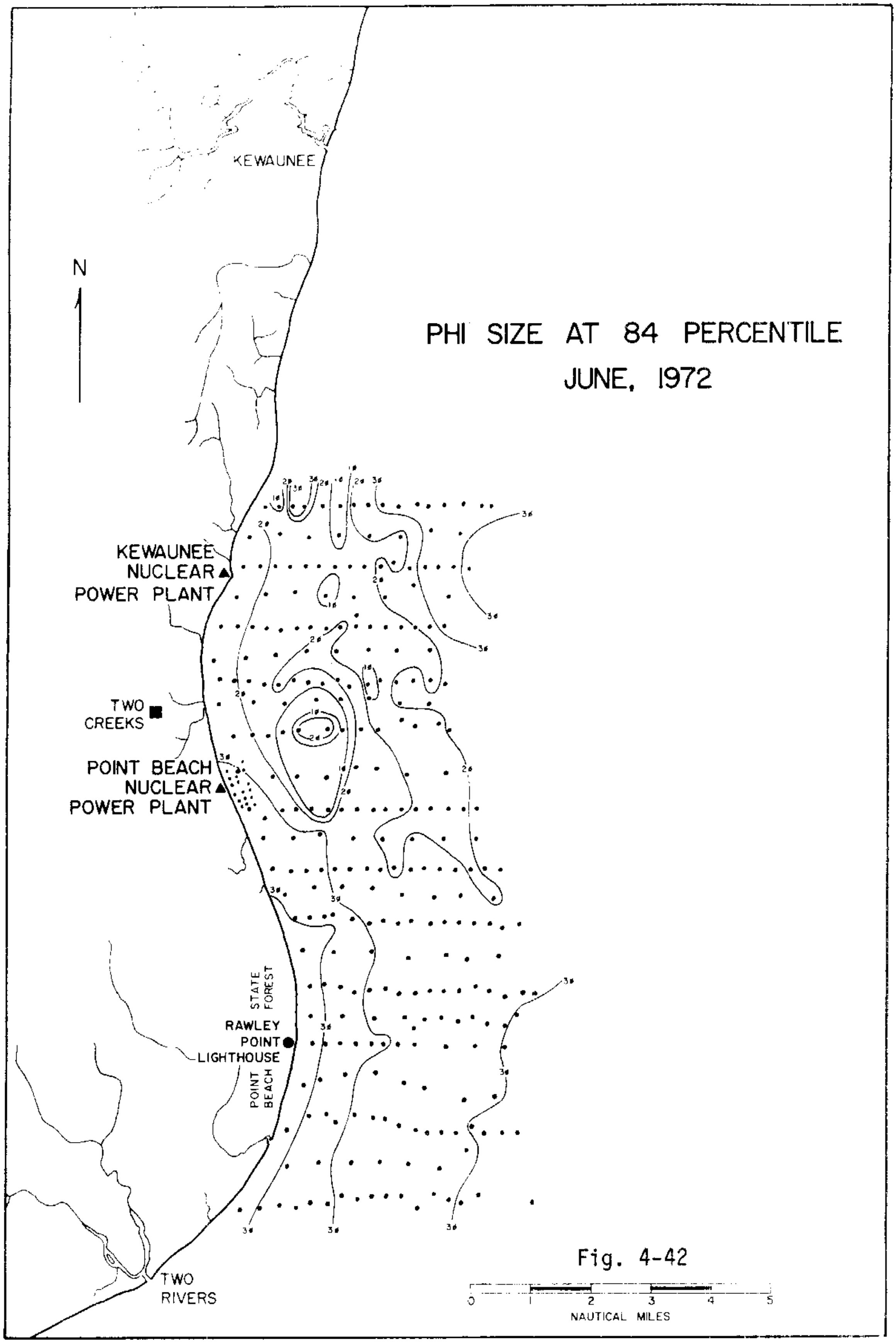
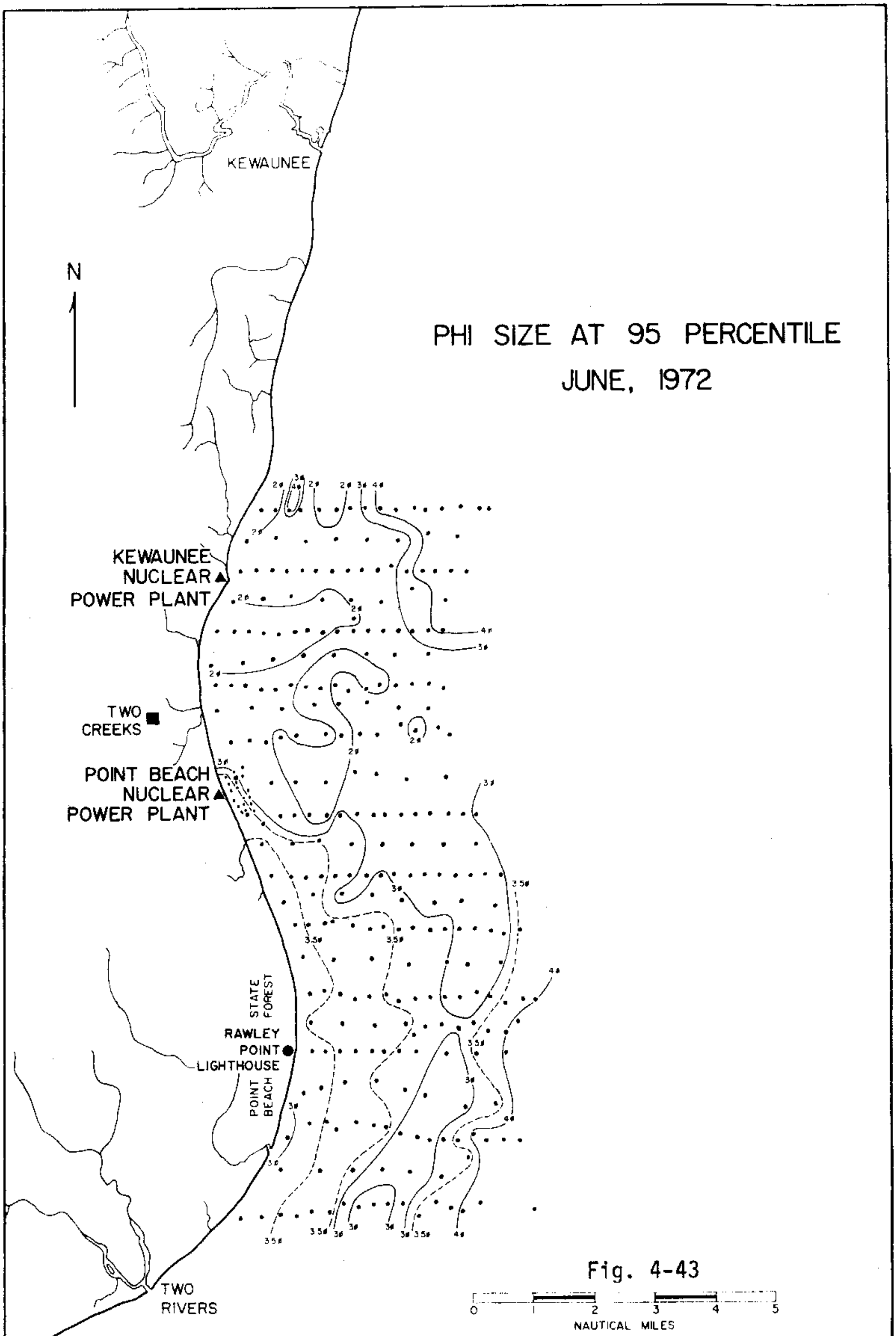

PHI SIZE AT 84 PERCENTILE
JUNE, 1972
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-42


KEWAUNEE
N
PHI SIZE AT 95 PERCENTILE
JUNE, 1972
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
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3
4
5
NAUTICAL MILES

Fig. 4-43

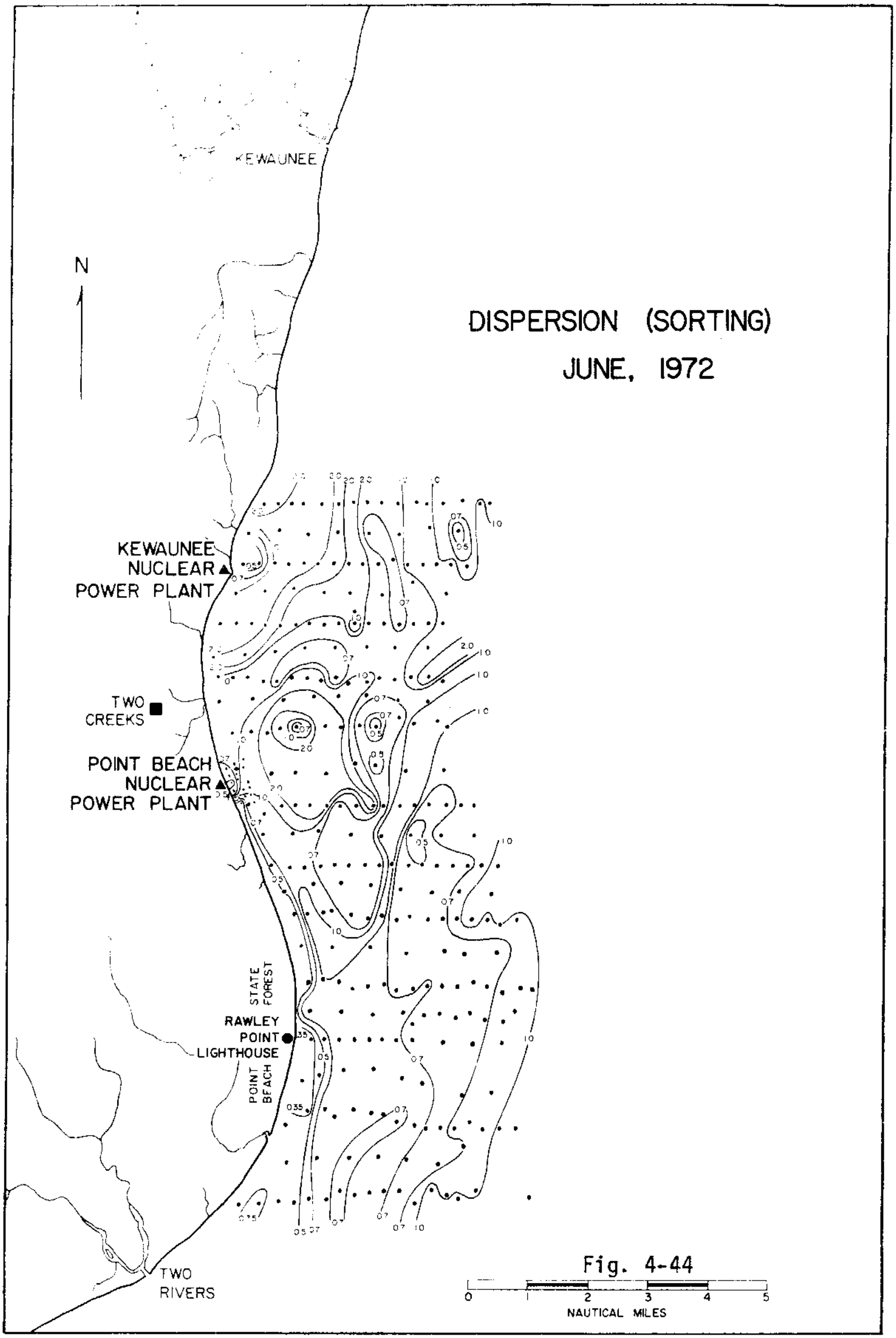
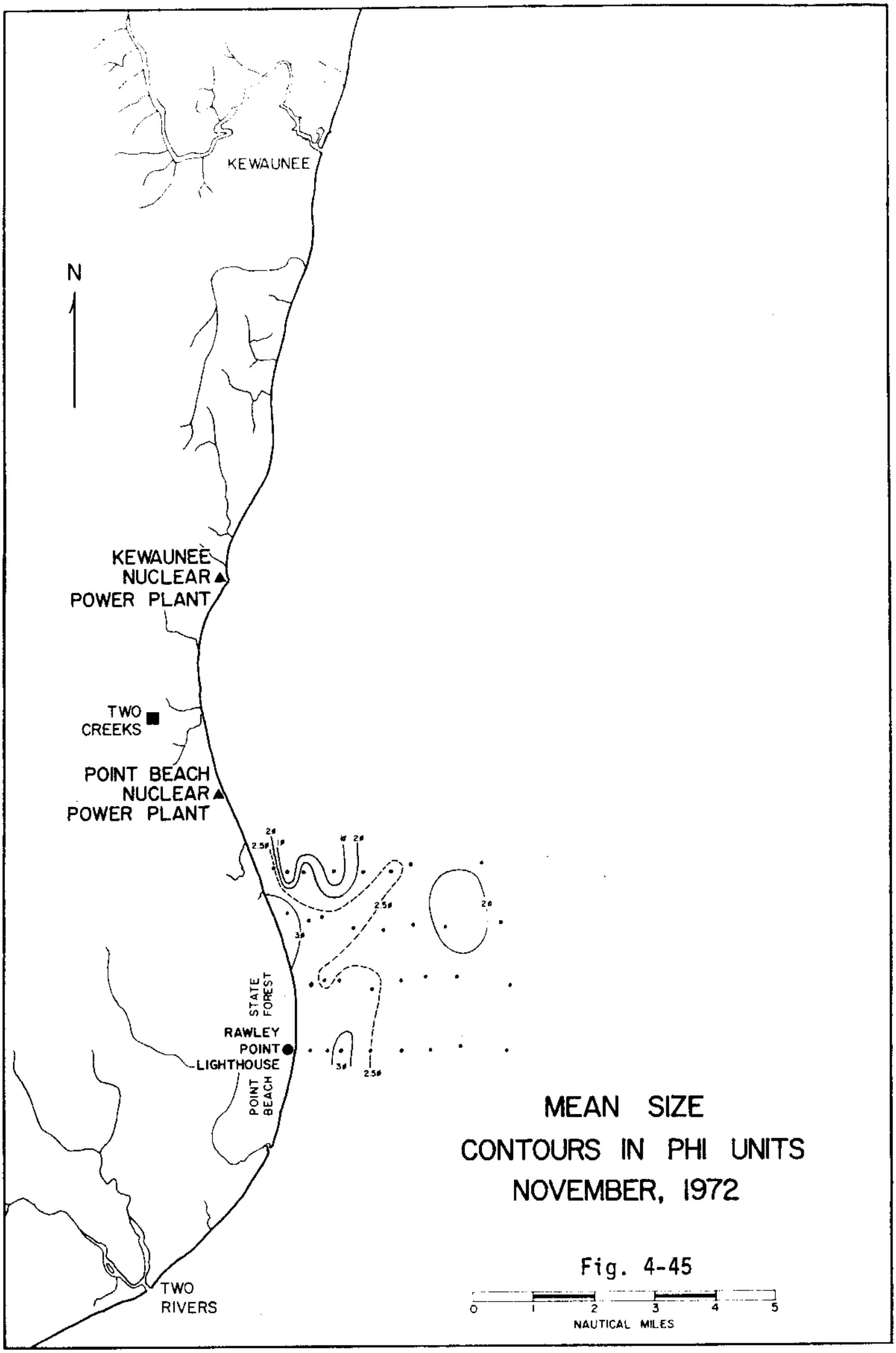

DISPERSION (SORTING)
JUNE, 1972
N
KEWAUNEE
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-44



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POINT BEACH
NUCLEAR
POWER PLANT
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RAWLEY
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LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
MEAN SIZE
CONTOURS IN PHI UNITS
NOVEMBER, 1972
0
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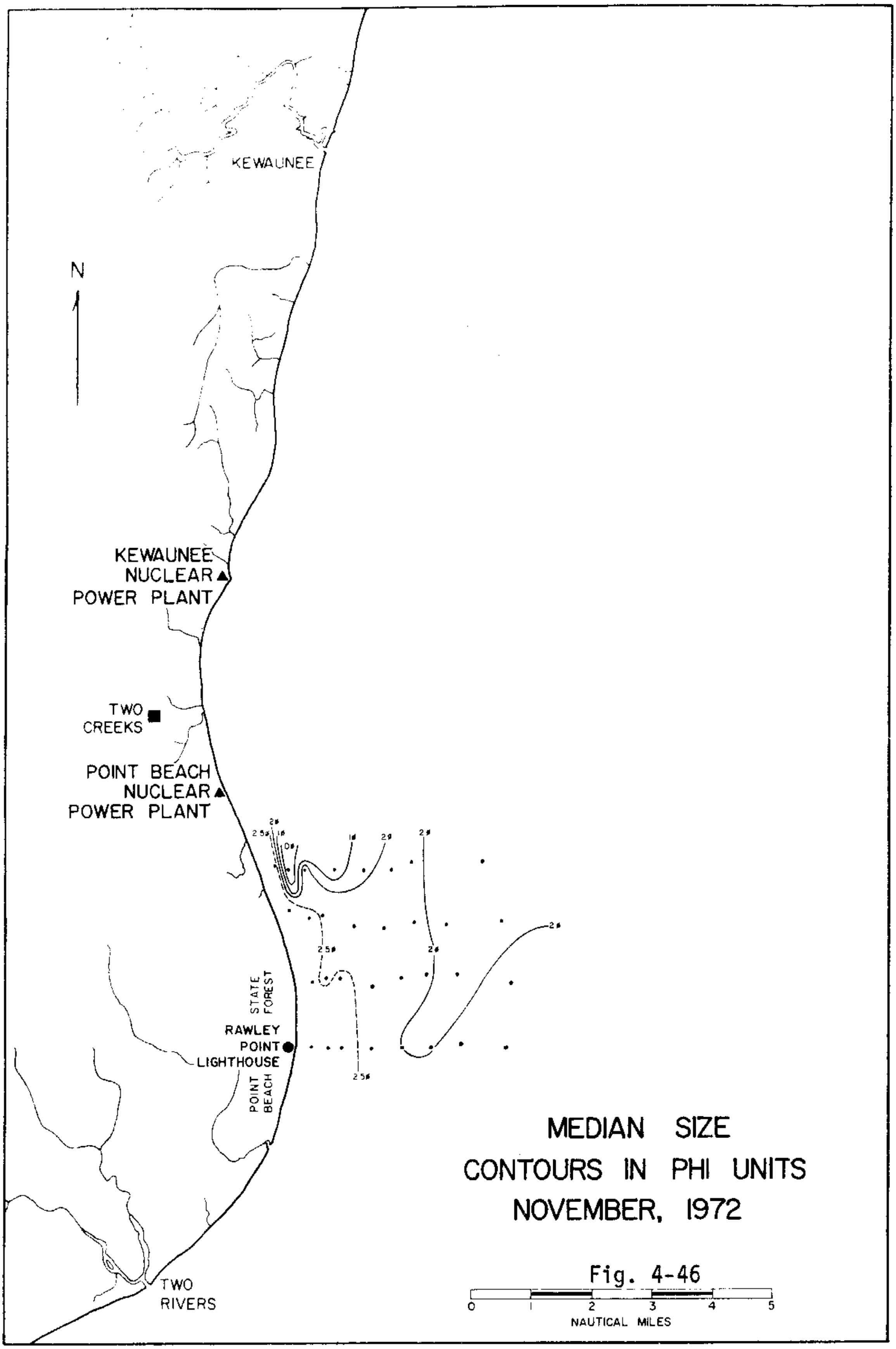
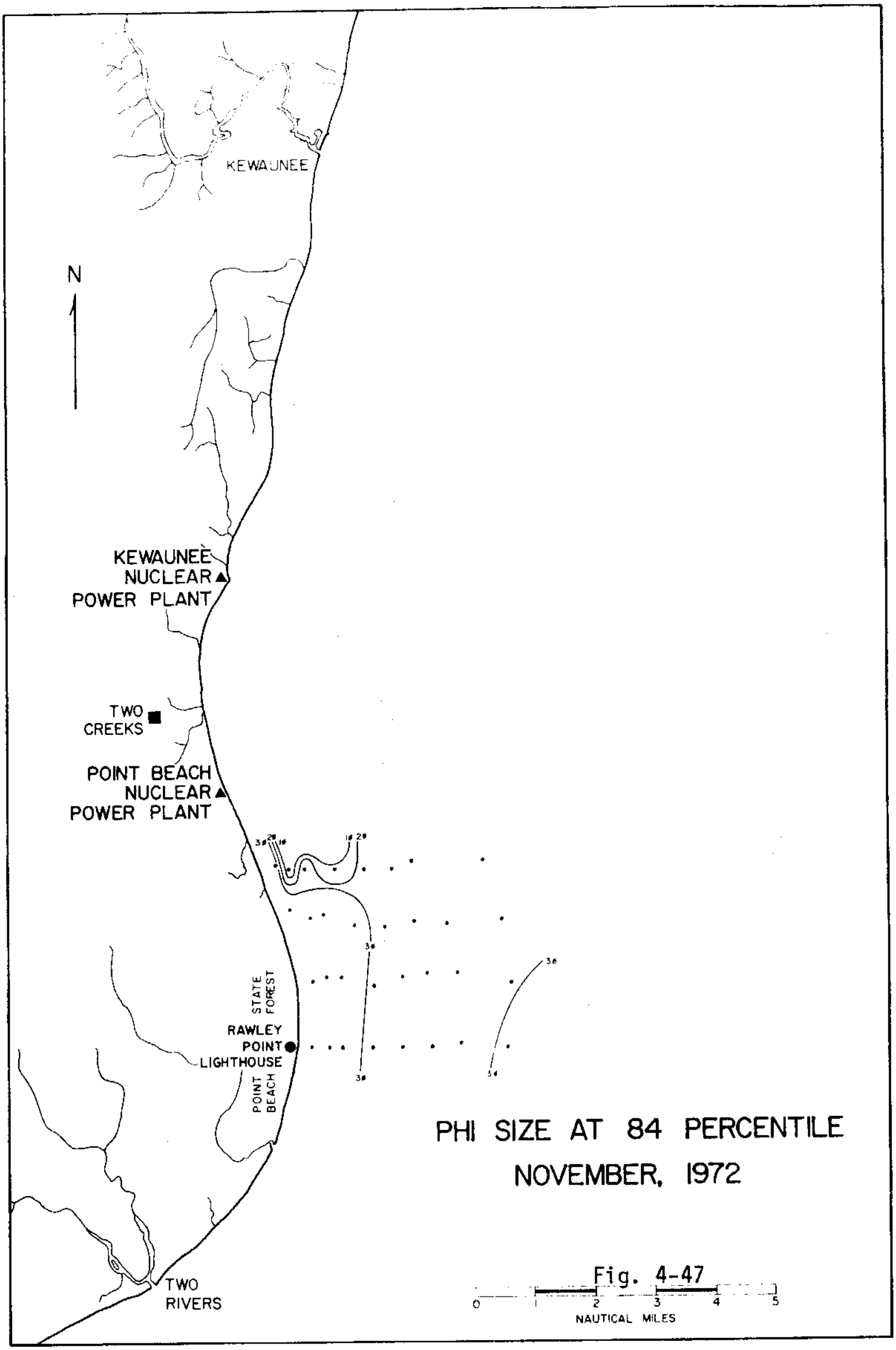
NAUTICAL MILES

Fig. 4-45



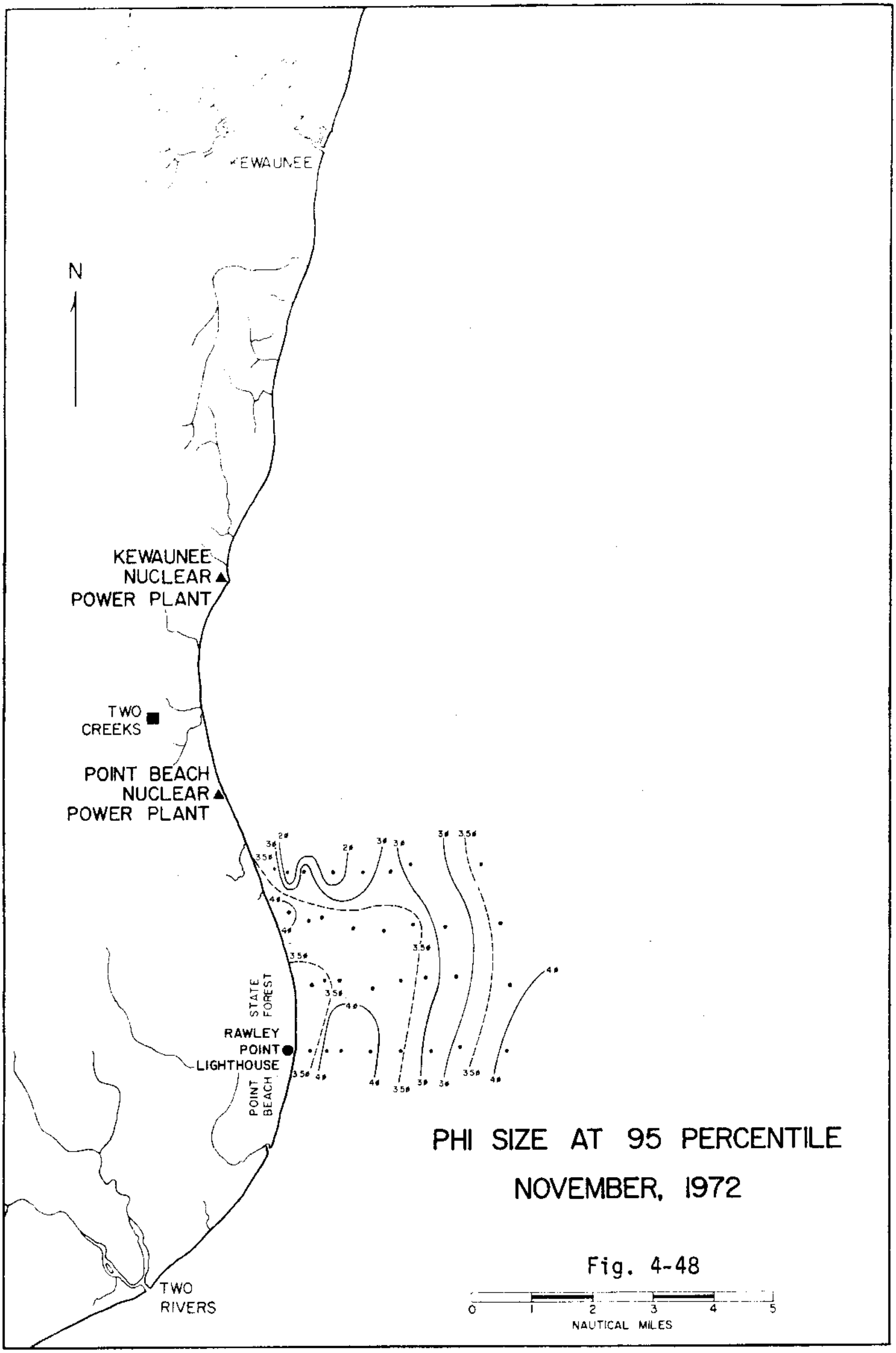
MEDIAN SIZE
CONTOURS IN PHI UNITS
NOVEMBER, 1972

Fig. 4-46



PHI SIZE AT 84 PERCENTILE
NOVEMBER, 1972

Fig. 4-47



PHI SIZE AT 95 PERCENTILE
NOVEMBER, 1972

Fig. 4-48

ø95 parameter also shows a gradation of a fine fraction towards shore from the 2.5-3.0ø values lying in a north-south band in the outer limits of the intermediate depths. Considering the sorting (Fig. 4-49), north-south trending bands are more apparent than they were in any of the other parameters. Nearshore, the sand was well sorted with a gradation towards poorly sorted material in the intermediate depths, particularly north of Rawley Point. Further offshore a band of better sorting existed.

Along with these textural parameters, the sorting by specific gravity must be considered. As reviewed earlier, the percentage of heavy minerals by weight can be indicative of areas of selective transport, erosion and deposition. Several zones of relative highs in the heavy mineral portion of the fraction finer than 1ø can be seen in the June, 1971 survey (Fig. 4-50). Along the coast, including one lobe extending northward into the intermediate depths and on the lakeward edge of the sampling grid, values from 2 to 4% were common. Higher values lay in a band running north-south through the study area, with even higher values scattered throughout the center. Zones of both high and low values were found at the southeast corner of the sampling grid.

Similar analyses of the June, 1972 survey reveal a more complicated pattern (Fig. 4-51). For about two miles on either side of Rawley Point a band of values between 2 - 4% occurred. Just south of Point Beach Power Plant and continuing north, values greater than 6% were found. Bordering these two zones for the length of the sampling grid was a band of values 4% above, with scattered zones of 6% and above. The continuation of these values directly east in contrast to the otherwise north-south trends of the values is significant. Both to the north and to the south of this eastward continuation of the 4+% were large zones of lower values whose centers were characterized by values less than 2%.

From these several surveys, a general description of the sediments in the study area can be made. First, the southern sector was dominated by fine sand with scattered patches of both finer and coarser material. Within the fine sand size class, the finer textures, as measured by the mean diameter, lay nearshore. While the ø84 and ø95 values support this generality they also show that, abutting the shoreline of Point Beach State Forest, the sediments had been washed clean of the finer material. These parameters also indicate that the offshore sediments in the north as well as in the south had a very fine fraction. Considering the sorting values, north-south trending bands were found in this southern fine sand area. Very near shore, well sorted sands appeared, reflecting the lack of a very fine tail in the textural curve. Further lakeward, moderately sorted sediments were found bordered by moderately well sorted material. Near the lakeward edge of the study area, sorting again decreased to moderate and poor levels, due to the fine component mixed with the sand fraction.

In the intermediate and nearshore waters north of Point Beach Power Plant the sediment patterns are complicated by three factors. First, the "clean" clay material was consolidated and therefore not subject to transport. Further, sediment of this sort is not amenable to sieve textural analysis. Second, on occasion during sampling, rocks were picked up. While some of these were undoubtedly half buried in the clay, and as such were relict sediments, others, particularly the pebbly gravels appeared to have actually been in transport in the modern regime. Finally, the mean and median can be rendered less significant by bimodal sediments, as were commonly found in this area. A gravelly sand was the most frequently found bimodal sediment of the area. Both the surficial sediment

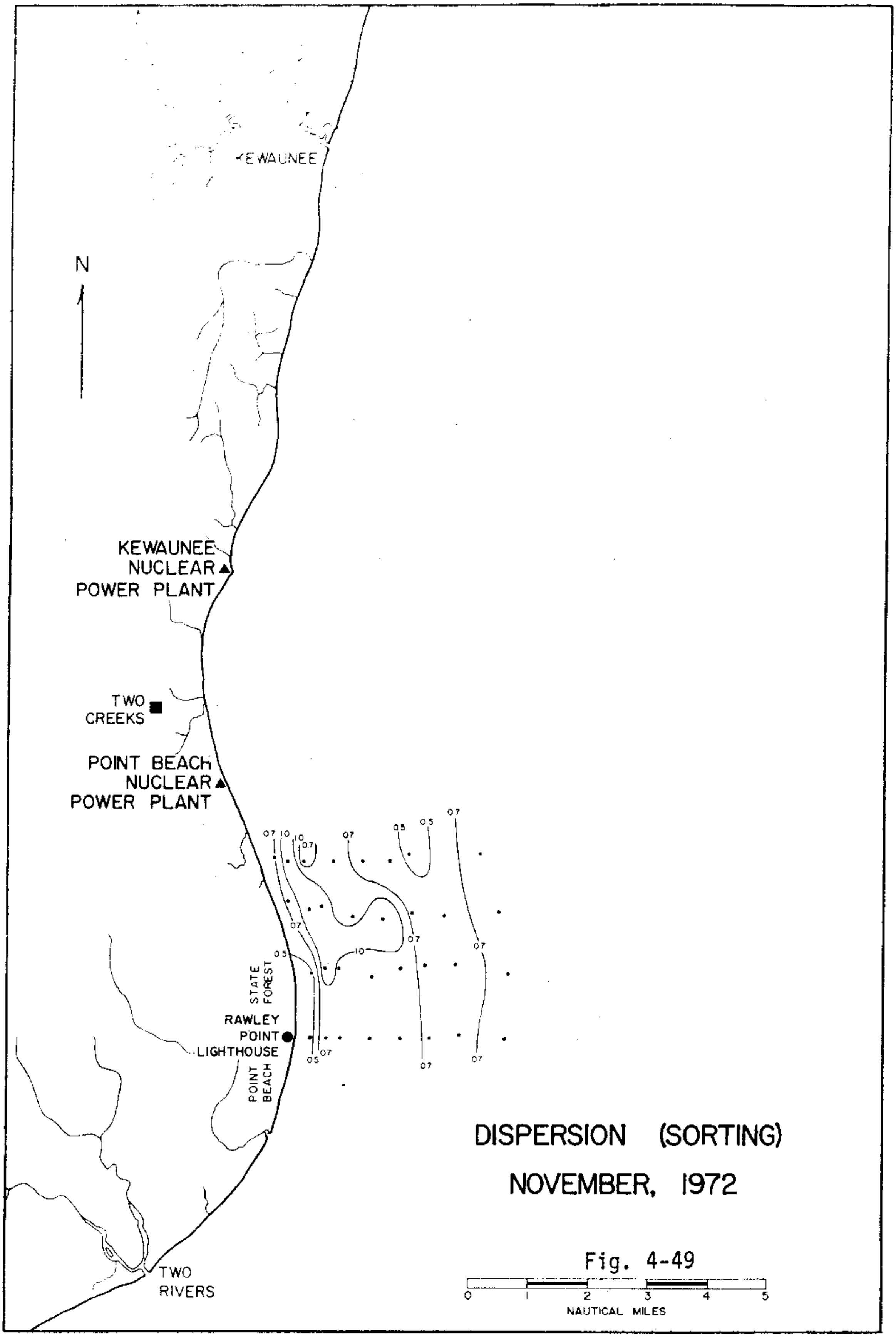

KEWAUNEE
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
DISPERSION (SORTING)
NOVEMBER, 1972
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-49

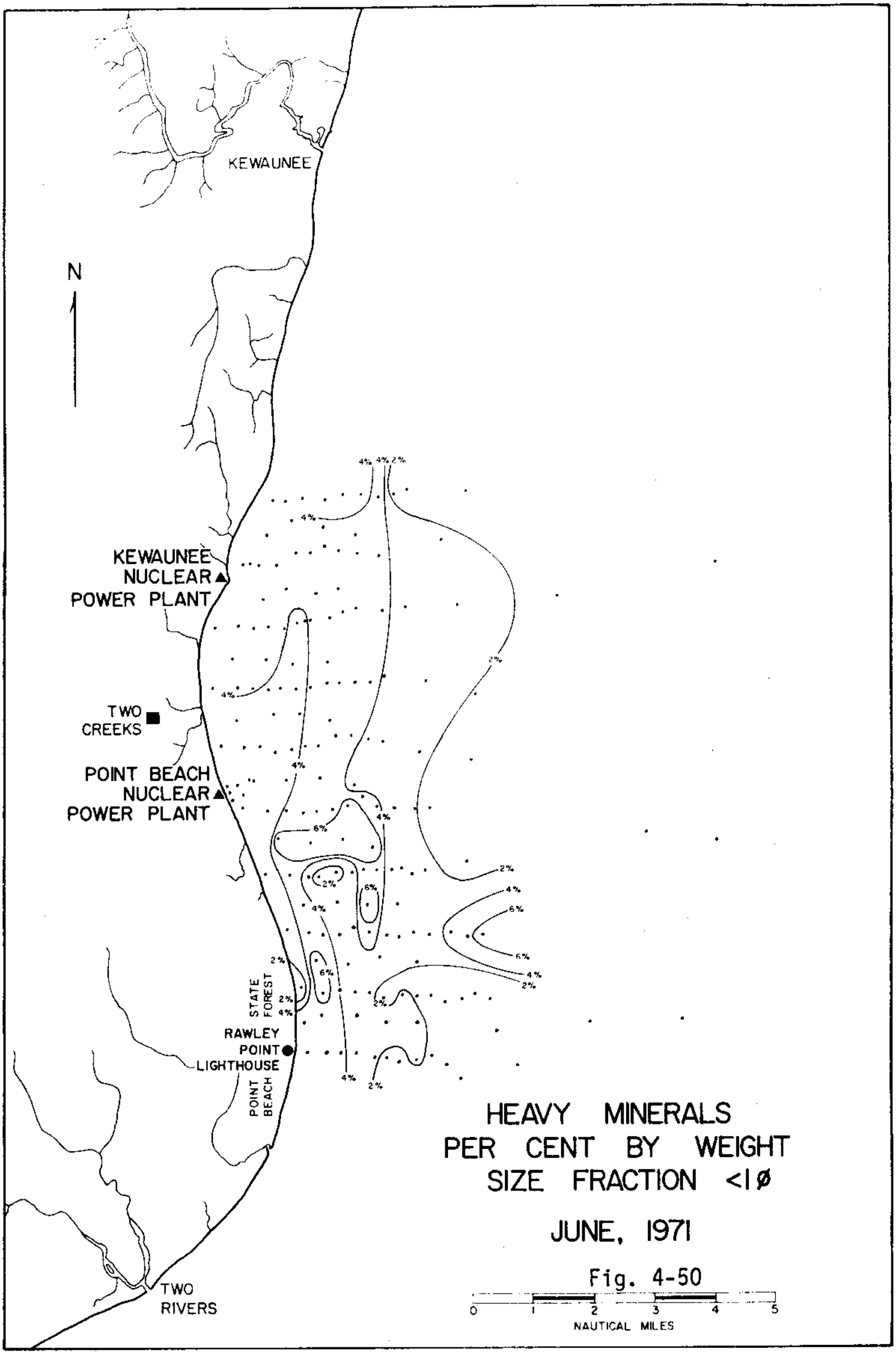
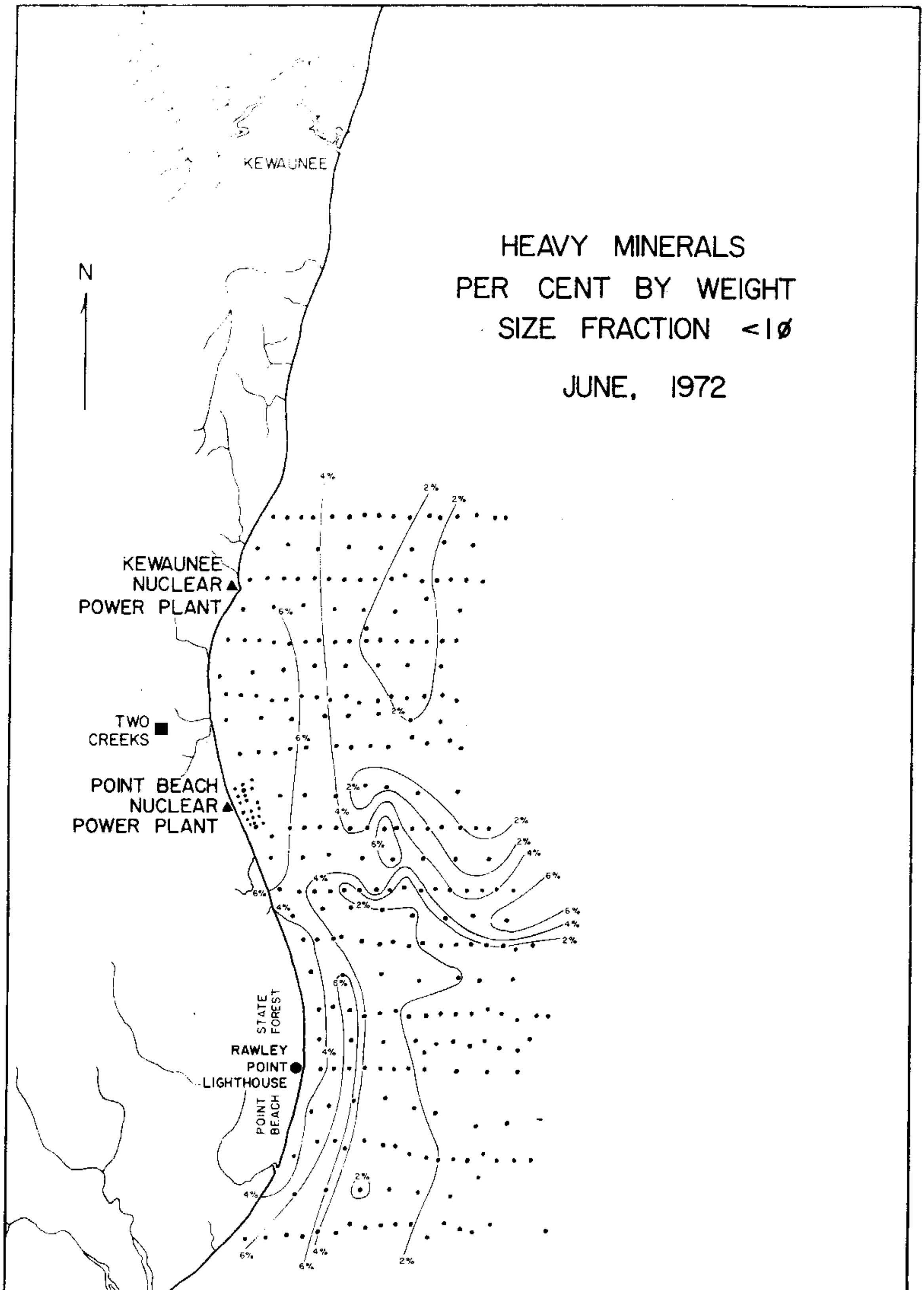

KEWAUNEE
N
KEWAUNEE NUCLEAR POWER PLANT
TWO CREEKS
POINT BEACH NUCLEAR POWER PLANT
STATE FOREST
RAWLEY POINT LIGHTHOUSE
POINT BEACH
TWO RIVERS
HEAVY MINERALS
PER CENT BY WEIGHT
SIZE FRACTION <1Ø
JUNE, 1971
0 1 2 3 4 5
NAUTICAL MILES

Fig. 4-50



KEWAUNEE
HEAVY MINERALS
PER CENT BY WEIGHT
SIZE FRACTION <1ø
JUNE, 1972
N
KEWAUNEE
NUCLEAR
POWER PLANT
TWO
CREEKS
POINT BEACH
NUCLEAR
POWER PLANT
STATE
FOREST
RAWLEY
POINT
LIGHTHOUSE
POINT
BEACH
TWO
RIVERS
0
1
2
3
4
5
NAUTICAL MILES

Fig. 4-51

charts and the modal listings show the location of these types of sediment. The sorting, ø84 and ø95 parameters aid in overcoming these difficulties.

The northern area, then, was characterized by a poorly sorted lobe of varying proportions of coarse and bimodal sediment with increasing amounts of fine material grading outward from it, as evidenced by the ø84 and ø95 values.

Offshore, finer sediments, generally muddy sands, were found. These muddy sands were generally bimodal, reflected in the higher sorting values.

Considering the distribution of the textural parameters and the theories of sediment movement the transport of material through the study area can be deduced. From the principal which states that the most mobile sands are those in the fine sand class and that coarser fragments are less subject to transport, a north to south movement of sediment is indicated. The widespread occurrence of gravels and gravelly sands in the north and sands in the south bears this out.

The discovery of desiccated red clay along the shore and in scattered patches of the northern sector is central to this idea. While very close to shore, with only a few exceptions, this material was devoid of overlying unconsolidated, transportable sediment; further offshore, veneers of mobile material of varying thicknesses were found overlying the clay. A large north-south trending lobe of coarse sediment surrounded by gradations of finer material was found in the intermediate depths of the northern area. That this sediment overlay a red clay basement was evidenced by the scattered clay patches found amongst this unconsolidated material. A picture emerges of mobile sediment moving from north to south over a surface of red clay, which being desiccated and consolidated, functions somewhat like a bedrock surface. The gravels would then be moved only under high energy conditions in the fluid regime and would roll and slide, rather than being in suspension. The sands found amongst the gravels are more mobile and no doubt move through the northern part of the study area much more rapidly than the gravels do. There are reports in the literature that the Valders deposits extend, on land at least, far south of the study area. Petersen (1967) showed these deposits to continue uninterrupted to the Milwaukee area. Thwaites and Bertrand (1957) published a cross-section (Fig. 2-3) along the shore of Lake Michigan near Two Rivers which shows a thick layer of Valders till and clay underlying more recent sand and gravel. These authors also noted that at Rawley Point, well logs indicate "sand with driftwood to a depth of 90 feet." (Ibid, p. 876)

Given this evidence that the Valders till extends along shore for the entire length of the study area, along with the recovery of similar material offshore, it can be concluded that a clay surface underlies, at varying depths, the recent sediments in the offshore area.

Why then does the northern sector of the study area have such different recent sediments than the southern zone? In fact, recent sediments are non-existent in some areas, in the northern zone, particularly in the nearshore waters. And, why, given a north-south transport, does the sand, which is transported through the northern sector, come to rest in the southern zone? The answer lies in the bathymetry and the apparent slope of the clay surface. It should be remembered that the offshore depths decreased much more gradually east of Two Creeks than east of Rawley Point. For instance, whereas the 50 foot contour lies less than one mile offshore from Rawley Point, off Two Creeks it lies about three miles offshore. The shallow depth of the clay surface puts it into a position in the fluid regime where transportation is easily accomplished. As a result, either the clay is swept clean by the moving water or gravels are moved over the clay. Also, sand transported into this area from the north is winnowed out of the gravels to continue its southward transport.

Off Rawley Point, the clay surface dips to a lower level (Thwaites and Bertrand, 1957). The lack of clay bluffs bordering the beach in this area along with the well records attest to this. Because the clay surface is lower, deposition of modern sediments can still occur on top of it. The bathymetry, the depth of the clay surface and the competancy profile of the fluid regime controls the zones of transport, erosion and deposition in the study area.

The heavy mineral percentages by weight give further insight into these processes of erosion and deposition. Considering the June, 1971 survey, samples recovered from the northern nearshore and intermediate waters display a heavy mineral concentration greater than 4%. This is consistent with a high energy environment in which the lighter material is more easily moved and the heavy minerals lag behind, becoming concentrated. In the southern sand zone, several local concentrations appear. First, values less than 4% are found nearshore from Two Creeks to just north of Rawley Point. At Rawley Point, and in the intermediate depths of this area, higher values are found. These higher values mark the areas where intermittant deposition and erosion occur, concentrating the heavies. The northern edge of the sand zone is marked by heavy mineral values greater than 6%. This agrees with the transportation and erosion/deposition trends noted earlier. At the edge of the sand zone, the erosion/deposition process would be more intense than in the more stable depositional environments at the center, resulting in these high concentrations of heavy minerals. In the offshore regions, values lower than 2% were discovered because the lighter fraction is more easily transported to these deeper waters.

Much the same situation was found during the June, 1972 survey. The higher values near the northern edge of the sand area are particularly significant and support the view that erosional and depositional fluctuations occur there. Further, the north-south trending band of higher values past Rawley Point further suggests the rapid alternation of erosion and deposition, resulting in lag deposits of the heavy minerals.

Given these patterns of transportation, erosion and deposition, what major changes have occurred during the period of study? First, the nearshore areas directly in front of the Point Beach Unit I flume have changed from a "clean" red clay surface with only scattered sand patches to a large, continuous zone of sand. In June, 1971, at only three closely-spaced stations were fine and medium sands recovered. Surrounding this sand patch was the clay surface. By July, 1971 the sand had been removed from directly in front of the flume but sand had been deposited along the shore to the north. By August, 1971 a large zone elongated parallel to shore of very fine to medium sand had been deposited in front of and to the north and south of the flume. This zone of sand is characterized by coarser, less well sorted sands directly in front of the flume, with a gradation to the north and south to finer, better sorted sands. Finally, in June 1972, the sand patch became a continuous lobe with the sand zone dominating the southern sector of the study area. The sorting values are poorest just south of the flume, with better sorting to either side.

The growing sand patch in front of the outfalls is a result of interactions between the littoral drift and the cooling water plume. As described in Chapter II, as the turbid water of the littoral current approaches the upwind edge of the plume, it moves lakeward, covering a wider zone along the shore; it decelerates; and it is finally deflected along the upwind edge of the plume. It must be remembered that the plume changes its path of flow and that the littoral current also reverses from time to time. Therefore the turbid littoral water approaches the upwind plume edge from opposing directions at different times.

In order for sand being carried in suspension to be deposited, the flow and upward turbulent forces must diminish. In order for bed load to be deposited and remain in an area, the flow over the bottom must decrease. It is believed that such decreases in the flow velocity and turbulent forces in the littoral current occur at the upwind sides of the plume. Because of the reversals of the littoral current, sand has been deposited, over a period of time, on both sides of the outfall.

The textural changes found also agree with this proposed mechanism. Very fine, well sorted sands were found farthest away from the outfall along the shore, grading to coarser poorly sorted material in front of the outfall. As deceleration of the littoral current occurs, the finer material would settle out first. The coarser material in front of the outfall is due to the plume sweeping over the bottom in various paths. As the plume flows over the bottom in an area where previously sand had been deposited, the fine sands are winnowed away and only the coarsest material remains.

A second change is the medium sand which moved into the intermediate depths east of Two Creeks, as detected in June, 1972. Where previously clay and coarse, poorly sorted sediments were found, moderately well and well sorted medium sands were found in June, 1972. Along with this change in surficial sediment type, changes in bathymetry must be considered. In June, 1971, a lobe of waters deeper than 40 feet extended shoreward just north of Two Creeks. In August, 1971, although no significant change, the surficial sediment pattern was found (patches of veneers of sand and gravel - sand gave way to a cleaner clay surface), the depth contours did not indicate a lobe of deeper waters extending towards shore. This most probably is due to the station spacing, particularly if the bottom is hummocky, as is indicated on the U.S. Lake Survey Chart. The depth profiles perpendicular to shore do show topographic highs in the area of 12 feet or more. In June, 1972, the depth contours followed the August, 1971 contours more closely than the June, 1971 patterns. Assuming an area of marked highs and lows which were not totally delineated by the station spacing, no significant change was observed in the bathymetry. The sand deposited prior to June, 1972, then, does not appear to have been thick enough to have, with certainty, changed the bathymetry. Nevertheless, that a significant deposition of medium sand had occurred in this area is apparent. Because this westward extending lobe of medium sand was continuous with the north-south band of medium sand (observed in June, 1972 and in previous surveys) it most probably was transported into the shallower hummocky regions from the east. This could be accomplished by an intense storm with predominately easterly winds. Reviewing the meteorological data supplied by the Wisconsin Electric Power Company, it was found that winds of 38 miles per hour from the north, northeast, and south were recorded between 2400 June 3, 1972 and 0600 June 5, 1972. (See Fig. 2-10)

The sediments of the study area, then, show natural variations due to storms and unnatural variations due to the change in the nearshore environment lakeward of the Unit I outfall.

LIGHT FRACTION MINERALOGY

The mineralogy of the sediments offshore was investigated to further delineate the sedimentary regime. This investigation would also aid in the identification of the source.

Differential staining of the feldspars showed that the potash feldspars (orthoclase and microcline) were generally more abundant than the plagioclase series feldspar. Potash feldspars ranged from 0 to 14.7% while the plagioclase varieties ranged from 0 to 5.3%. The greater survival during mechanical weathering of the potash feldspars was predicted by Goldrich (1938). Quartz grains were also counted and ranged from 55 to 98%. Random distributions were found when the feldspar and quartz contents were plotted versus station positions. Tertiary plots of the total feldspar content, quartz, and the remaining grains are shown in Figures 4-52 - 4-60. Each survey is plotted individually by grain size.

The tertiary plots revealed that the sands fell within a small area near the quartz corner. Two trends appear: 1. In the 1ø size, scatter increases toward the "other" category; 2. Feldspar content increases slightly in the 3ø size. The first trend is no doubt due to a lesser degree of mineralogical maturity in the large grains. As Pettijohn (1957, p. 113) points out, "there is a gradation in grain size and corresponding gradation in both chemical and mineralogical composition." Pettijohn (1957, p. 118) went on to note that "The detrital quartz grains of most sandstones are under 1.0 millimeter in diameter and most are less than 0.6 millimeter. Grains larger than 1.0 millimeter are generally composite grains of quartzite or like material." So, in the 0-1ø, multimineral grains would be common and would thus be counted as neither feldspar nor quartz.

The fact that the feldspar increased in the finer fraction (2-3ø) is in direct opposition to the general view that, since feldspar is less stable during mechanical weathering than quartz, the feldspar content should decrease with decreasing grain size (Pettijohn, 1957). Indeed, Pettijohn (1957, p. 125) reviewed the data supporting this claim and deems it "somewhat contradictory." There are two possible explanations for higher feldspar content in the 2-3ø sizes. It is possible that in the large grain size, multimineralogic grains containing feldspars were not completely stained and were thus not counted as feldspars. Or, the source would be contributing feldspars only in the smaller grain size.

The sands in the study area are relatively homogeneous with a total feldspar content ranging from 0-20% along with a primary component of quartz. No significant change was noted in the feldspar/quartz content during the period of study. Using Pettijohn's (unpublished, 1944) classification system, as reported by Krumbein and Sloss (1963), a sand of this mineralogy would be termed a quartzose or feldspathic sand. While a quartzose sand has 10% or less feldspar, a feldspathic sand has 10-25%. This sand then falls on the borderline between these two types. Krumbein and Sloss (1963, p. 170) write that, "Feldspathic sandstone has from 10 to 25 percent feldspar, mainly potash feldspar." This is in agreement with the findings of the differential staining results. It is geologically interesting to note that these same authors report that "Quartzose sandstone is typical of basal sands developed by encroaching seas." (Ibid., p. 169) A basal sand, as defined by the American Geological Institute (1963, p. 40) is a "well-sorted and lithologically homogeneous sedimentary deposit which is found just above an erosional break. The initial stratigraphic unit overlying an unconformity, formed by a rising sea level or encroaching sea." This is exactly the situation developing in the study area.

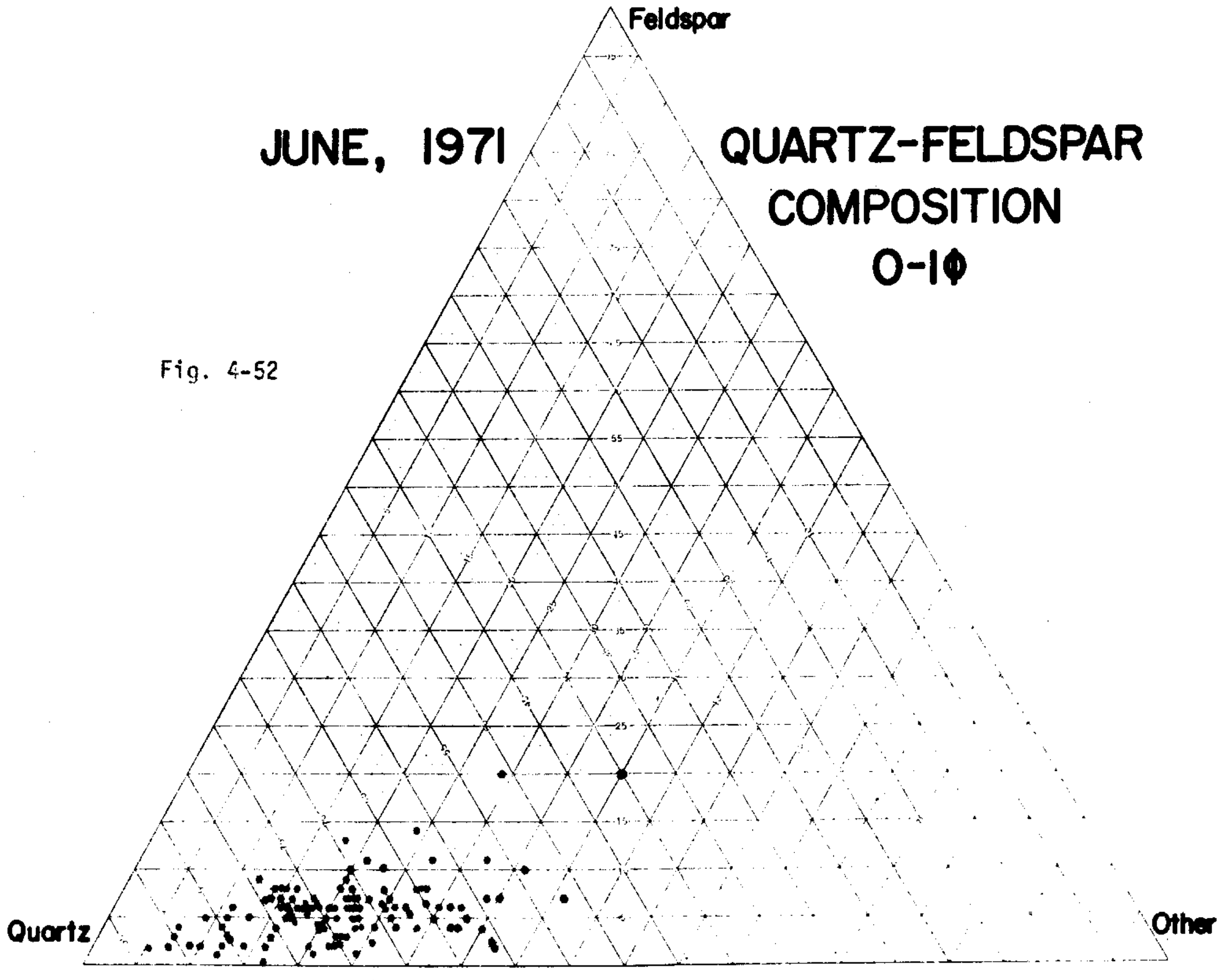
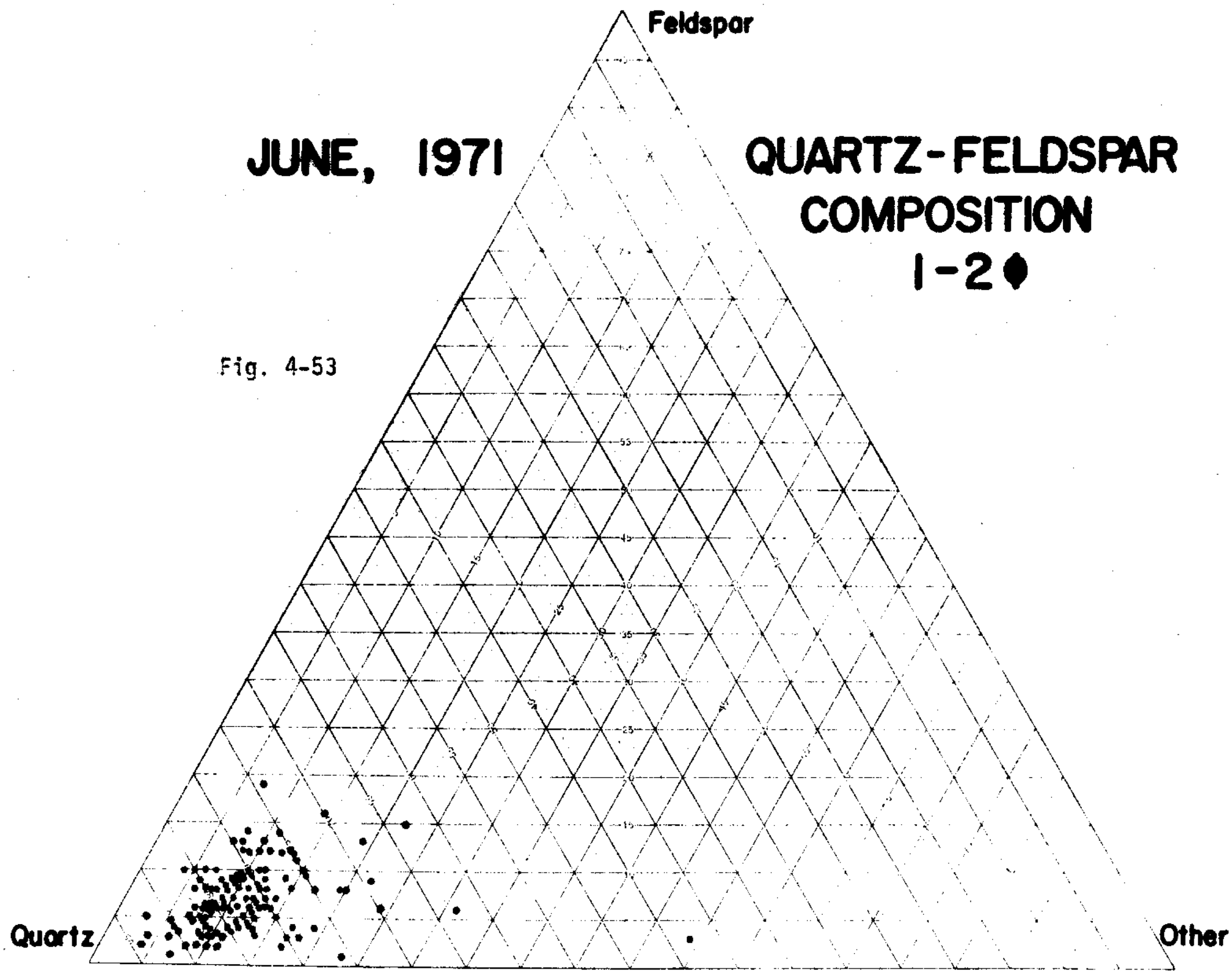

JUNE, 1971
QUARTZ-FELDSPAR
COMPOSITION
0-1Φ
Feldspar
Quartz
Other

Fig. 4-52

JUNE, 1971

QUARTZ-FELDSPAR COMPOSITION 1-2ϕ

Fig. 4-53



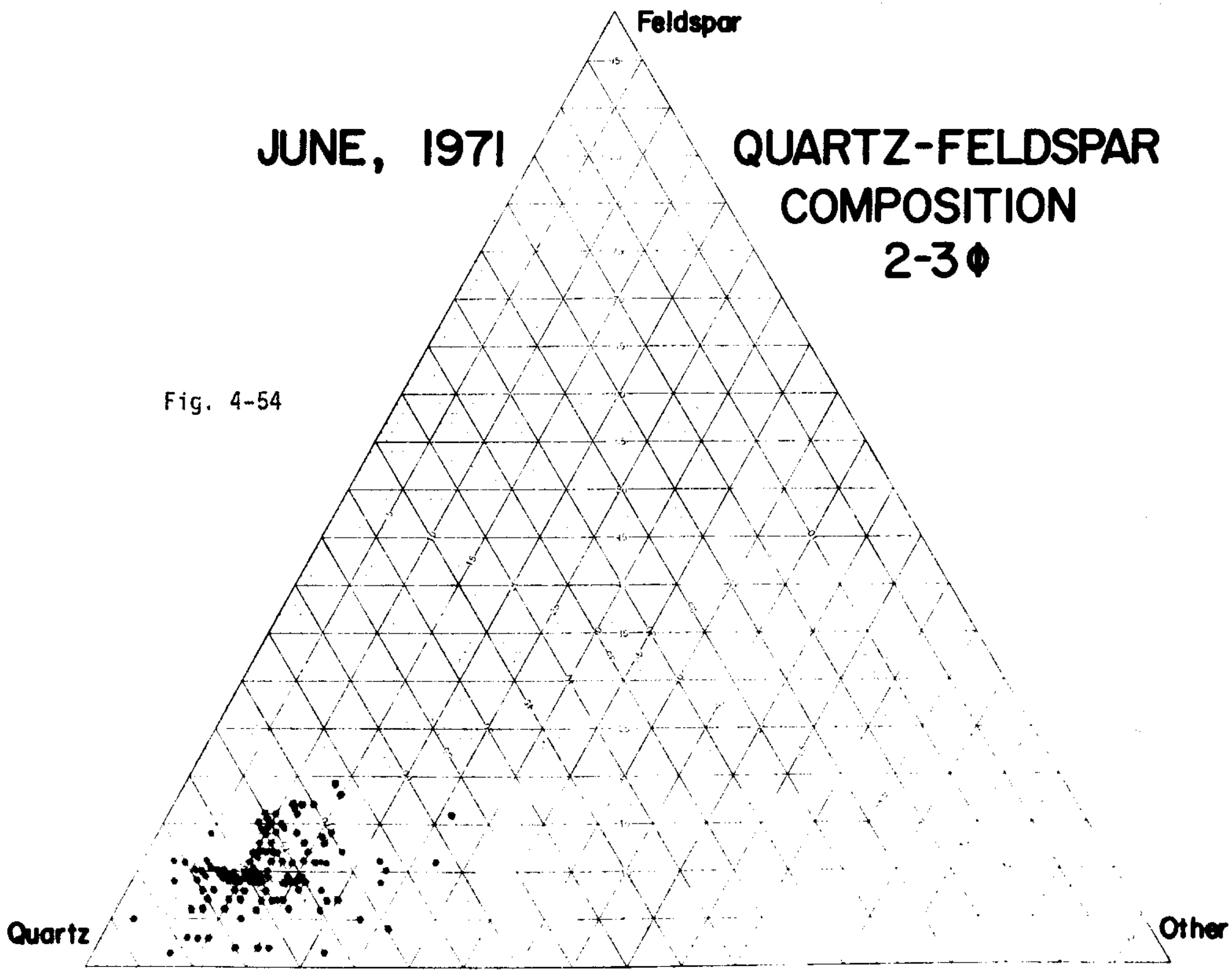

JUNE, 1971
QUARTZ-FELDSPAR
COMPOSITION
2-3Φ
Feldspar
Quartz
Other

Fig. 4-54

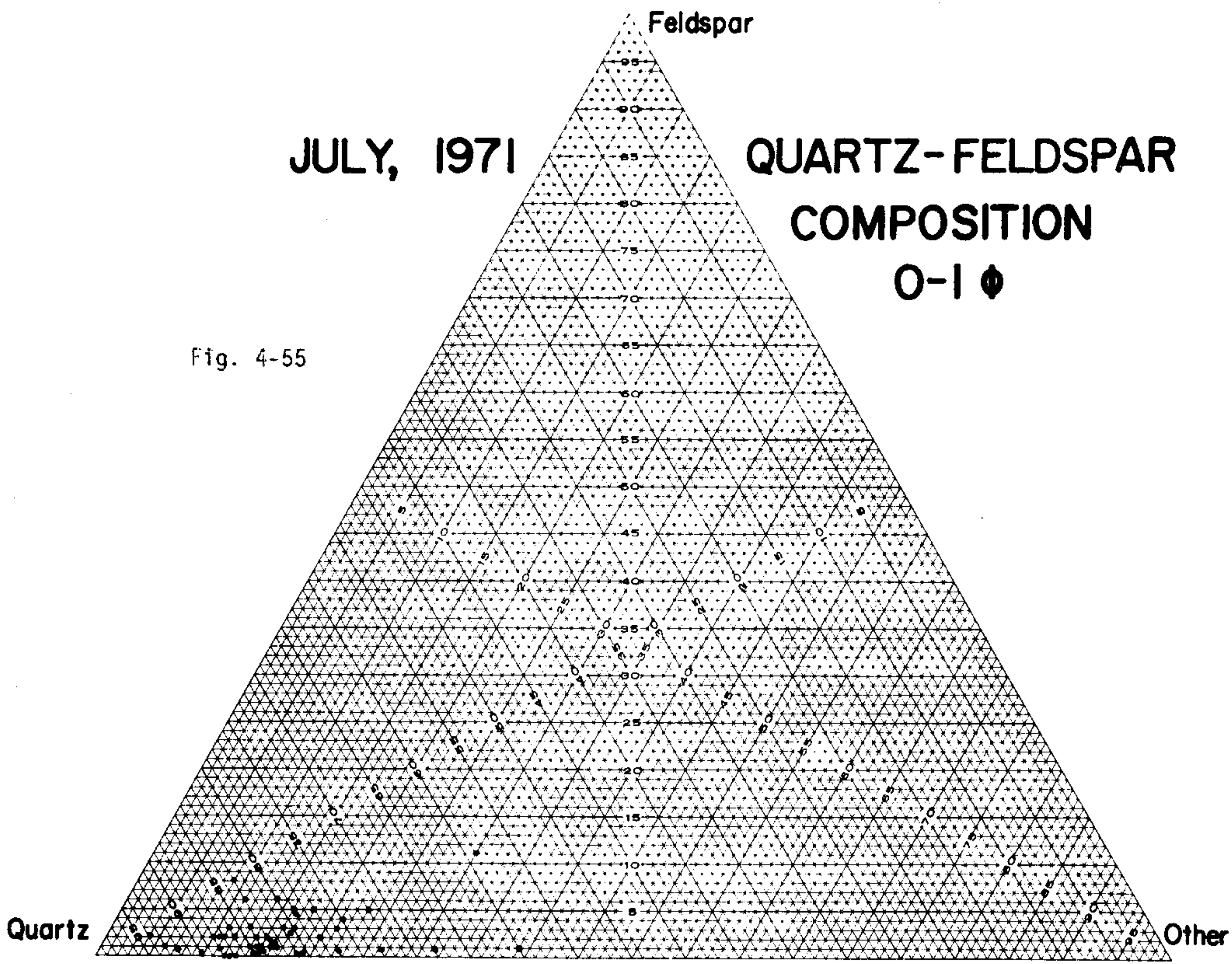

JULY, 1971
QUARTZ-FELDSPAR
COMPOSITION
0-1 Φ
Feldspar
Quartz
Other

Fig. 4-55

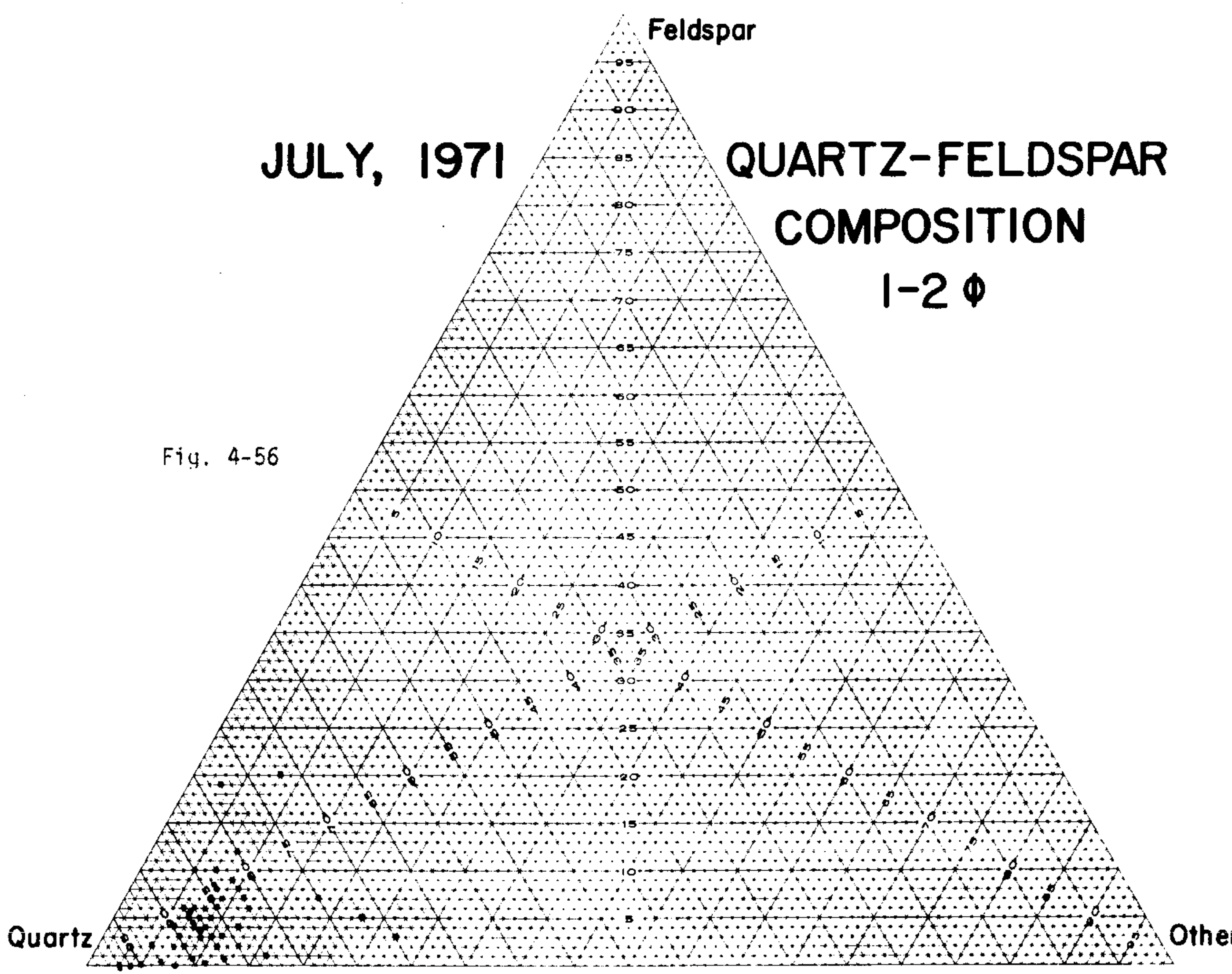

JULY, 1971
QUARTZ-FELDSPAR
COMPOSITION
1-2 Φ
Feldspar
Quartz
Other

Fig. 4-56

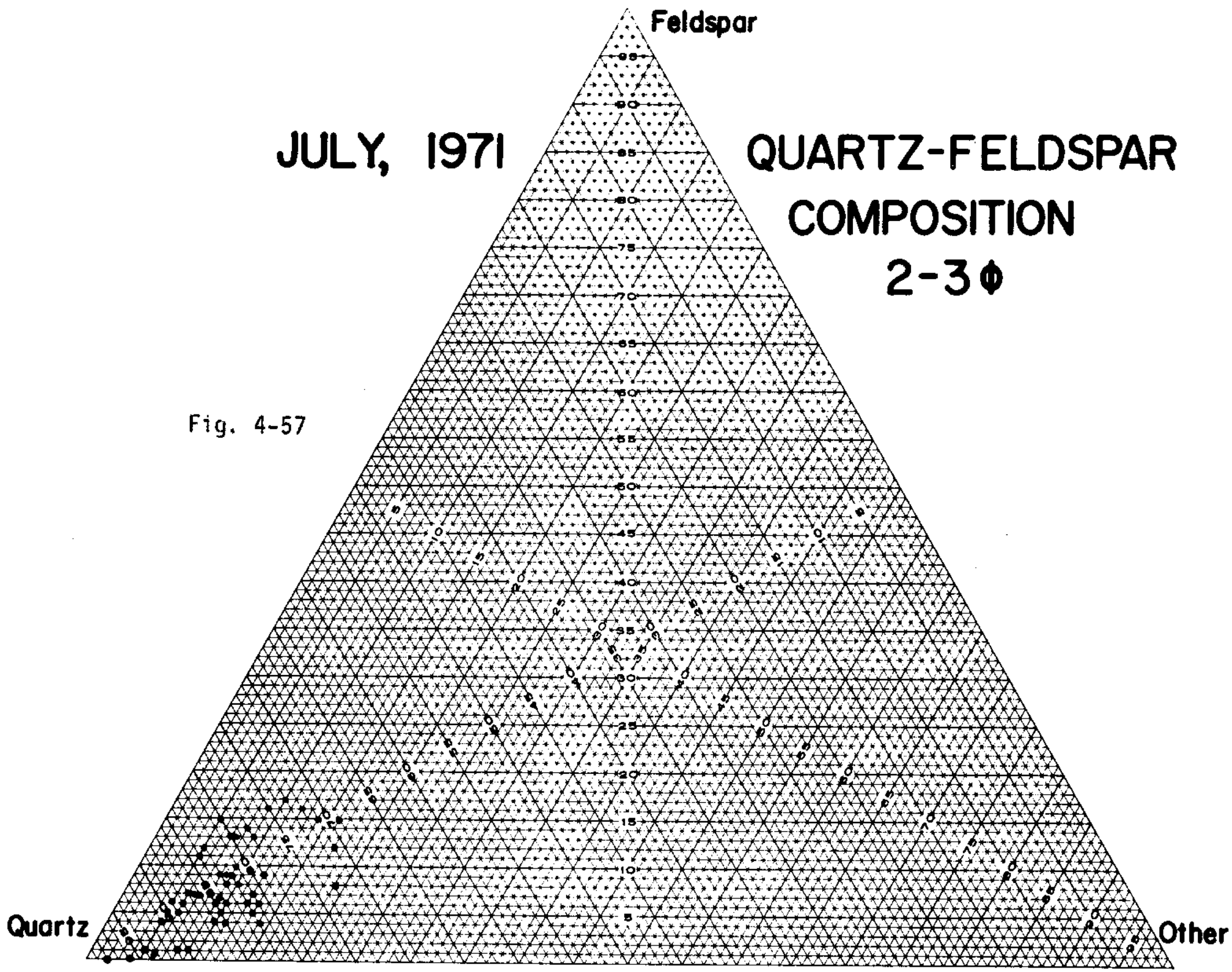

JULY, 1971
QUARTZ-FELDSPAR
COMPOSITION
2-3φ
Feldspar
Quartz
Other

Fig. 4-57

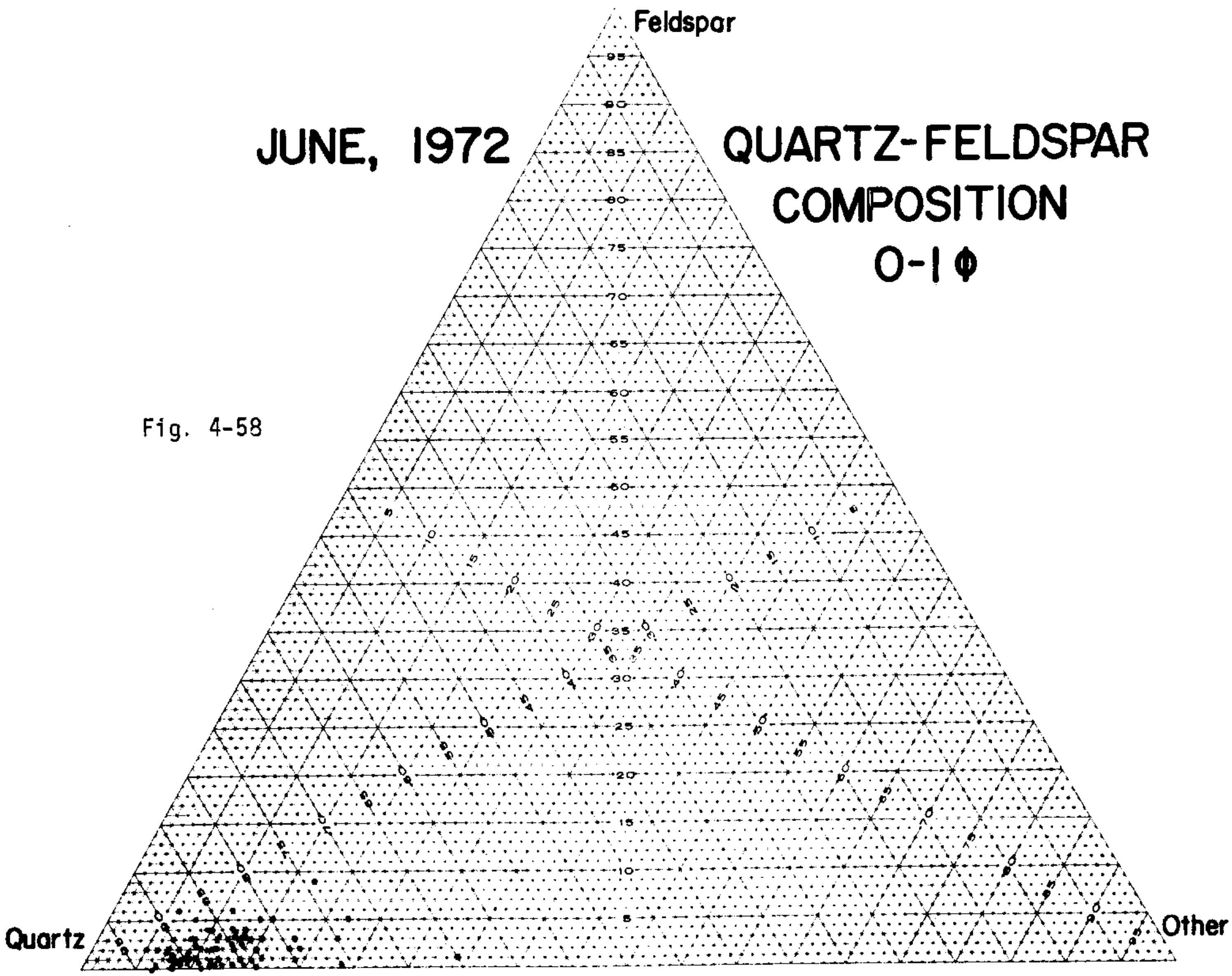

JUNE, 1972
QUARTZ-FELDSPAR
COMPOSITION
0-1 Φ
Feldspar
Quartz
Other

Fig. 4-58

JUNE, 1972

QUARTZ-FELDSPAR COMPOSITION

1-2 Φ

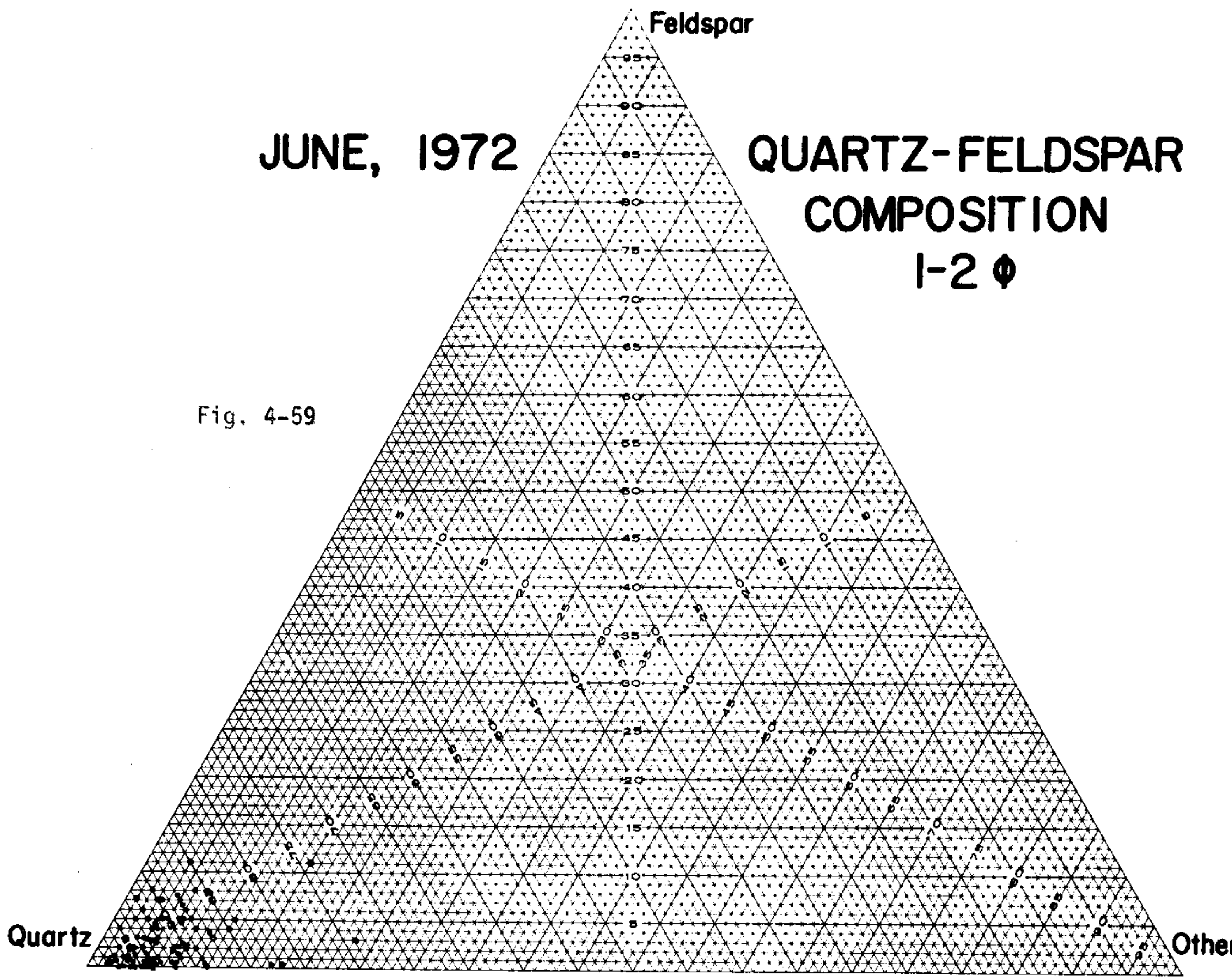


Fig. 4-59

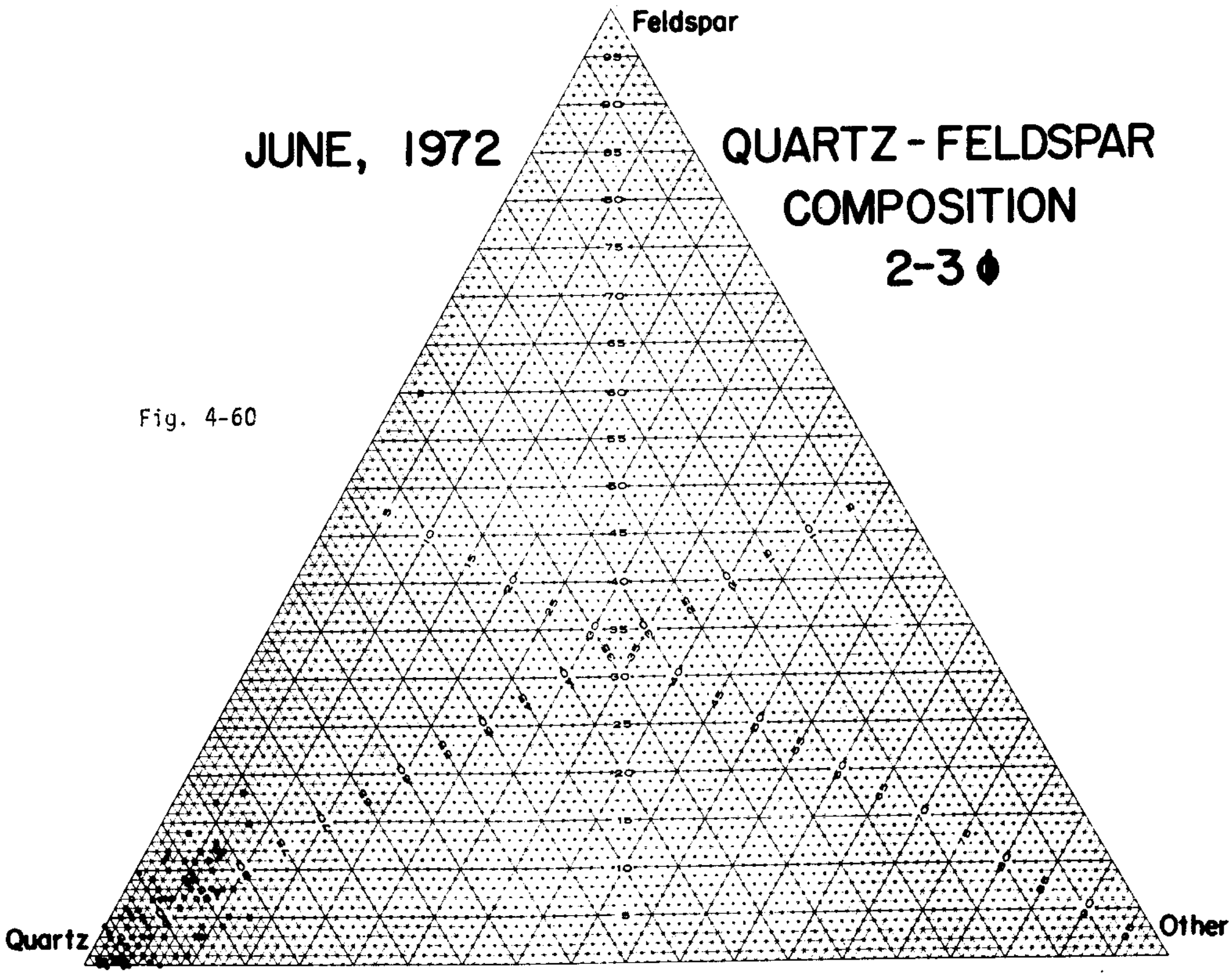

Feldspar
JUNE, 1972
QUARTZ - FELDSPAR
COMPOSITION
2-3 ϕ
Quartz
Other

Fig. 4-60

HEAVY MINERAL X-RAY DIFFRACTION

X-ray powder diffraction analysis was done on selected heavy mineral concentrates in order to identify the principal minerals present and to investigate the mineralogical homogeneity of this fraction. Simply when the x-ray beam strikes a crystal at steadily increasing angles, the beam is deflected at specific angles, depending on the minerals present as a function of the angle of the x-ray beam. Using the American Society for Testing and Materials (1967) file, a compilation of the intensities of the reflections at specific angles for each mineral, the mixture of minerals in the sample can be identified. When the major reflections for two or more minerals in a sample are superimposed within 0.5° of another, problems of identification and quantification arise. Identification must then be made using the reflections of lesser intensity. While the recorded reflection intensities from a mineral in a mixture is related to the concentration of that component in the mixture, it is not a linear relationship (Nuffield, 1966). In the identification process, this means that, for minerals present in quantities from 5-15%, the less intense reflections may not be significantly above background. As a result, positive identification becomes impossible.

This non-linear relationship between concentration and reflection intensity together with reflection superposition is the crux of the quantification problem. If the reflections from a mixture are not superimposed, a series of standard mixtures can be prepared and used to quantify the unknown samples. When superposition of the reflections is present, this becomes impossible as there is an apparent increase of intensity in reflections which are superimposed (Nuffield, 1966). The investigator can never know exactly what portion of the intensity of a reflection is due to each mineral.

Several other problems arise in the x-ray diffraction analysis of heavy minerals. First, unequal grinding can produce varying crystallinities in the samples. If the particles are ground too much, the crystal structure can be destroyed. No reflections can then result during x-ray diffraction. In this study, the samples were ground between 25-35 minutes. The variable time was necessary because the sample, on occasion, became packed into one corner of the ball mill chamber and resisted grinding. While the degree of crystallinity cannot be assumed to be completely equal, it is as equal as can be obtained using a mechanical device.

Another problem arises from the sample mounting procedure. Pryor and Hester (1969) noted that many heavy minerals have certain crystal planes along which breaking is easier than along other planes, resulting in particles flatter and longer in two directions than in the third. Upon packing in a powder mount, the particles may preferentially orient themselves so that these long flat surfaces are directed towards the x-ray beam. To eliminate this source of error, each sample was packed and the x-ray beam was run back and forth over the 13.3° reflection three times. If after repacking, the reflection was at the same intensity as before, preferential orientation was known not to exist.

A third problem arises if the wavelength of the x-ray beam is improperly chosen. Heavy mineral suites commonly contain minerals in which iron is found. If a standard copper x-ray source is used, the x-ray beam will be absorbed by the iron, weakening the reflection pattern and secondary radiation will be generated by the iron, (flourescence), increasing the background (Nuffield, 1966). To eliminate this problem, an iron x-ray source was used, as recommended by Nuffield (1966).

X-ray diffractograaoms from the heavy mineral suites (Figs. 4-61 - 4-70) show significant reflections above background at 13.3° (2θ), 23.3°, 33.7°, 35.2-35.5°, 37.8°, 38.5°, 39.0-39.5°, 42.0° and 44.3° --- 45.5°. The reflection at 23.3° is the result of the $Al(OH)_3$ which was added to each sample in the event an internal standard became necessary. Quartz is represented by its principal reflection at 33.7°.

A continuous series in chemical composition and physical properties within the pyroxene group is represented by the species diopside and augite. (Berry and Mason, 1959). The diffraction patterns of these two species is very much the same with the most intense reflection of augite at 37.8° and the primary reflection of diopside at 37.9°. Augite has less intense reflections at 35.2°, 38.5°, 39.6°, 44.5° and 45.4°. At each of these positions, reflections are present. Diopside has secondary reflections at 39.2° and at 45.2°. Again, these reflections occur. Clearly, the pyroxene group represented by the species augite and diopside is present in the heavy mineral suite. Another continuous series within the pyroxene group is represented by the species enstatite and hypersthene (Berry and Mason, 1959). Again, similar reflection patterns result from these two species. Enstatite has its major reflection at 35.5° while hypersthene has its major reflection at 35.2°. In the region of these two angles, a reflection occurs. A secondary reflection for hypersthene occurs at 39.1° while the secondary reflection for enstatite appears at 39.4°. The broad peak between 39.0° and 39.5° accommodates these two reflections. While superposition occurs between the 35.2° reflection of augite and the major reflections of hypersthene and enstatite, the presence of all of these minerals is clearly defined by their other reflections. The final mineral which is certainly present is hornblende, a member of the amphibole group. The principal reflection occurs at 42.0° with secondary reflections at 13.3°, 33.3°, 34.3°, and 36.5°. The 42.0° and 13.3° reflections are unobscured and marked on the diffractograms.

Several other minerals may occur in the heavy mineral suites but their identifications are unsure. For instance, magnetite, which is believed to occur because some of the grains adhered to a small hand magnet, has it major reflection at 45° and is thus superimposed on the augite-diopside reflections. While it is almost certainly present, it cannot be proven by x-ray diffraction. Another common heavy mineral, ilmenite might also be present. Its major reflection is at 41.4°, where a very small reflection appears on many of the diffractograms.

Finally, the broad reflection between 39.0° and 39.5° is problematical. Secondary reflections from augite, hypersthene, and enstatite lie in this area. In addition, the major reflections from dolomite (39.2°) and epidote (39.1°) are found there. There are no other reflections from these two minerals sufficiently intense to be used for identification. While both of these minerals may be probably contained in the heavy mineral suites, their presence cannot be proven through x-ray diffraction analysis. The presence of these minerals will be discussed in the section concerning the source of the offshore sands.

The presence of quartz (specific gravity - 2.65) in the heavy mineral suite is problematical. It cannot be the result of an incomplete separation, as only the heavies sink to the bottom. An incomplete separation might result in an error in the percent of heavy minerals, but not in light minerals sinking. The quartz, then, must be due to grains containing more than one mineral or actual mineral intergrowths. In any case, the grains as a whole act as "heavies" in the fluid regime.

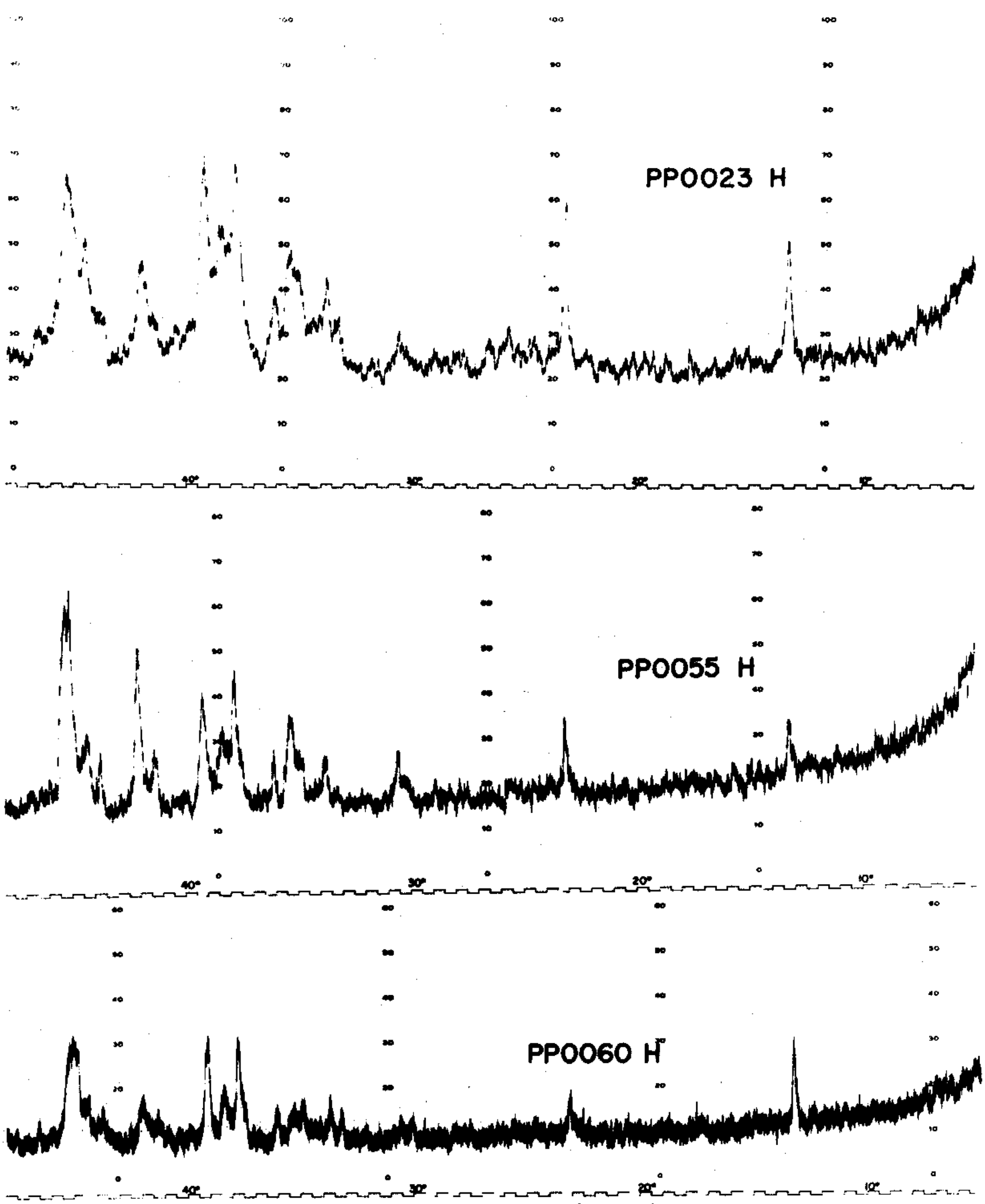


Fig. 4-61

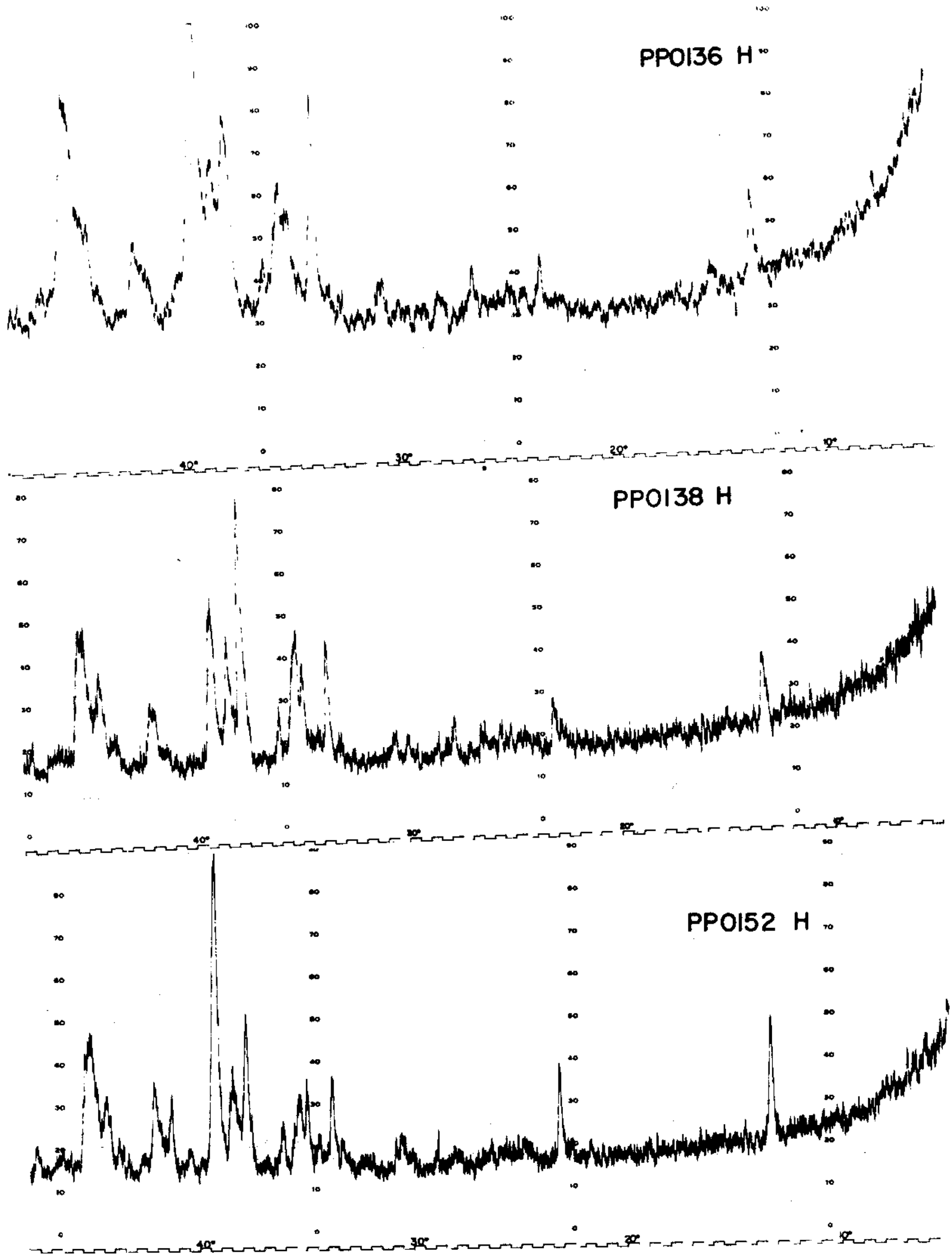


Fig. 4-62

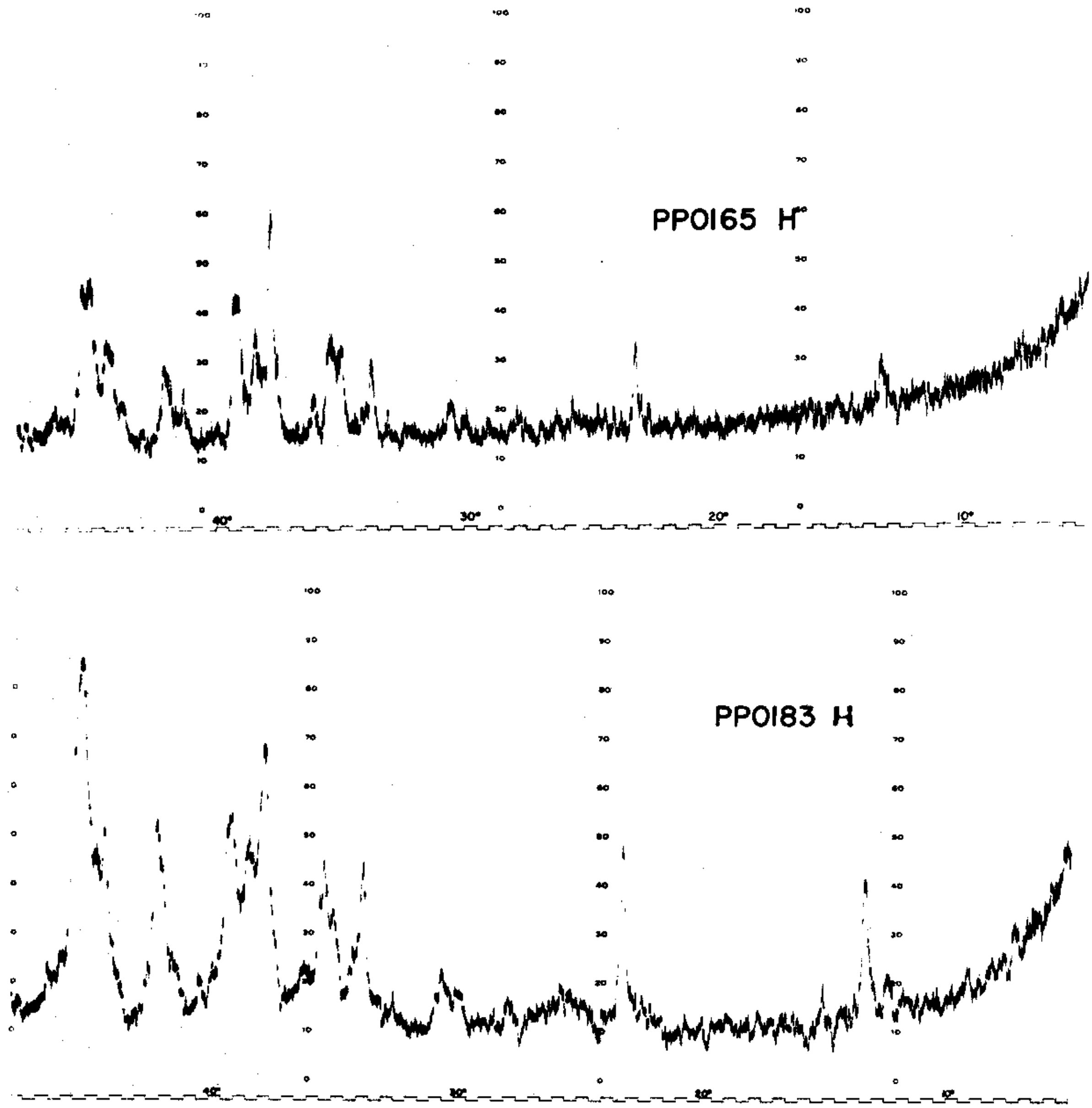


Fig. 4-63

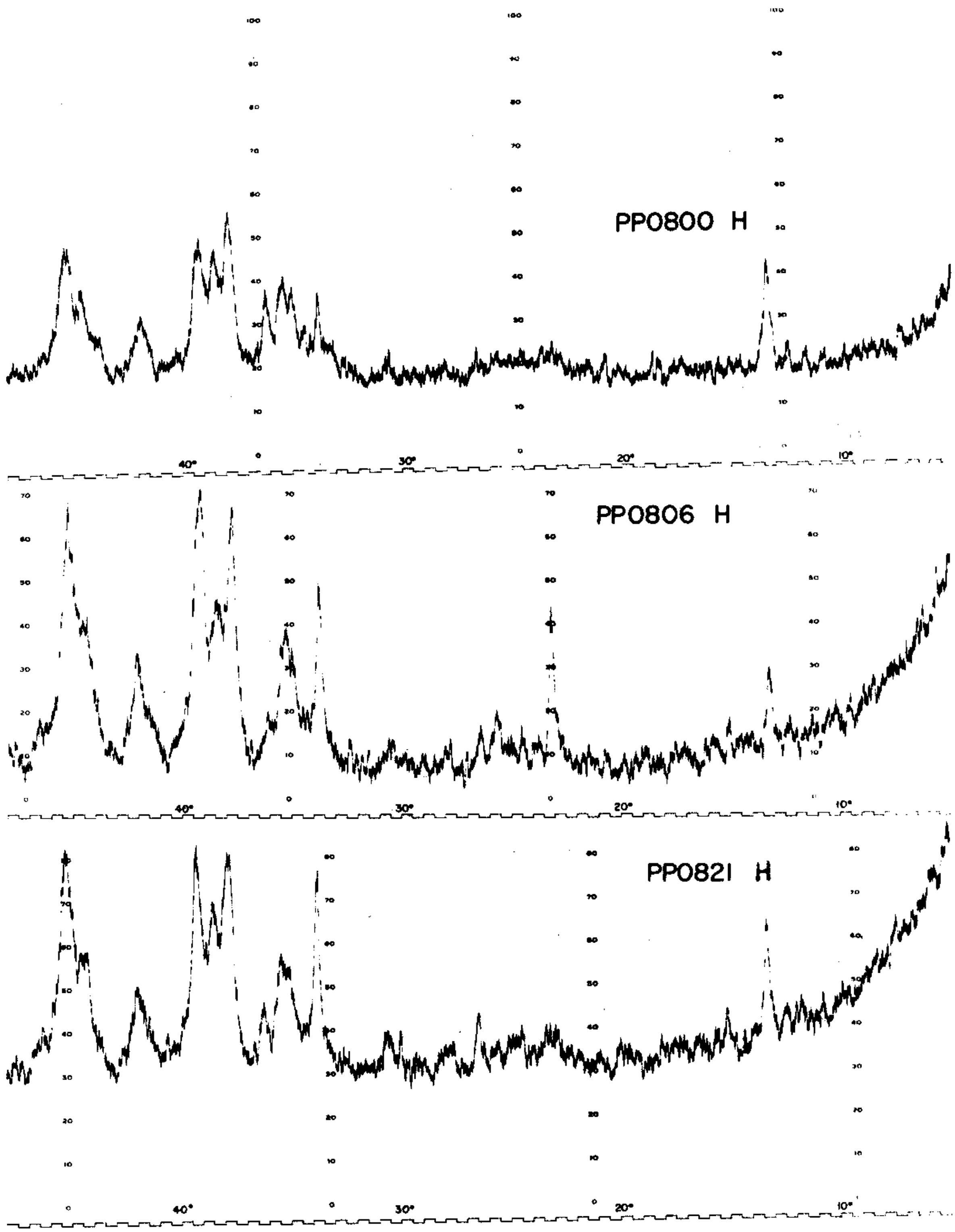


Fig. 4-64

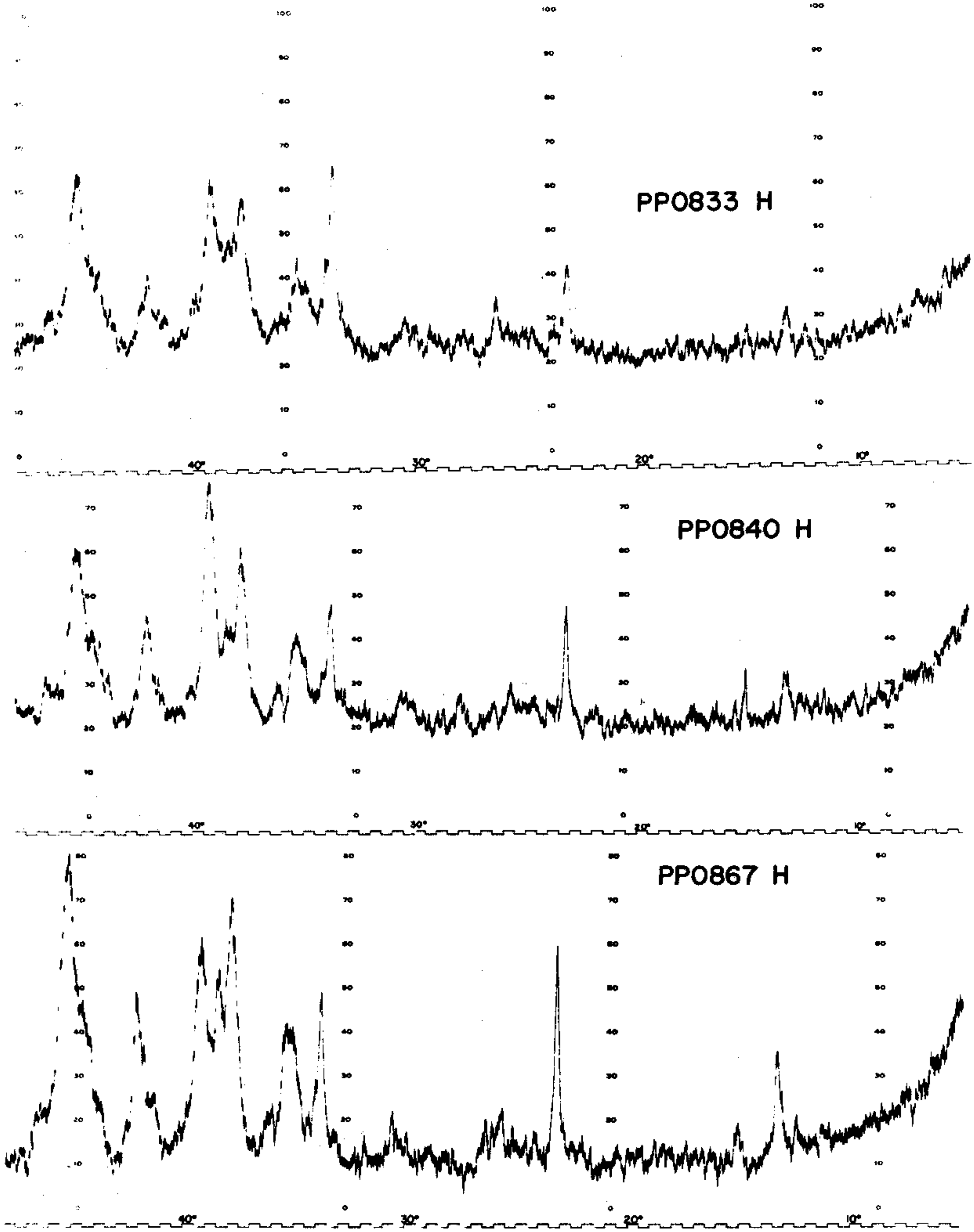


Fig. 4-65

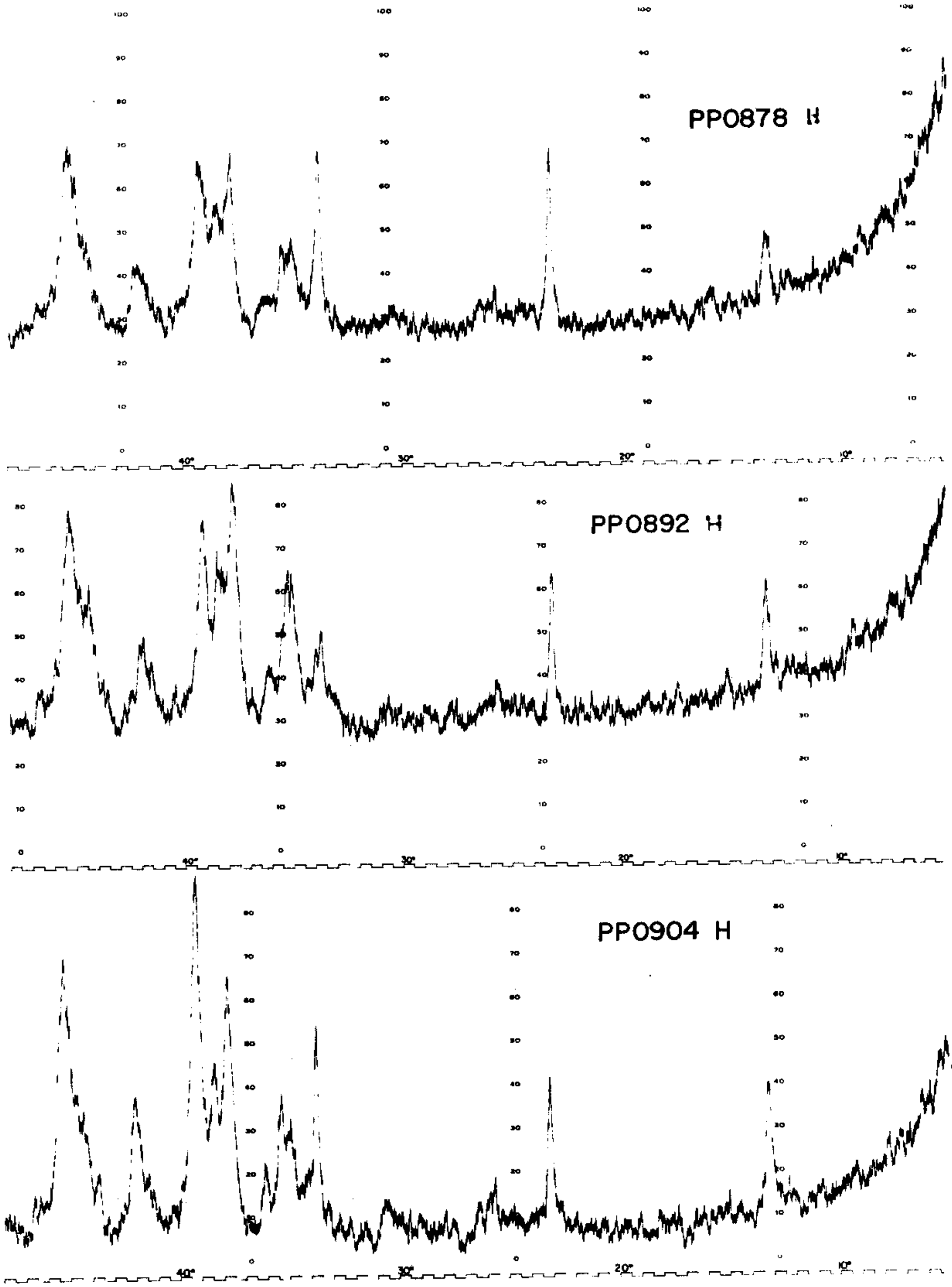


Fig. 4-66

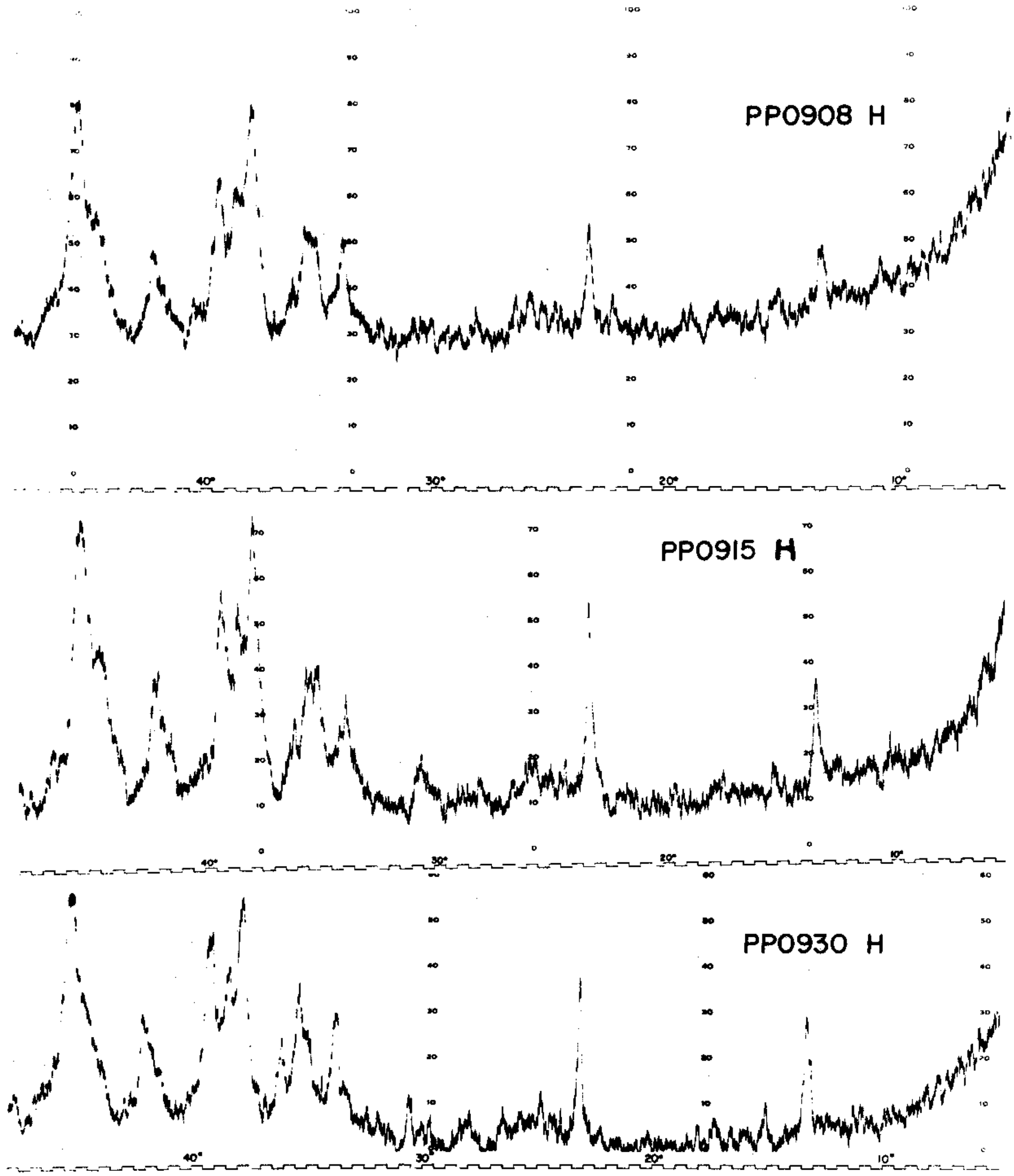


Fig. 4-67

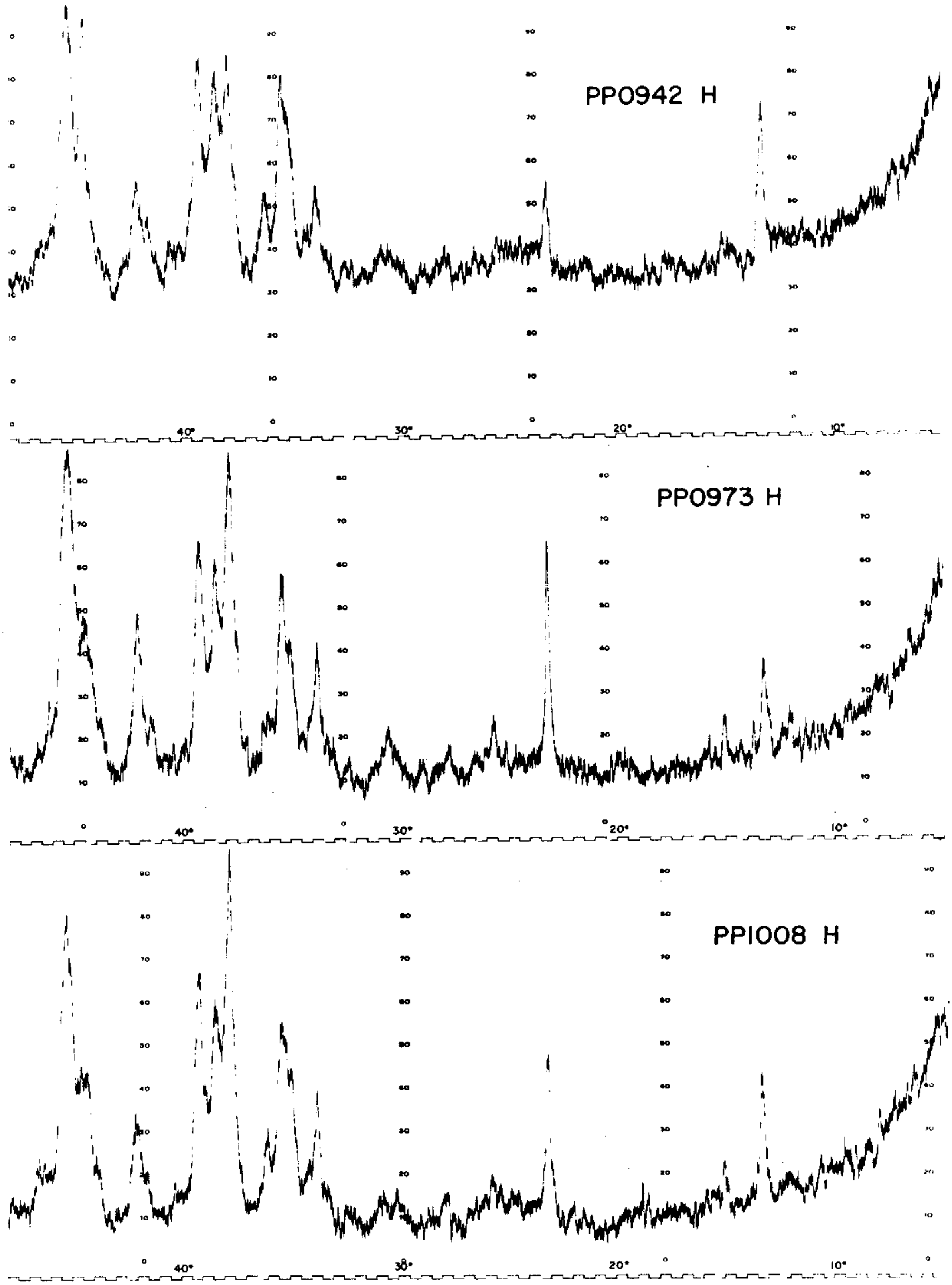


Fig. 4-68

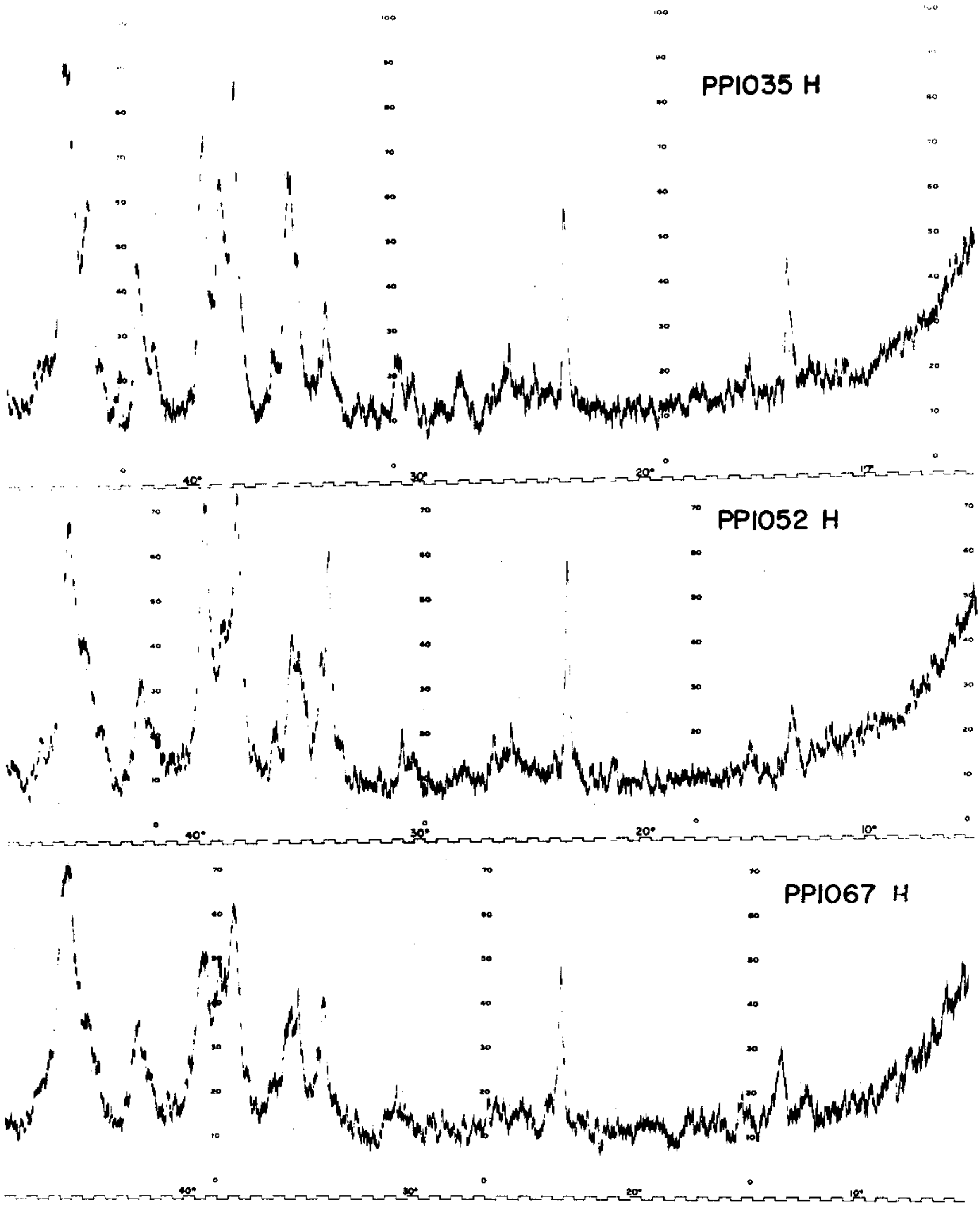


Fig. 4-69

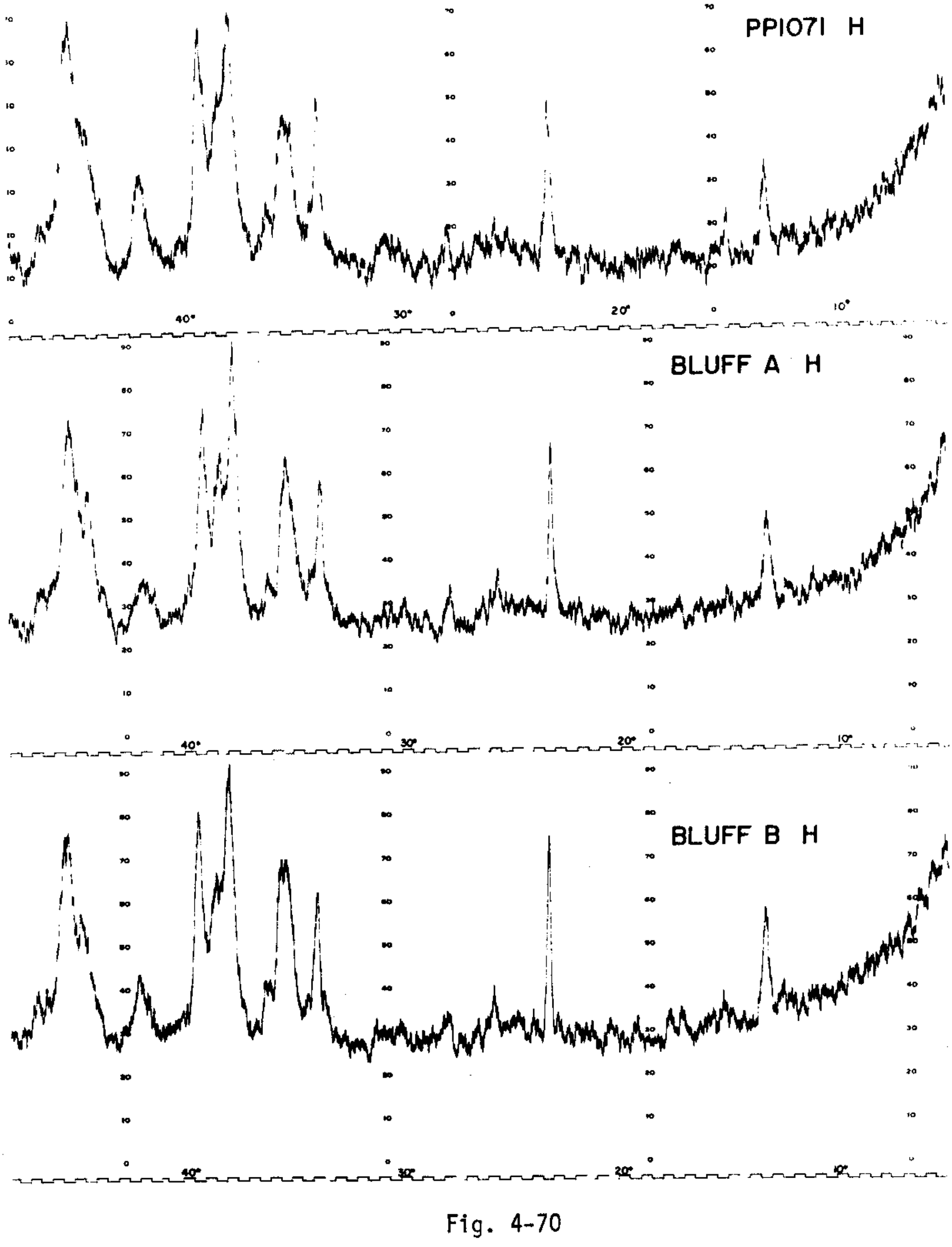


Fig. 4-70

Because of the reflection superposition in this suite, no quantitative analysis was done. However, Pryor and Hester (1969, p. 1384) reported: "Heavy mineral samples can be grouped according to their gross diffraction patterns or diffraction "finger prints," which correspond to petrographic groups." They use this method of "finger printing" to arrange heavy mineral diffractograms into groups, and this method was used in this investigation. By comparing the x-ray diffractograms reproduced in Figures 4-61 through 4-70, a marked similarity is apparent. In none of the diffractograms, and just a selected sample is reproduced here, were new minerals intoduced. While the relative intensities of the reflections change somewhat, each mineral previously identified as being present, is present in all the records. Therefore, based on a visual comparison of the diffractograms, the suite of heavy minerals is the same throughout the study area and for both the June, 1971 and June, 1972 surveys.

CLAY X-RAY DIFFRACTION

In an effort to both characterize the desiccated red clay material found offshore and to investigate its relationship to the similarly appearing bluff material, x-ray diffraction was done on selected samples from both these locations.

Identification was based on the American Society for Testing and Materials (1967) files and the behavior of the clays after several treatments, as described by Nelson (1960). Quartz was represented at 26.7° and 20.4°. Similarly, calcite was represented by the reflections at 29.55° and 39.6° while dolomite was identified on the basis of reflections at 31° and 41.3°. Reflections at 27.6° and 28.0° indicate the presence of potash feldspar and plagioclase feldspar, respectively.

Considering the clay minerals, illite was shown to be present by a strong reflection at 8.8° which was not affected by glycolation. Chlorite and kaolinite both give reflections at 12.5° and 25° which collapse after heating to 600°C. However, chlorite is distinguished by the intensification of the reflection at its 6.3° following heating to 600°C. While a reflection in the 6.0 - 6.5° region from an air-dried sample can result from 14 Å montmorrillonite or vermiculite, in addition to chlorite - if vermiculite is present - this peak gradually shifts toward 9° upon heating towards 500°C. and if montmorrillonite is present, glycolation results in expansion of the reflection to 5°. Since no shifting is apparent on heating, vermiculite cannot be present. That a small amount of 14.2Å montmorrillonite is present is shown by the small peak, after glycolation, at 5°. Two of the samples displayed a reflection at 5.5°. The American Society for Testing and Materials file (1967) showed that a mixed layer clay composed of chlorite and montmorrillonite can cause such a reflection, and it is here so identified.

Components of the silt- and clay-size fraction include quartz, dolomite, calcite, feldspars, and the clay-minerals illite, chlorite, and small amounts of 14.2Å montmorrillonite and occasionally a mixed layer clay.

In Figures 4-71 to 4-75 the diffractograms from the air-dried analysis of each of the samples and the entire set from sample number 642 are reproduced. It is apparent that while small variations occur in the relative intensities of the reflections, the "fingerprint" of the suite appears the same in all of the offshore samples. Hence these clay samples can be considered to have been taken from the same formation.

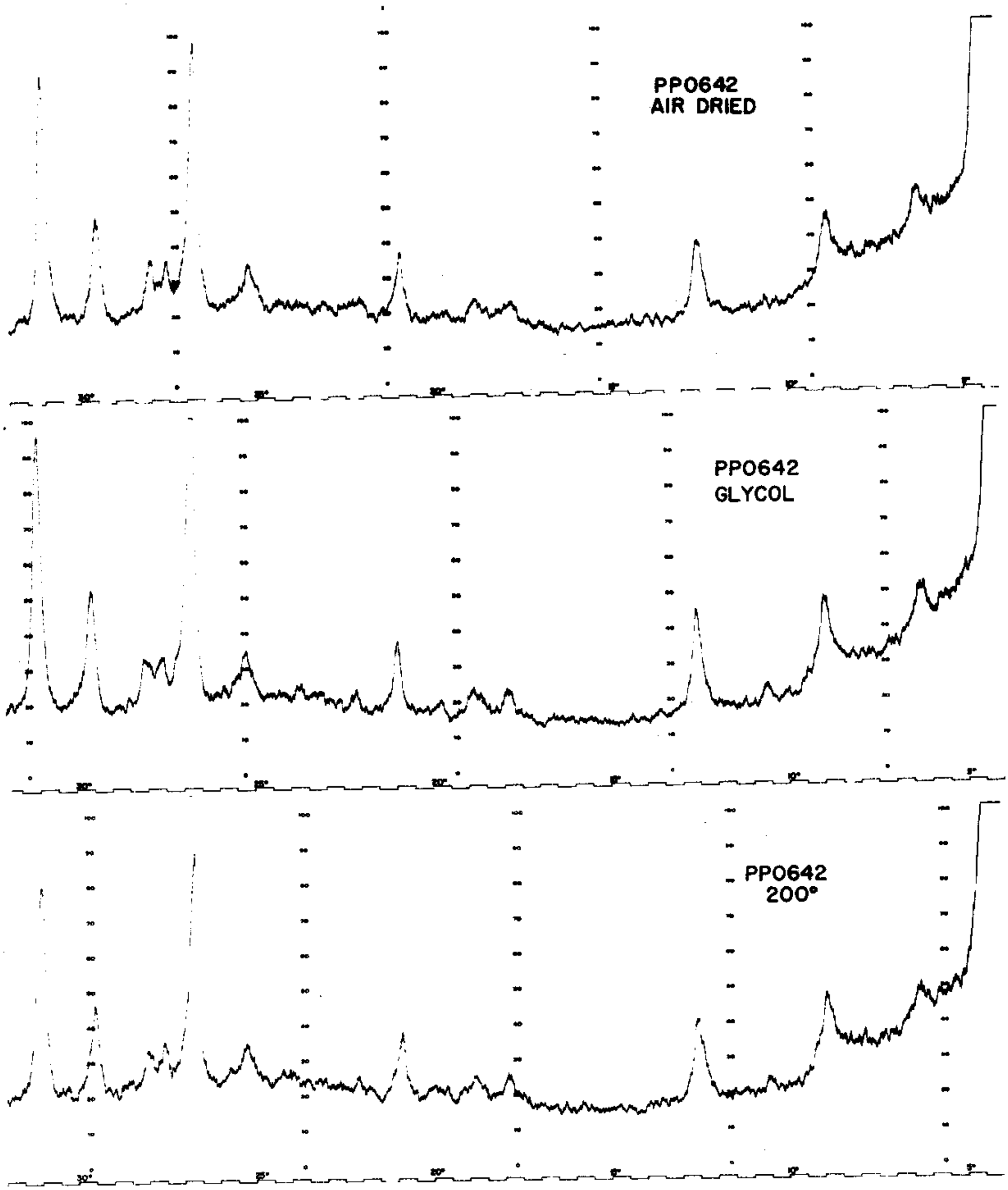


Fig. 4-71

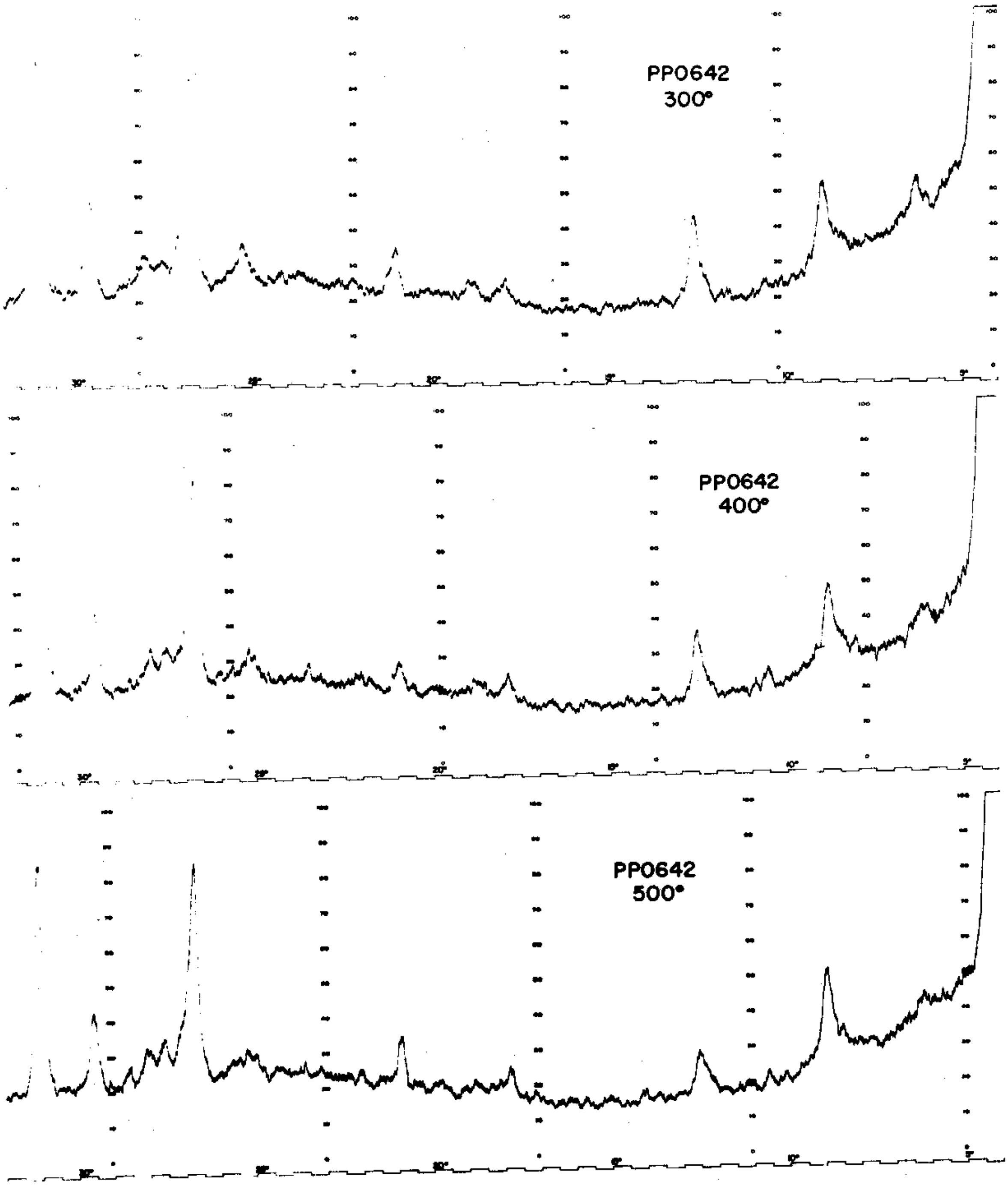


Fig. 4-72

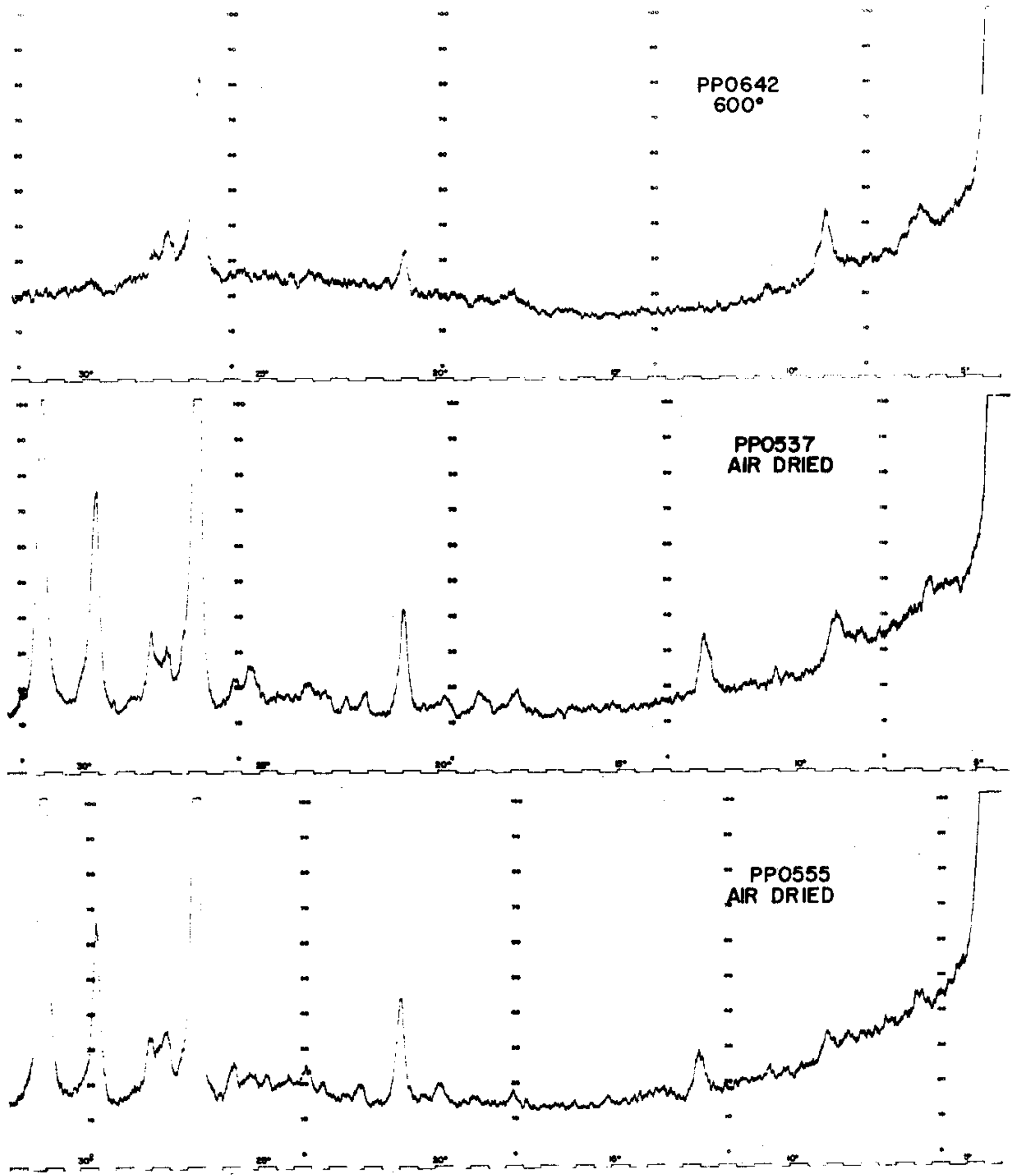


Fig. 4-73

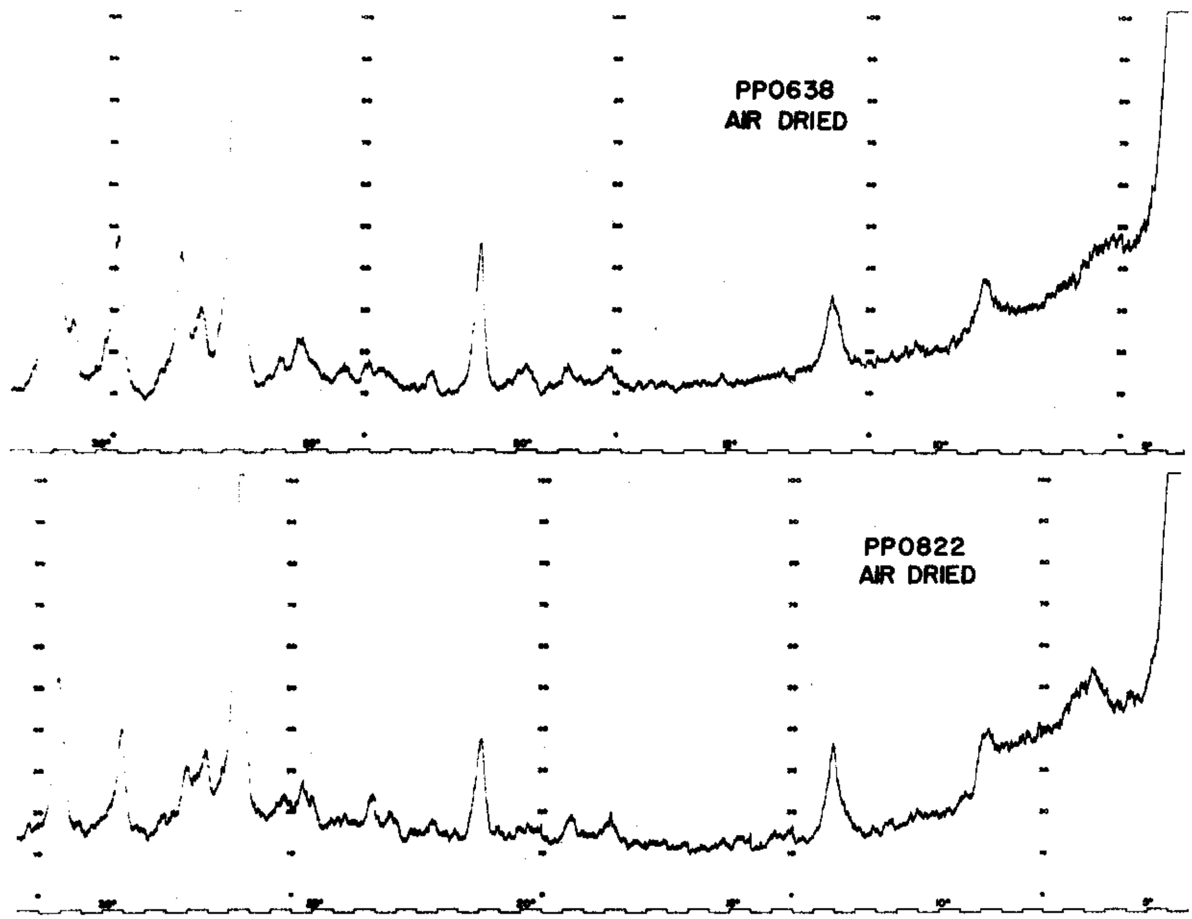


Fig. 4-74

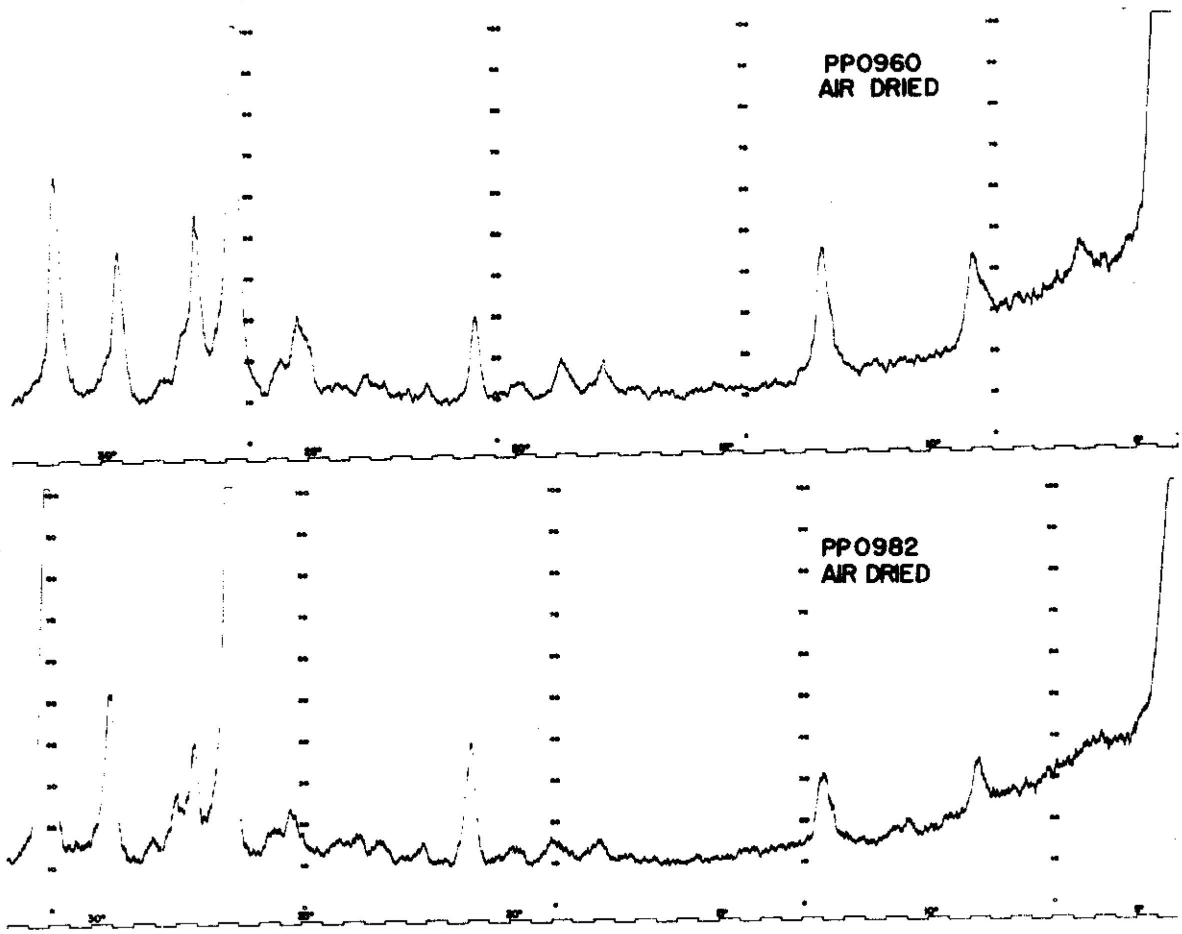


Fig. 4-75

SOURCE

To identify the source, both the texture and the mineralogy of the offshore sediments must be considered. Texturally an entire range of material must be contributed, from gravel to sand to silt and clay. Mineralogically, quartz and feldspar, and more importantly, the minerals identified in the heavy mineral suite offshore must be contributed.

Because the waters of the study area are bordered by a narrow (5-70 feet) beach which is in turn bordered by bluffs of Valders drift, and because the erosion of these deposits has been well documented, the bluffs were considered as a probable source. To test this hypothesis, the materials contained within the bluffs were investigated both texturally and mineralogically. Comparisons were then made between the results of these analyses and comparable analyses of the offshore sediments.

The texture of the Valders drift is well documented in the literature. Moore (1953) found that, after removing the gravels larger than 4 mm., Valders till contained between 11 and 50% sand, the remainder being silt and clay-size particles. Lee, et al. (1962) discussed the variability of the Valders drift and noted that of 288 samples studied, 232 were till, which is nonsorted, nonstratified glacial material. They further wrote that all the till samples contained at least 5% sand and over 10% sand was found in all but 5 of the till samples. Finally, Lee, et al. (1962) found gravel, varying from cobbles to boulders, in most of the till samples. Clearly, the Valders drift contains a sizable (50% or more in some cases) fraction of sand and gravel. Texturally, then, this material can serve as a source for the sand and gravel sediments in the study area.

Mineralogical evidence comes from two sources, heavy mineral separation and x-ray diffraction. Heavy mineral separations performed on two bluff samples, one taken just north of Point Beach Power Plant and the other at Two Creeks Lake Access, showed that, in the 1-4ϕ size fraction, heavy minerals constituted 3.3%. This same value was found for both samples.

X-ray diffractograms of these two samples showed a remarkable similarity to those from the offshore heavy mineral suite (Fig. 4-70). All of the minerals identified offshore are present and no new ones occur. Hornblende, diopside, augite, enstatite, hypersthene, dolomite, epidote, magnetite and quartz were identified.

It is informative to compare the results of these analyses to the heavy mineral suite in the Valders till, as reported by Murray (1953). He listed the three most common types, as determined from samples taken at Valders and Sturgeon Bay, Wisconsin, opaques (magnetite, hematite, illmenite), hornblende and epidote. A second heavy mineral suite of interest is that of northeastern Lake Michigan, determined by Moore, (1961). In samples from this area, magnetite, pyroxene and amphibole were found. The sand in the bluff drift, then, contains the same heavy mineral suite as the offshore sediments and contains a sufficient amount to act as a source for the offshore heavy mineral concentrations.

Finally, the silt- and clay-size fractions of the bluff samples were x-rayed. Also x-rayed was the suspended matter filtered from a water sample (Fig. 4-76). First a comparison can be made between the desiccated red clay material found offshore and the Valders drift material. The similarity is indeed striking

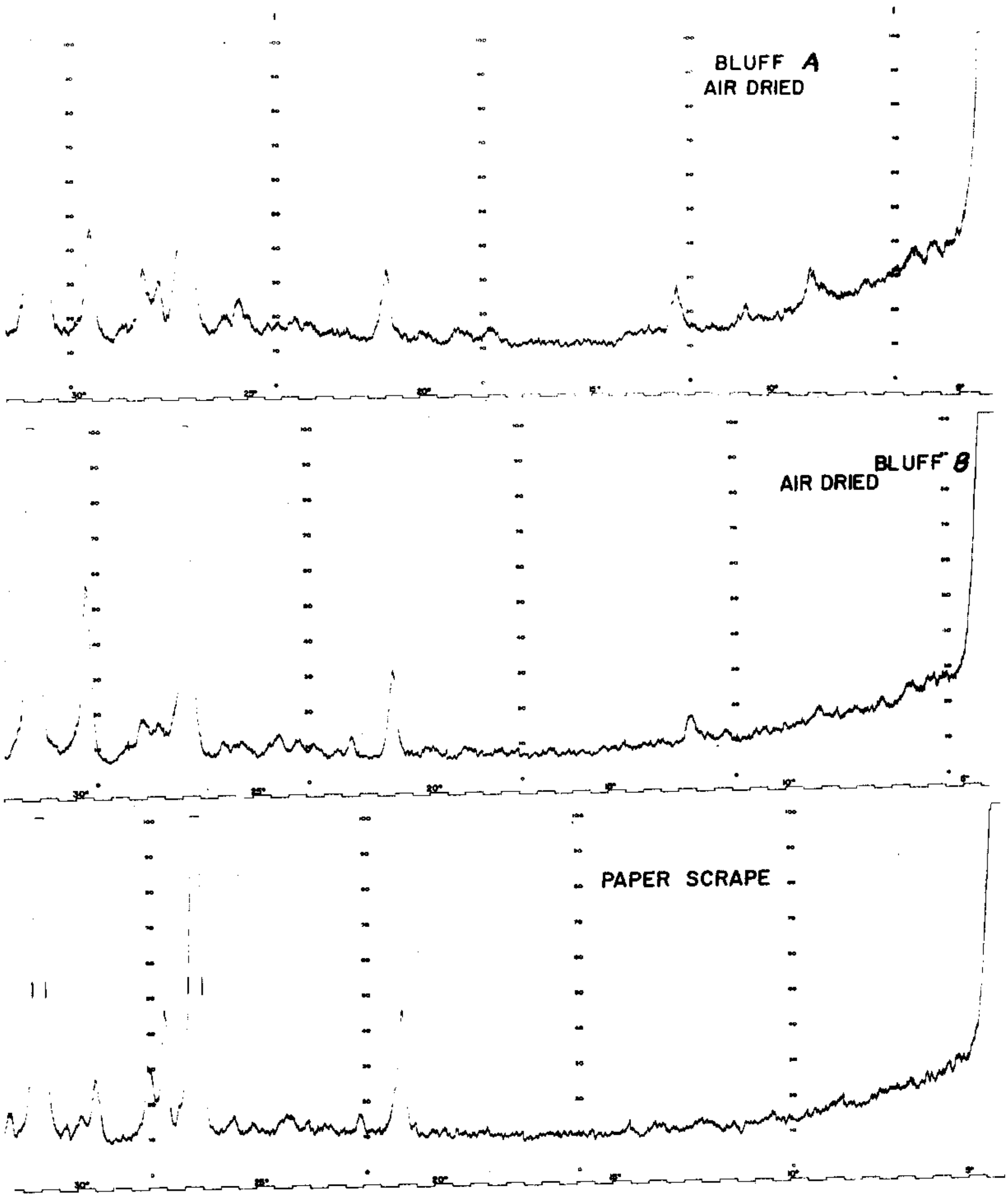


Fig. 4-76

with the quartz, calcite, and dolomite reflections most intense and the chlorite and illite less so. Small amounts of 14.2Å montmorrillonite and the chlorite-montmorrillonite mixed layer clay mineral are also present.

There are several reports in the literature of the mineralogy of the silt and clay-sized material in the Valders drift. Quartz and dolomite are the principal minerals in the clay-size fraction (Murray, 1953). Murray noted, however, that the photographs suggested the presence of clay minerals but that the reflections were not sufficiently intense to warrant further study. The silt and clay-sized materials were more thoroughly investigated by Petersen et al. (1967). Quartz, feldspars, calcite, dolomite, chlorite, and illite comprised the silt-sized component while in the clay-sized fraction, montmorrillonite, illite, vermiculite, chlorite and inter-stratified clay minerals. Similarly, the clay minerals montmorrillonite, chlorite, and illite along with quartz, feldspar, dolomite, and calcite were identified in the Valders drift material by Lee, et al. (1972). The results of this investigation are in good agreement with the findings of previous authors. There seems to be no question, then, that the offshore desiccated red clay belongs to the same deposit as the desiccated red tills onshore, the Valders drift.

Suspended matter yielded a diffractogram which compared favorably with the pattern displayed by the bluff material. While the peaks of quartz, dolomite, calcite and the feldspars are most intense, the clay mineral reflections are faint but observable. Chlorite, illite, and a mixed layer (chlorite-montmorrillonite) clay mineral are present on the diffractogram. The silt- and clay-size fraction of an offshore muddy sand (PP829) was also subjected to x-ray diffraction analysis. While calcite did not show up markedly, the clay minerals were the same as in the Valders drift. (Fig. 4-77)

Considering the textural evidence along with the mineralogy of both the heavy mineral suite and the silt and clay-size fraction, the Valderan age deposits can, without question, be identified as the source. As Thwaites and Bertrand (1957) mapped the Valders drift to the tip of the Door Peninsula, and on into Northern Michigan, the source is sufficiently large is obvious.

BACKGROUND RADIOACTIVITY COUNTS

Table 4-3 shows the results of the background radiation counts and the type of sediment that they were associated with. The lowest values, 1.93 and 2.92 picocuries per gram, were found in the gravelly sand material. Clay and the muddy sand types displayed the highest values, 8.93 to 12.08 picocuries per gram. Intermediate values, 3.43 to 5.66 picocuries per gram, were measured in the sand classes. Clearly, the background radioacitvity is concentrated in the finer textures.

The clay minerals are well known for their ion exchange and adsorption capacity, or the ability to sorb "certain anions and cations and retaining them in an exchangeable state" (Grim, 1968, p. 185). Grim (1968, p. 185) also noted: "The exchange reaction is stoichiometric and thereby differs from simple sorption. This distinction, however, is difficult to apply since nearly every ion-exchange process is accompanied by sorption or desorption." Regardless of any distinction between these two related chemical processes, that clays can extract trace metals from sea water is well known (Riley and Chester, 1971).

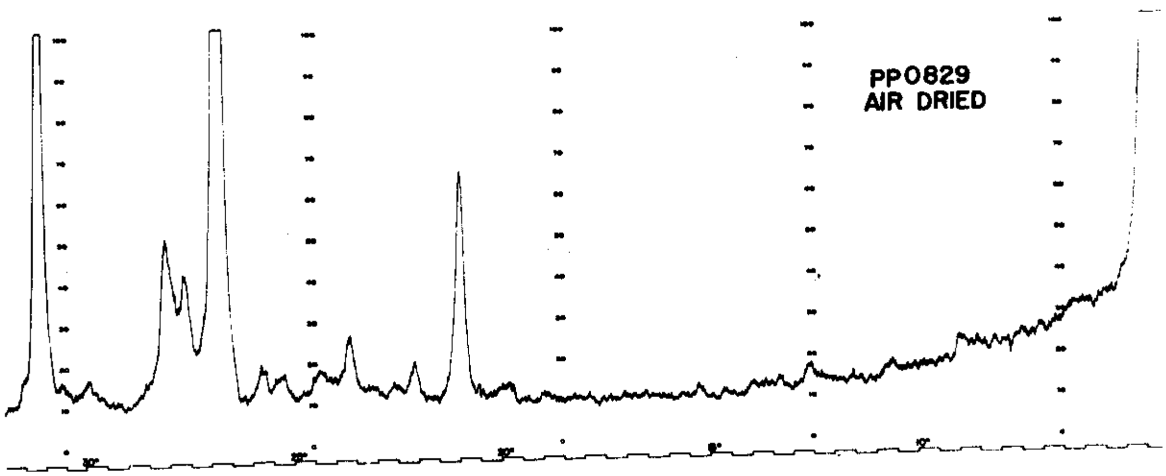


Fig. 4-77

TABLE 4-3

BACKGROUND RADIATION

SAMPLE NUMBER	CPM/GR COUNTS PER MINUTE PER GRAM	CPM/GR ÷ 2.22 PICO CURIES CURIES x 10^{-12}	SEDIMENT TYPE
PP 023	10.39	4.68	Fine Sand
043	12.19	5.49	Fine Sand
051	10.22	4.60	Fine Sand
065	10.87	4.90	Fine Sand
071	6.49	2.92	Gravelly Sand
077	7.63	3.43	Fine Sand
082	19.83	8.93	Clay
096	24.92	11.23	Clay
097	7.79	3.51	Medium Fine Sand
104	9.84	4.43	Medium Sand
117	4.28	1.93	Gravelly Sand
153	12.52	5.64	Very Fine Sand
182	11.00	4.95	Fine Sand
183	12.56	5.66	Fine Sand
184	26.82	12.08	Clay
188	11.65	5.25	Fine Sand
190	14.16	6.38	Clay
191	20.40	9.19	Muddy Sand
023 (Blind)	12.39	5.58	Fine Sand
096 (Blind)	25.60	11.53	Clay

Radioactive nuclides found in both oceans and lakes are of three types: (1) Naturally occurring elements and their daughter products existing in the environment since the formation of the earth, (2) Short-lived nuclides, naturally occuring, produced by cosmic radiation in the atmosphere, and (3.) Artificially induced nuclides due to weapon explosions or discharges from nuclear facilities (Burton, 1965).

While there is almost 300 radioactive nuclides, (Burton, 1965) the principal ones are listed in Table 4-4. The Environmental Protection Agency (1972) reports the presence of tritium (<0.9 ± 0.2 nannocuries/liter), Cesium-137 (<0.78 ± 0.14 picocuries/liter) and Strontium-90 (< 1.5 ± .2 picocuries/liter) in Lake Michigan water during August - September, 1970. Also reported were radioactivity contributions in sediments by the following nuclides:

1. Potassium-40 (6.89 p Ci/mg)

2. Natural Uranium (.4- <.1 µg/g)

3. Natural Thorium (2- < 2 µg/g) and

4. Radium-226 (1.30-< 0.05 p Ci/g)

The sediment type associated with these values were not reported.

Given the ion exchange and sorption properties of the clay minerals and the presence of radioactive nuclides in lake water, the explanation for the concentration of background radiation in the finer textures is clear. That trace elements yielding radioactivity in sea water are concentrated in the clay minerals is well documented by Chester (1965). He points out, for instance, that strontium is associated with the clay minerals through ion-exchange/sorption processes. The high background radiation counts found in the finer textures must be due to ion-exchange/sorption concentration of the trace metals by the clay minerals. No conclusion can be reached as to whether this concentration is modern or occurred when the desiccated red clay was deposited.

TABLE 4-4

PRINCIPAL NUCLIDES

Compiled from Burton, 1965

I. Naturally Occuring Nuclides

ELEMENT	HALF-LIFE
Potassium-40	1.27 x 10^9 Years
Uranium-238	4.51 x 10^9 Years
Thorium-232	1.39 x 10^{10} Years
Uranium-235	7.1 x 10^8 Years
Radium-226	1622 Years

II. Nuclides Formed by Cosmic Radiation

Tritium	12.3 Years
Silicon-32	500 Years
Carbon-14	5568 Years
Berylium	2.5 x 10^6 Years

III. Artificially Induced Nuclides

A. Fission Products

Strontium-90	28 Years
Cesium-137	30 Years

B. Induced Activities

Tritium	12.3 Years
Carbon-14	5568 Years
Iron-55	2.94 Years

V. THE BEACH REGIME

At the interface between water and land, unique interactions develop between the fluid regime and the materials comprising the shore. It is at this interface that disturbances in the fluid regime -- waves, currents, and oscillations -- change their form as they interact with both the topography and the materials forming the shore. As the fluid regime is undergoing change, it alters the topography and distribution of the materials of the shore. Unconsolidated materials are moved from place to place, while consolidated materials are torn from their places of rest.

THE LITTORAL ZONE

The littoral belt is the term used by marine geologists to denote the zone between the lower limit of wave influence on the bottom upwards to the back edge of the beach (Fairbridge, 1968). In this zone, a littoral current is developed.

As waves approach a shoaling bottom they change form. Wave energy which was previously geared to deeper water must re-align in response to the more shallow fluid regime. First, the wave velocity and length decrease, the wave energy as a whole reduced slightly by friction at the bottom. After this small decrease in wave height, it increases to a maximum, the point of breaking (Johnson, 1956). The water particles of waves in the open sea, deep water, travel in orbits. Shepard (1963, p. 65) writes that "when the depth $\underline{h}$ is equal to the wave height $\underline{H}$, the wave phase velocity is equal to the orbital or particle velocity." Waves break when the orbital velocity of the water particles at the crest of the wave exceeds the diminishing wave velocity. At this point, the instability of the wave is manifested by breaking (Shepard, 1967). Depths at which this occur equal about 0.7 of the wave height (Shepard, 1968). Obviously, the depth of water in which waves break is a function of the character -- the wave height and steepness -- of the incoming waves.

Highly turbulent flow conditions in the fluid regime are the result of the breaking action. The turbulence is characterized by high accelerations and velocities of the water particles (Johnson, 1956).

The breaking of waves is the result, then, of the shoaling bottom topography altering the nature of the fluid energy regime. But two other important influences on the incoming waves are the shape of the coastline and angle of approach of the waves. When waves approach a straight coast at an angle, or if a point of land is encountered, they are bent or refracted. The portion of the wave striking the shoaling bottom first is slowed up, therefore gaining a slower velocity than that part of the wave still in deeper water. This change in velocity causes the waves to be bent more parallel to the contours of the bottom topography. However, because the refraction process is not perfect and because the offshore bottom topography is often not exactly parallel with the shore itself, waves can still strike the shore at an angle (Johnson, 1952).

It is waves breaking at an angle that direct the littoral current. One other feature of the incoming waves plays a part in the induction of the littoral current. Waves in shallow water cause a forward mass transport of water, superelevating the water surface near the shore. Counteracted by gravity, this excess water must be discharged from the area in one or two ways. Pushed by waves breaking at an angle, the water can flow parallel to the shoreline, or the excess water can flow directly outwards locally as a rip current (Shepard, 1963).

Waves breaking at an angle, together with the net forward mass transport of water, cause a littoral current.

Several factors influence the velocity of the littoral current. Simply it is a function of the wave angle, the wave steepness and the wave energy. The results of an increase in wave angle and an increase in wave energy are obvious. An increase in the angle of the incoming waves will yield a greater alongshore component of energy. Greater wave energy will input greater energies to the littoral zone. Saville (P. 562, 1950) likewise delineates the cause of increased velocities due to steeper shorter waves. "This is because the larger waves feel the bottom sooner, and refract more than the shorter period waves. For these long waves which refract more parallel to the beach, the longshore component of the mass of water set in motion by the breaking wave is much less than that for the shorter, steeper wave and thus produces a smaller littoral current."

LITTORAL TRANSPORT

Littoral currents transport unconsolidated material in two ways: 1. Oscillatory water movement induced by successive waves causes sedimentary particles to roll in a zig-zag motion across the beach face; 2. Sediments in suspension are carried along by the littoral current itself. (Saville, 1950). The first process is merely one of shifting the material exposed at the beach face. The second is slightly more complicated. As waves break, much of the energy of the falling water is directed at the bottom (Shepard, 1967). Also, in a breaking wave, a great deal of turbulence is developed. The combination of these two actions causes sediment from the bottom to be put into suspension. Once in suspension, they are carried along by the littoral current until their fall velocity exceeds the upward turbulent force of the water. As Einstein (1948, p. 654) pointed out "sediment particles can be suspended indefinitely in a turbulent flow."

Considering the two processes of sediment movement along a shoreline, which mechanism transports the greatest volume of seidment? Saville (1950) has investigated this problem and reported that the situation varies with the nature of the fluid regime. The amount of material transported in suspension, rather than in beach drift, reaches a maximum, about 60% of the total transport, when steep storm waves are striking the shore. Only a few percent of the total transport moved in suspension by long, less steep waves.

In regard to the <u>total</u> movement of sediment along a shore, Saville (1950) made a rather startling discovery. His experiments showed that "transport along summer beaches was much greater than along storm beaches for waves with the same energy content." (Ibid., p. 564). Steeper waves, then, increase the littoral current and increase the amount of material in suspension, but do <u>not</u> increase the total volume transported along the shoreline. Komar and Inman (1970, p. 5921) support Saville's ideas when they wrote "The results therefore suggest that the suspended load transport of sand in the surf zone is less important than bed load transport." While storm waves erode great amounts of beach material, it is deposited in offshore depths rather than being moved down the coast. The less steep waves cause a greater volume of material to be moved as beach drift.

The littoral transport, then, causes larges volumes of sediment to be moved along the coast. Frequently this current is called a "river of sand" or as Bascom (1964, p. 213) puts it, "the littoral conveyor belt."

BEACH CHARACTERISTICS

With this complex interaction between the forces of the fluid regime and the material of the land, one would expect the beach to take a variety of forms. Bascom (1964, p. 186) put it succinctly when he wrote "beaches are everchanging, restless armies of sand particles, always on the move." Changes in the form of the beach would necessarily depend on the form and angle of the incoming waves, the configuration of the coastline, and the materials on the beach.

The difference in the sediment transport caused by long, low waves as opposed to short steep waves caused two classes of beach topography. One is the result of long low waves with their great capacity to transport material toward and along the shoreline. The beach is thus built up and the berm moves seaward. This is often termed a summer beach. When the waves become shorter and steeper, as the result of a storm, for instance, the beach is cut back as material is carried seaward. The eroding beach becomes narrow and the beach face becomes steep. While this is usually called a winter beach, it can be formed anytime storm waves attack the shoreline. Beaches, therefore are always in equilibrium with respect to the wave regime adjusting themselves toward an equilibrium profile.

The form of the beaches also depends on the configuration of the shoreline. Beaches on a point of land where the offshore topography shoals abruptly can be subjected to intense wave action. They will, in general, be narrower and contain a smaller amount of material than a protected beach. A beach lying inside of a bay, protected from the waves by the shallow offshore topography may be broader, with more abundant beach materials.

Beaches are formed from unconsolidated materials, varying in size from large boulders to very fine sand. Sand beaches are the most common type. The size of the material present determines the possible equilibrium slope of the beach face. Table 5-1 reproduces the general relation between these two parameters. Although the slope is clearly related to sediment size, it is really a function of the permeability of the beach face. Permeability is in turn determined by the grain size. As the waves slosh up the beach, some of the water discharges into the beach material and the rest runs back down. Clearly, the amount of water washing back down, and carrying sediment with it, will determine the beach slope.

While the beach face reaches a dynamic equilibrium with the wave regime, the back beach may retain remnant features of more intense wave regimes. Frequently, more than one berm may be identified. No only will a marked change in slope be apparent, but gradations in sediment size will be found.

SHORE EROSION

If the beach is subjected to intense wave action, it may totally disappear. Without this bit of moderating topography, the wave regime will strike at the material forming the back edge of the beach. The erosion process begins as the waves remove the material forming the base of the bluff. When the bluff has been undercut, the upper part becomes unstable and slumps down. Areas in the study area where erosion has recently occurred are often marked by large trees laying on the beach. Often, if the top of the bluff is covered with grass, a sheet of sod bends down over the front of the bluff as the material underneath is washed away.

TABLE 5-1

SEDIMENT DIAMETERS RELATED TO AVERAGE BEACH FACE SLOPES

Type of Beach Sediment	Size	Average Slope of Beach Face
Very Fine Sand	1/16-1/8 mm.	1°
Fine Sand	1/8-1/4 mm.	3°
Medium Sand	1/4-1/2 mm.	5°
Coarse Sand	1/2-1 mm.	7°
Very Coarse Sand	1-2 mm.	9°
Granules	2-4 mm.	11°
Pebbles	4-64 mm.	17°
Cobbles	64-256 mm.	24°

From: Shepard (1963) p. 171

There are two processes affecting erosion besides intense storm action. Lake level changes and the formation of ice on the beach both play a role in the erosional process. While erosion proceeds at all lake levels, it is accelerated when the lake level is high (Beach Erosion Board, 1946).

Bruun (1962) has analyzed the relationship between sea-level rise and shore erosion. He first assumes that the profile of the beach and nearshore bottom will alway- come into equilibrium with the fluid regime. That this is true has been well demonstrated by Johnson, (1949), Saville (1950), and Bascom (1964).

When a rise in sea-level occurs, Brunn (1962) theorized that the three following events occur as a profile of equilibrium is developed.

1. The upper beach is eroded as a result of the shoreward displacement of the beach profile.

2. The volume of material eroded from the shore equals the volume of sediment deposited on the nearshore bottom.

3. Nearshore sediments continue to be deposited until the rise of the bottom equals the rise in sea-level. In this manner, "the bottom may be raised together with the sea-level until it is covered by the same depth of water at the same distance from the (new) shoreline as it was before the rise." (Bruun, 1962 p. 129).

By this process of shore erosion and deposition offshore, the profile reaches equilibrium after sea-level rise. Also, the amount of shore erosion will be sympathetic with the necessary increase in sea level. The rate at which this adjustment proceeds depends on the offshore bottom slope. Bruun (1962) wrote that gentle offshore slopes will respond less rapidly to changes in sea-level and may respond only to long-term changes. Also, there may be considerable lag time between the sea-level rise and the adjustment of a gentle offshore slope (and hence shore erosion) to it. Steep offshore slopes, however, will display a quick response to sea-level rise and therefore will be more sensitive to short-term changes.

Schwartz (1967) demonstrated the validity of the Bruun theory through laboratory and field tests and found that it was correct in all of its three parts. In particular, he found "that there is a one-to-one correspondence between the magnitude of the water-level rise and the rise of the nearshore bottom." (Schwartz, 1967, p. 90). The time period necessary for the profile to adjust after sea-level rise was estimated by Schwartz, (1968). He designated the following relationships:

Mean Verticle Variation	Mean Period for Adjustment
10^1 cm.	10^1 min.
10^2 cm.	10^4-10^5 min. (7-1/2 days - 6 months)
10^3-10^4 cm.	10^9-10^{10} min. (10,000 - 20,000 yrs.)

The Bruun theory of sea-level rise and shore erosion is directly applicable to Lake Michigan where the lake level changes from month to month. The Beach Erosion Board (1966) listed the difference between the maximum low and high in the period 1860-1964 to be 6.59 feet. During the study period the difference between the maximum high and low was 1.36 feet. The largest change in the mean monthly level during a one month period was 0.56 feet (April to May 1972). It must be understood that the lake level would rise somewhat gradually during the month so that a gradual re-adjustment of the bottom topography would follow.

The shores of Lake Michigan generally become ice bound in late November or December, not to become ice free until late March or April. Shore ice must be considered, then, as it covers the beach about 1/3 of the year. (Zumberge and Wilson, 1953). An ice-foot on the beach can have two opposing effects on the erosion process. On one hand, when the beach is ice covered, a protective blanket is provided for the unconsolidated material attack (Zumberge and Wilson, 1953; U.S. Congress 1955; Beach Erosion Board, 1966). Waves, rather than expending their energy on the beach and bluff base, will dissipate when hitting the front of the ice-foot, as shown in Figure 5-1.

On the other hand, damage to the shoreline can result when ice is piled up on the shore or shifted on the beach by winds and waves, as shown in Figure 5-2 (Beach Erosion Board, 1966; U.S. Congress, 1955). However, the amount of such damage is normally superceded by the protective nature of the ice formations. Ice, then, is largely an asset in preventing erosion of the shoreline by winter storms.

Because of the rise in lake levels since 1971, the narrow nature of the beach, the moderating topography between lake and land and the easily erodable material at the back beach, many instances of land erosion have been noted during the study period.

Table 5-2 lists the bluff erosion rates at the profile sites as evidenced by washing away of the fence stakes and measurements of the bluff edge from intact markers. It is important to note that the erosion rate is far from being uniform along the distance of the shore of the study area. Several factors contribute to the variation in the rate of erosion along the shoreline in the study area. First, the back edge of the beach is made up of different kinds of materials. Second, the shoreline is curved and hence sections of it will react differently to storm waves coming from any one direction. Third, the offshore topography is not the same the entire length of the study area. Finally, the beach width changes with time and space in the study area; if the beach is narrow just before a storm due to an accelerated rise in the lake level the bluff will be more apt to be eroded.

At Site G, no erosion occurred during the study period. However, at all the other profile sites where markers were placed, erosion occurred. The greatest amount of erosion was found at Site D where greater than 12.5 feet of stabilized sand was eroded during the course of eight months. It is significant to note that this erosion was concentrated during two distinct time periods, rather than occurring uniformly and continuously. Further, while drift was eroded, (the greater than 4 feet at Site I, for instance) this material was in general more stable than the sand.

Fig. 5-1 Waves striking ice-foot

Fig. 5-2 Ice damage to shoreline

TABLE 5-2

Rates of Bluff Erosion

Site	Date	Bluff Material	Rate
D	Oct., 1971-Jan., 1972	Sand	>6 Ft.
D	Spril, 1972-June, 1972	Sand	>6.5 Ft.
E	July, 1972-Sept., 1972	Sand	>3 Ft.
E	Oct., 1972-Nov., 1972	Sand	>6.8 Ft.
F	July, 1972-Sept., 1972	Sand	>7 Ft.
G	No Change	Sand	
H	April, 1972-June, 1972	Sand	0.5 Ft.
H	July, 1972-Sept., 1972	Sand	>4 Ft.
I	July, 1972-Sept., 1972	Drift	>4 Ft.
J	Oct., 1972-Nov., 1972	Drift	0.5 Ft.

The erosion was not confined to any one season of the year. At one or more profile sites, erosion occurred throughout the year. The period of July through September, 1972, showed the most marked erosion along the shore with Sites E, F, H, and I all undergoing significant change.

BEACH PROFILES

To investigate the variable character of the beach, the moderating topography between land and lake, measurements were made of the beach slope and materials. Because beach profile site markers were placed at intervals along the shore, the rate of erosion of the bluffs at the back edge of the beach was also measured.

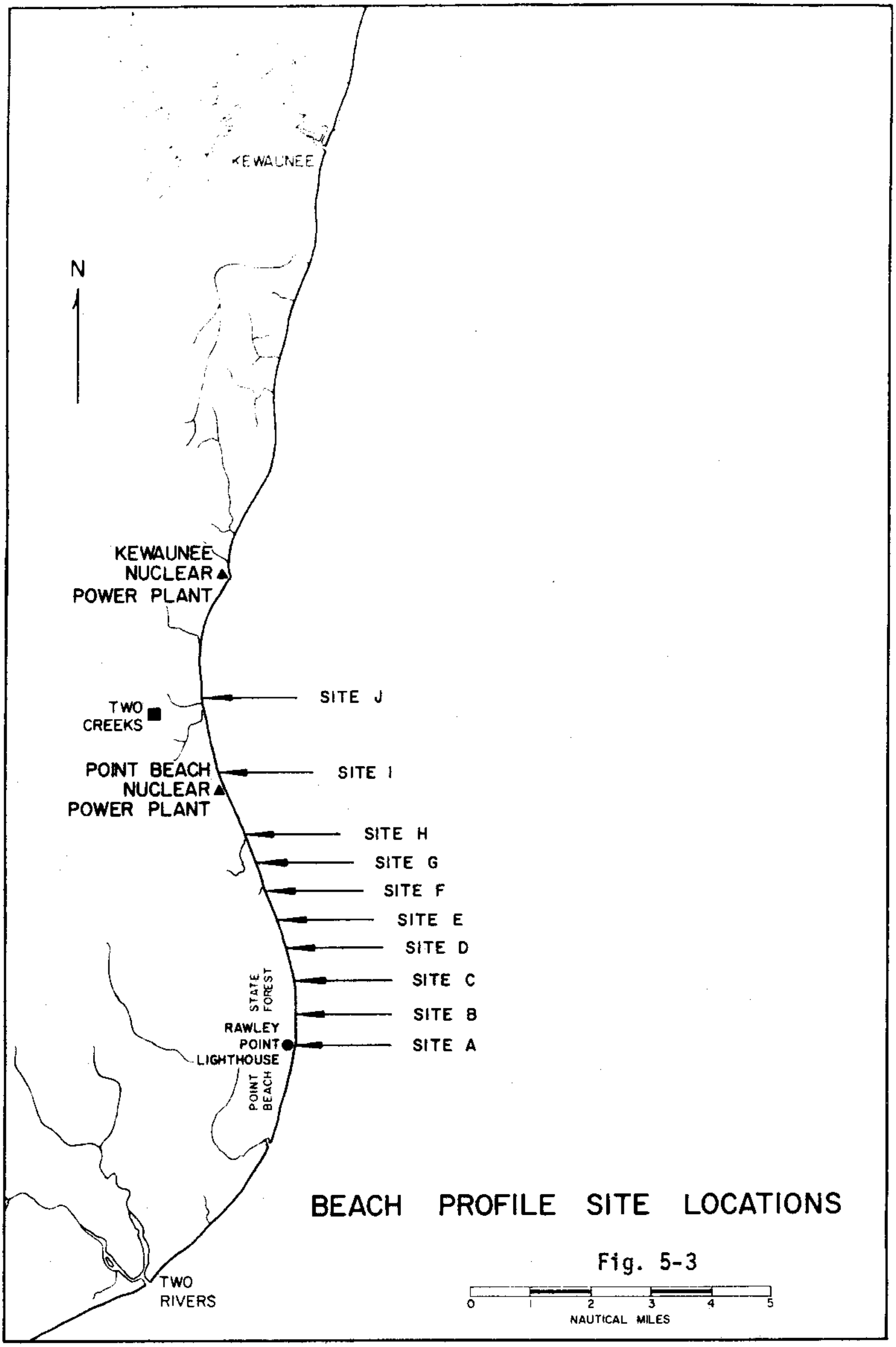
Figure 5-3 shows the location of the beach profile sites in the study area. The sequences of beach profiles taken at each site are shown in Figures 5-4 through 5-13.

The manner in which these profiles were taken is important to this interpretation. The objective was to delineate the width, slope and materials of the beach. This was essential to understand the exchange of sediment between the offshore regime and both the beach and bluffs. Because of the unexpectedly high rate of erosion and the resulting washing away of the profile site markers, it was not always possible to begin a profile at exactly the same point on the line perpendicular to the shoreline. Each profile, rather, was begun at the base of the bluff, at the back of the beach. When erosion occurred, the bluff base, of course, was moved landward. In addition, each profile was measured using the surface of the beach at its head as the 0 point. This was, of course, not precisely the same elevation from one profile to the next as deposition or erosion occurred along the entire width of the beach. Therefore, profiles should be viewed as structures rising above the water line, keeping in mind the changes in lake levels listed in Table 2-3.

The series of beach profiles taken at ten permanent sites revealed the variability in topography and sediment distribution, in both time and space along the shore. No one profile site behaved like any other during the study period.

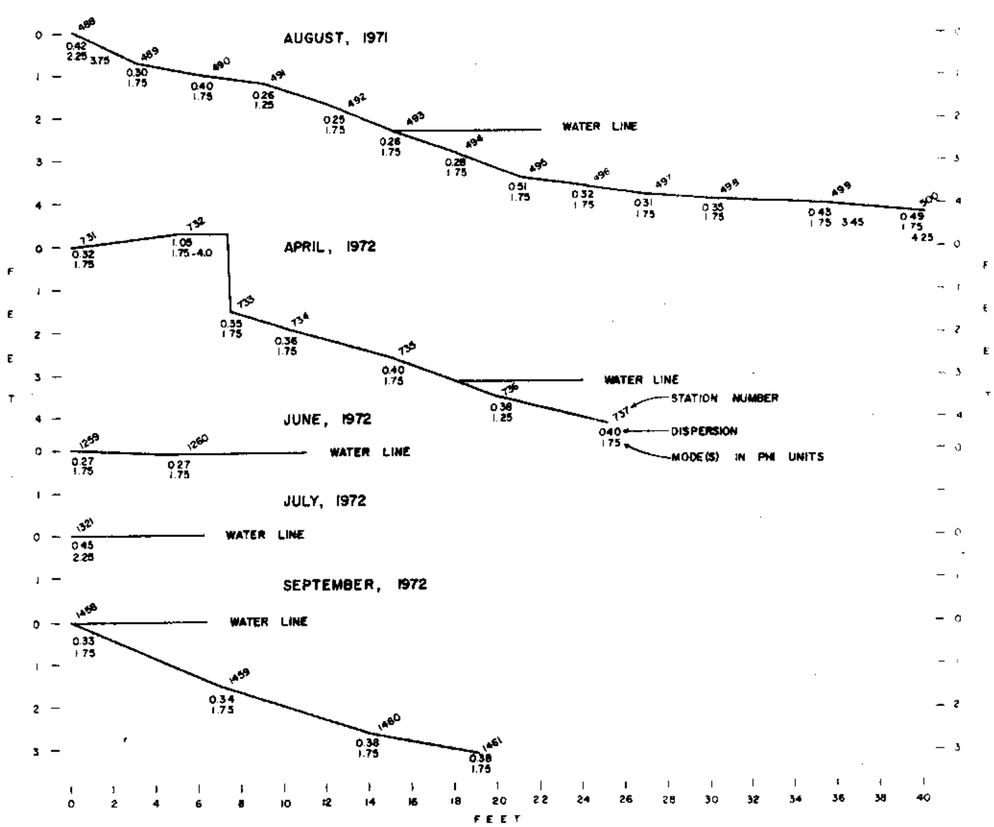
Site A, at Rawley Point, the southernmost profile, displayed obvious erosion of the beach during the study period. Each profile measurement was begun at the base of a small sand bluff only two feet high. In August, 1972, when the lake level stood at +3.06 above datum, a modest beach composed of well-sorted medium sand was found. By April, 1972, a steep erosional face had formed, even though the lake level was only +2.30 feet above datum. By June, 1972, and continuing through the fall, the lake was lapping at the stabilized sand above the vegetation line. Lake levels during this period ranged from +3.01 feet to +3.44 feet. Throughout the time cycle, the surficial sediments on the beach and below the water line were well-sorted medium sand with the exception of station PP732 at the top of the erosional face where bimodal gravelly sand was found.

At Site B, one-half mile to the north, a more complex pattern was found. In August, 1971, well-sorted fine sands comprised the beach with bimodal gravelly sands below the water line. A slight bar was found offshore. By April, 1972, while the slope was approximately the same, the length had increased and the surficial sediments were more varied. Gravels were concentrated at the head of the profile and above and below the water line. The gravels at the head of the



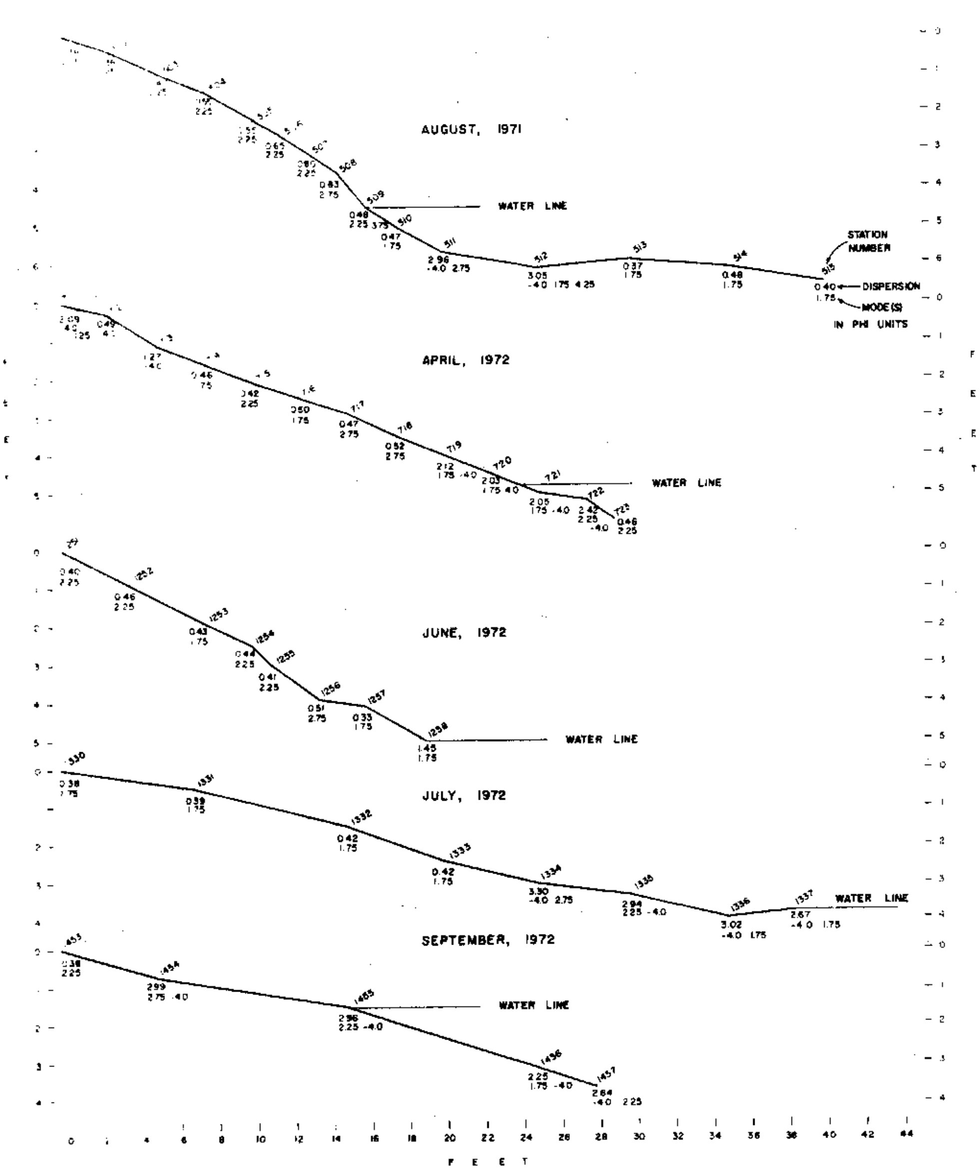
BEACH PROFILE SITE LOCATIONS

Fig. 5-3



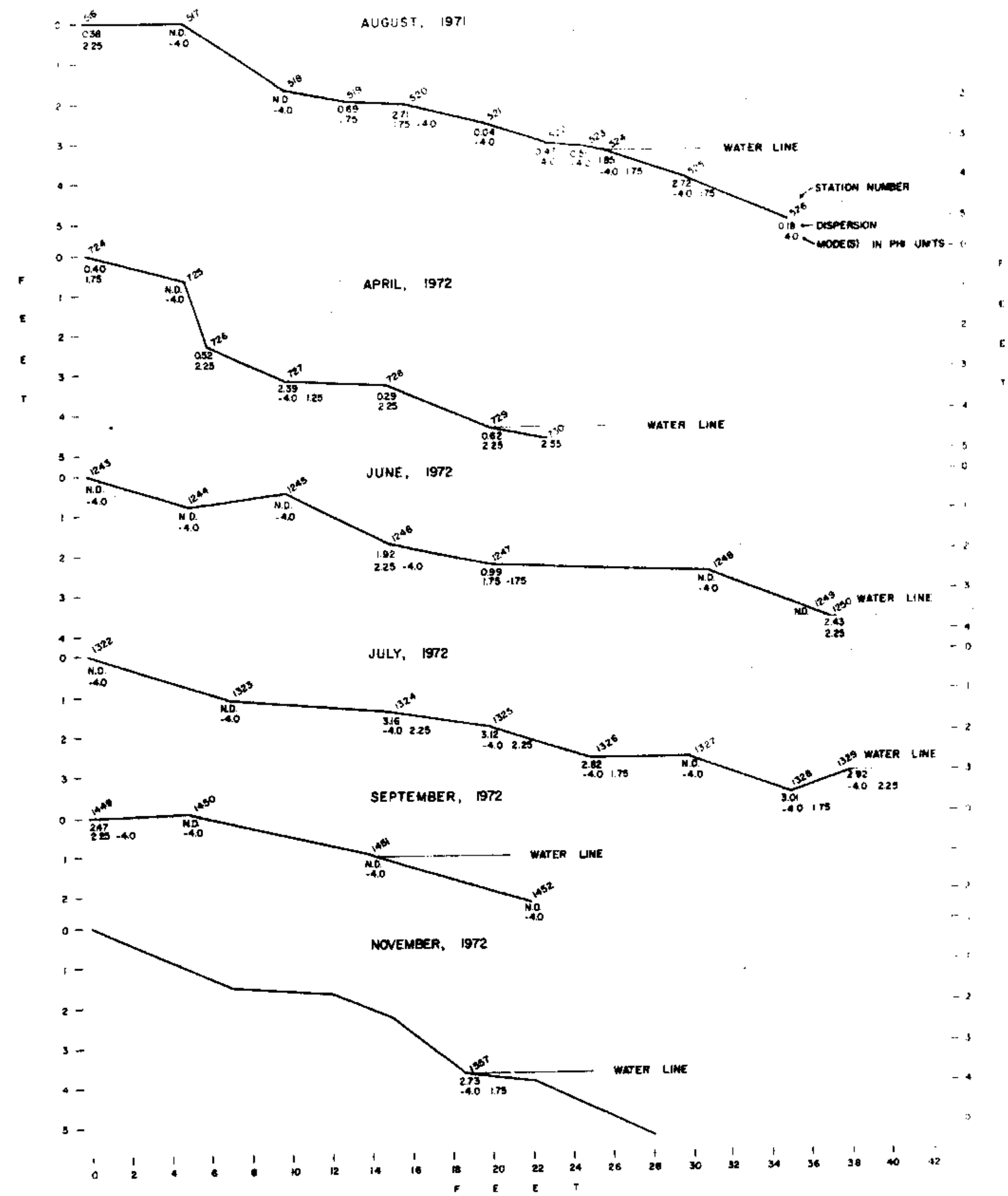
BEACH PROFILE SITE A

Fig. 5-4



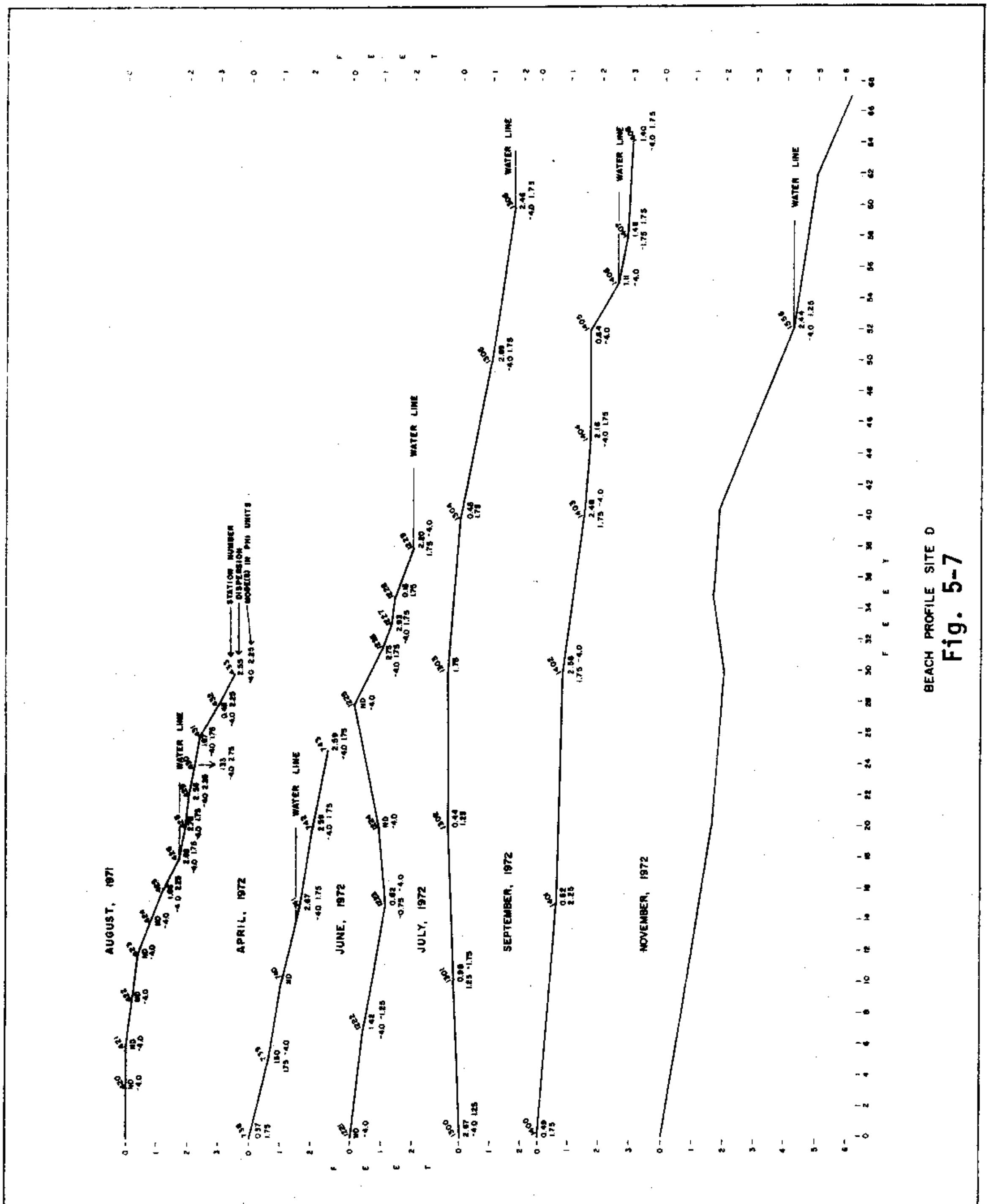
BEACH PROFILE SITE B

Fig. 5-5



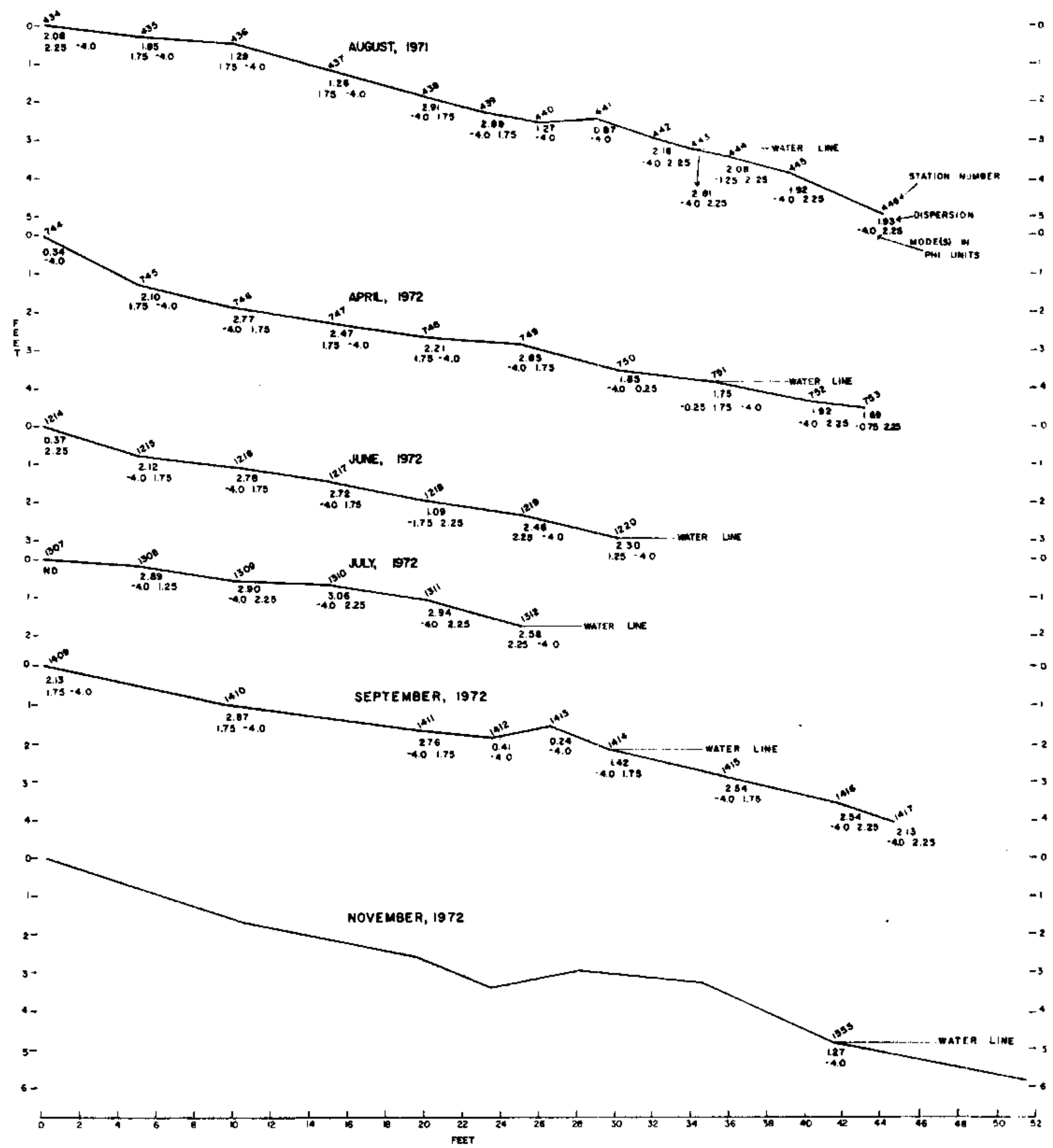
BEACH PROFILE SITE C

Fig. 5-6



BEACH PROFILE SITE D

Fig. 5-7



BEACH PROFILE SITE E

Fig. 5-8

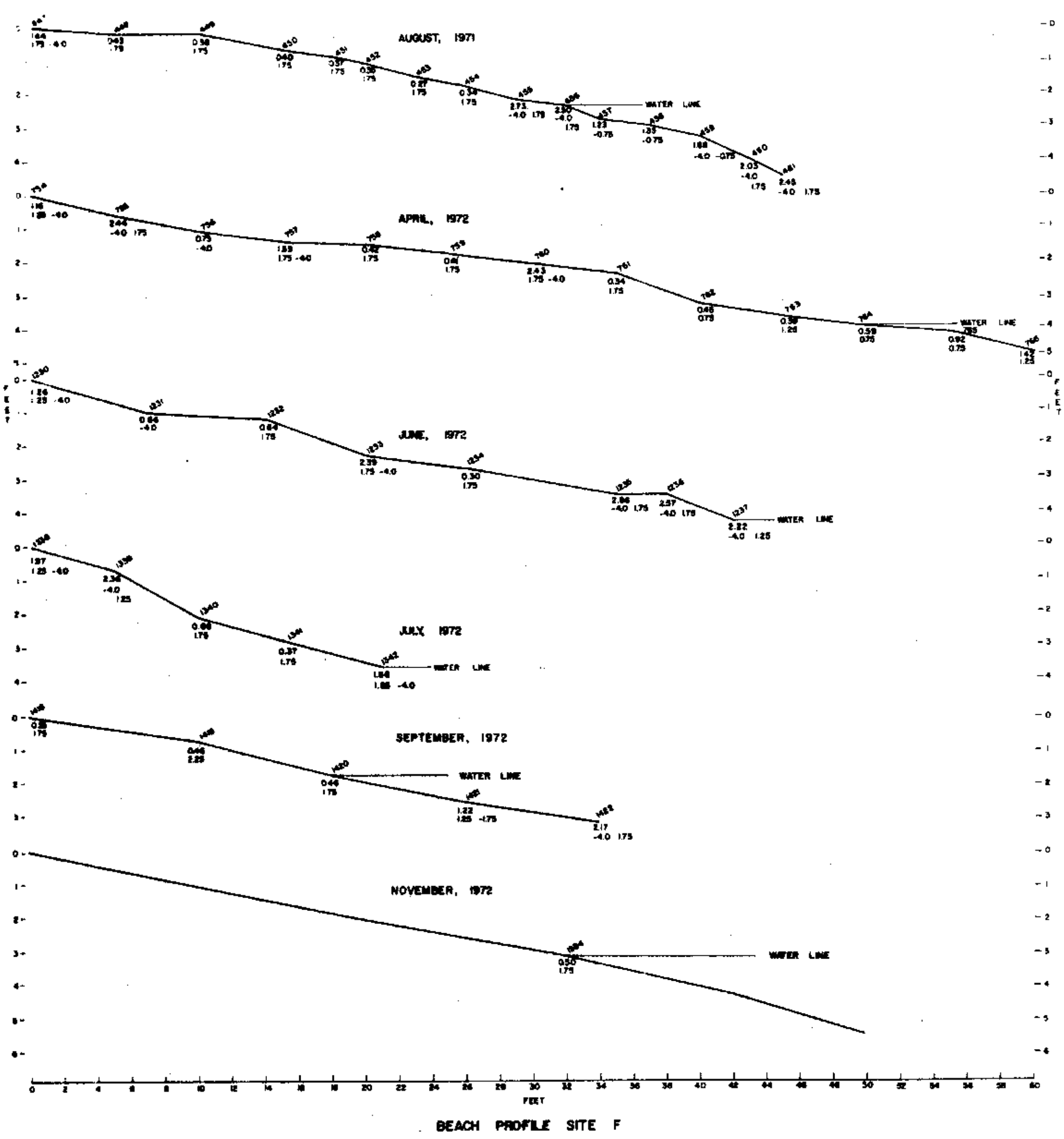
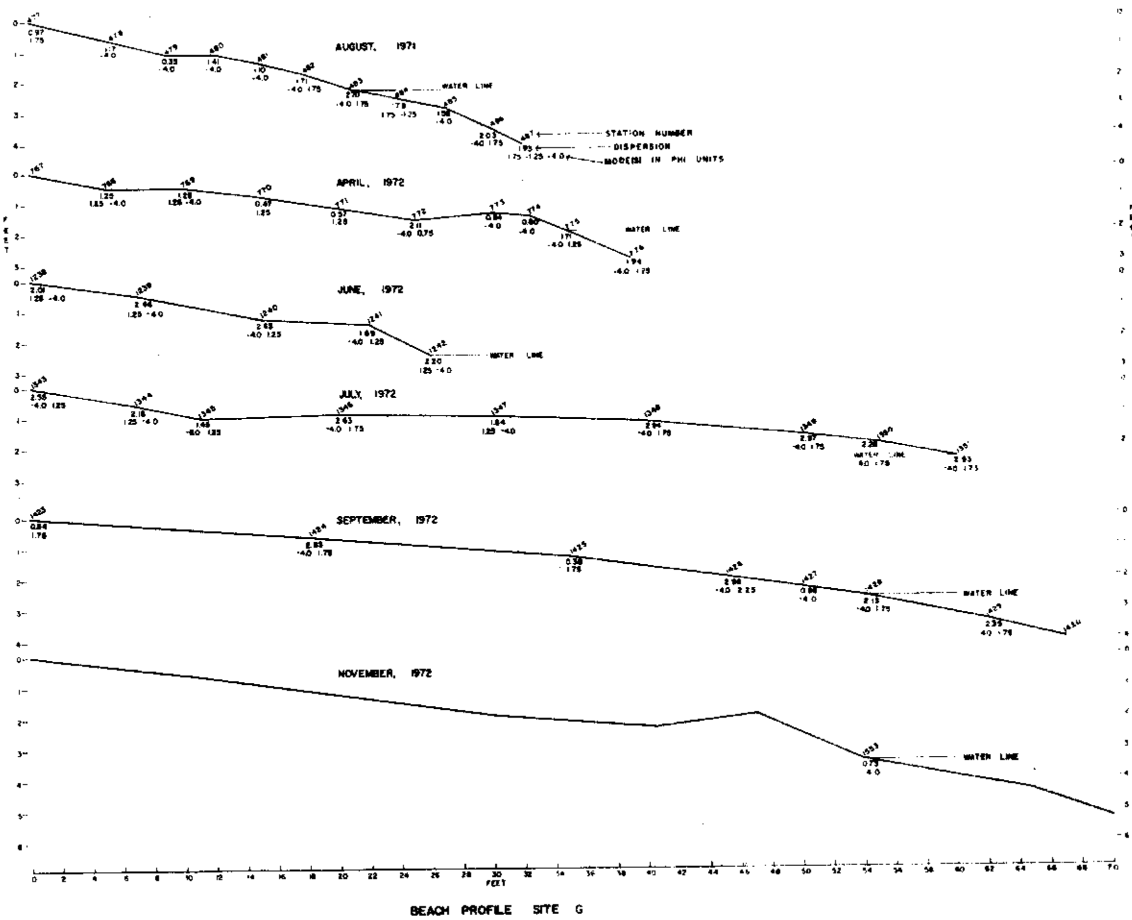
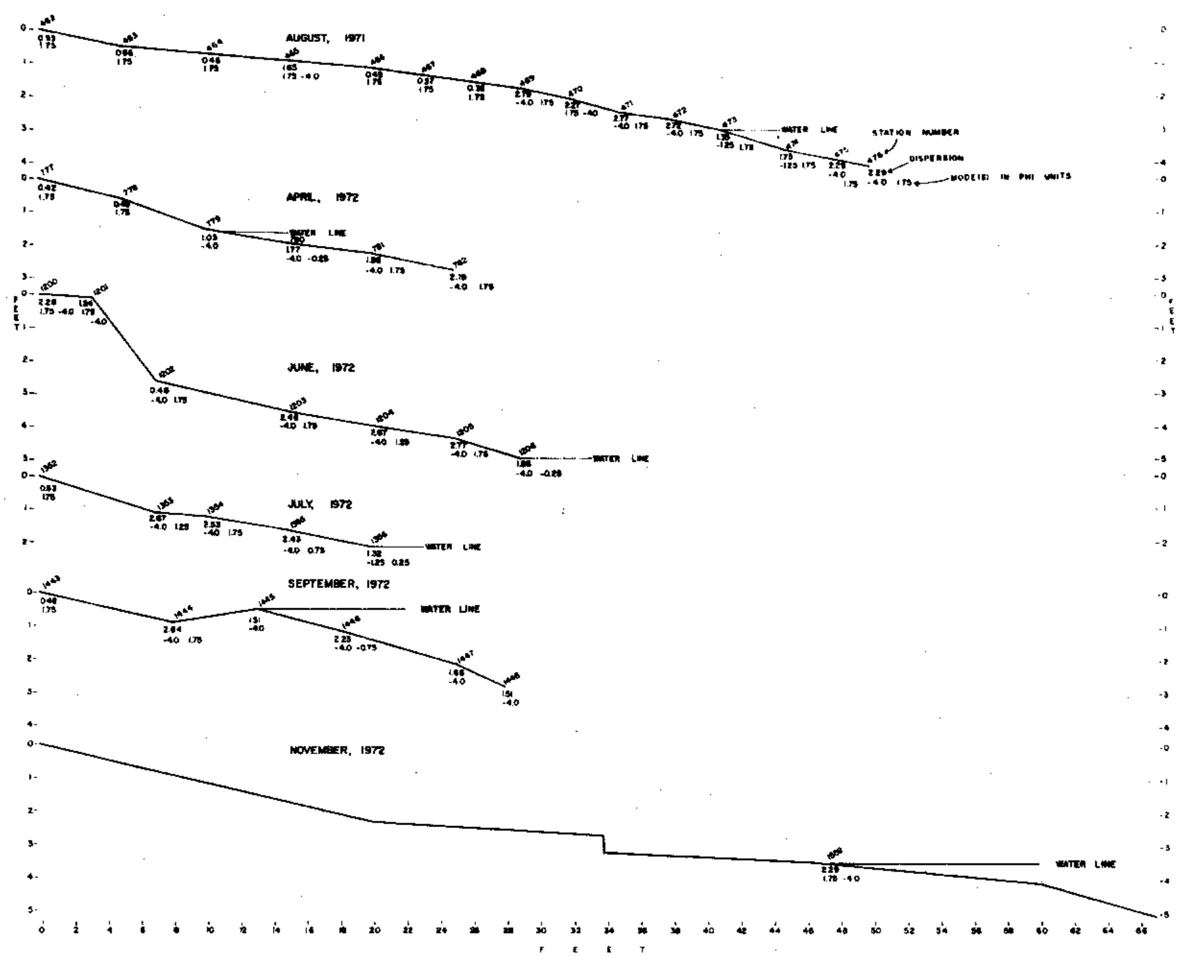

AUGUST, 1971
APRIL, 1972
JUNE, 1972
JULY, 1972
SEPTEMBER, 1972
NOVEMBER, 1972
WATER LINE
FEET
BEACH PROFILE SITE F

Fig. 5-9



AUGUST, 1971
STATION NUMBER
DISPERSION
MODE(S) IN PHI UNITS
APRIL, 1972
JUNE, 1972
JULY, 1972
SEPTEMBER, 1972
NOVEMBER, 1972
WATER LINE
FEET
BEACH PROFILE SITE G

Fig. 5-10



BEACH PROFILE SITE H

Fig. 5-11

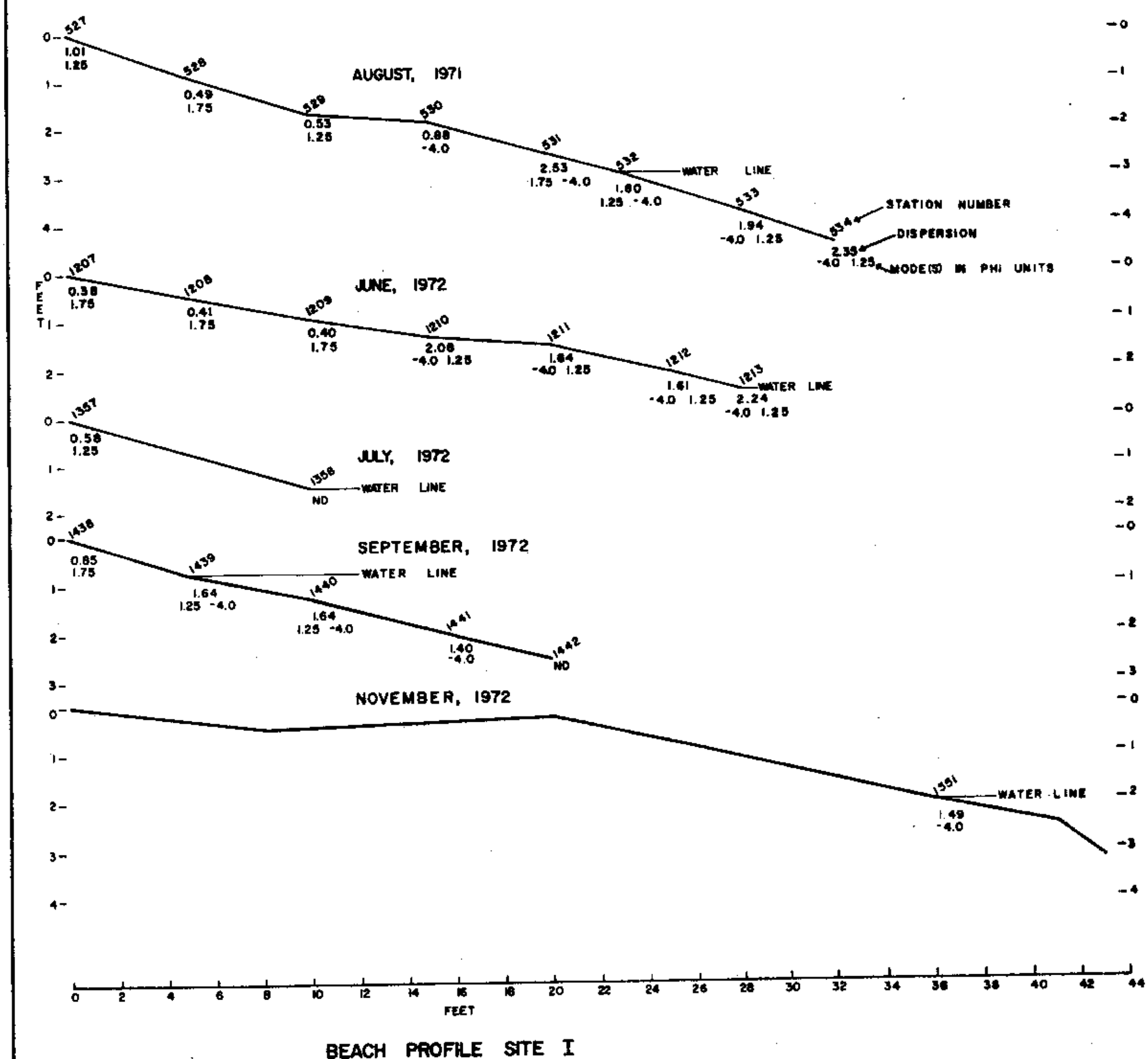
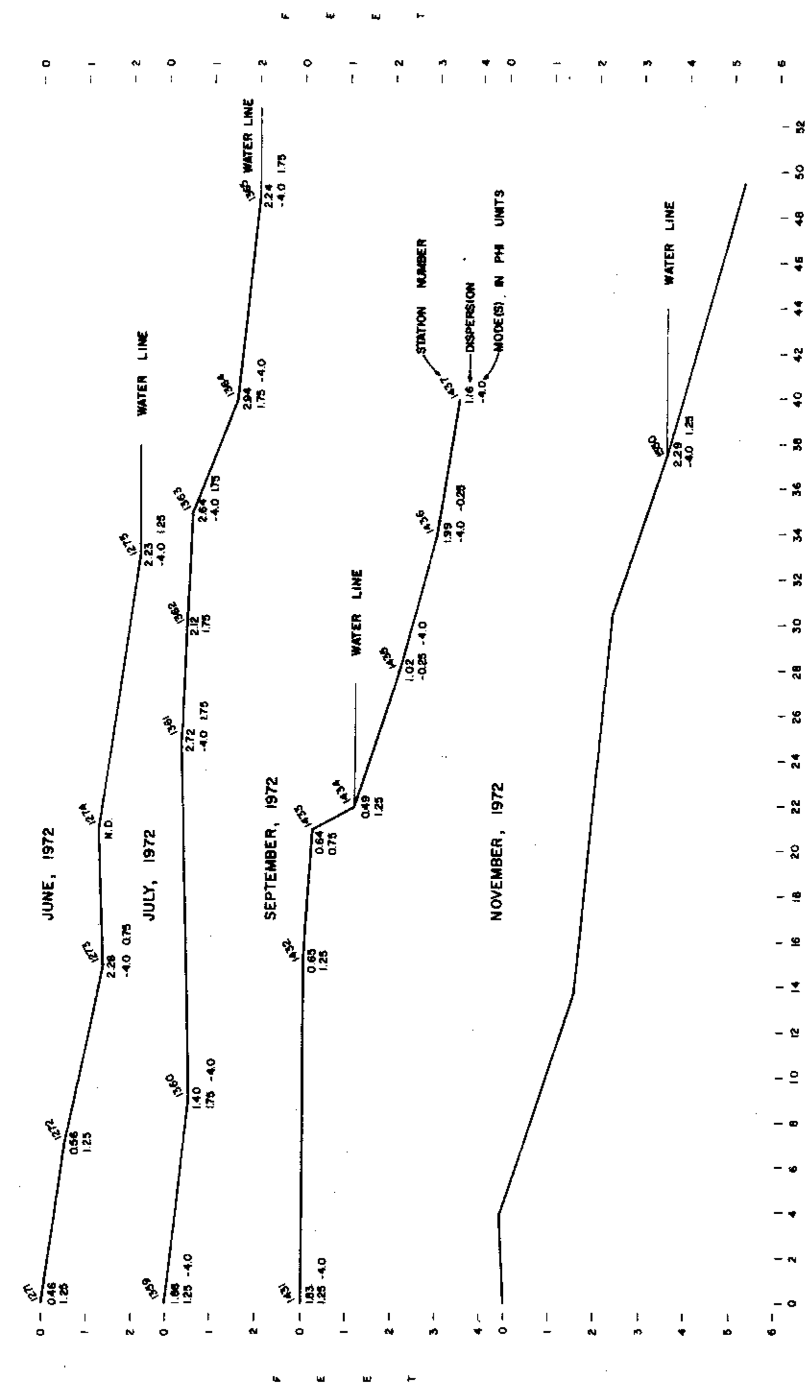

AUGUST, 1971
527
1.01
1.25
528
0.49
1.75
529
0.53
1.25
530
0.88
-4.0
531
2.53
1.75 -4.0
532
1.60
1.25 -4.0
WATER LINE
533
1.94
-4.0 1.25
534
2.35
-4.0 1.25
STATION NUMBER
DISPERSION
MODE(S) IN PHI UNITS
JUNE, 1972
1207
0.38
1.75
1208
0.41
1.75
1209
0.40
1.75
1210
2.08
-4.0 1.25
1211
1.64
-4.0 1.25
1212
1.61
-4.0 1.25
1213
2.24
-4.0 1.25
WATER LINE
JULY, 1972
1357
0.58
1.25
1358
ND
WATER LINE
SEPTEMBER, 1972
1438
0.85
1.75
1439
1.64
1.25 -4.0
WATER LINE
1440
1.64
1.25 -4.0
1441
1.40
-4.0
1442
ND
NOVEMBER, 1972
1351
1.49
-4.0
WATER LINE
FEET
FEET
BEACH PROFILE SITE I

Fig. 5-12



BEACH PROFILE SITE J

Fig. 5-13

profile are no doubt remnants of intense storm action. During the summer the beach underwent a cycle of erosion, deposition, and erosion. Medium and fine sands predominated, with bimodal gravelly sands found above and below the water lines in July and September, 1972. At this location, while erosional and depositional processes alternated during the year, no long-term trend of erosion was noted. Likewise the surficial sediments were predominately sands throughout the year.

At the northern edge of Point Beach State Forest at Site C, similar cycles of erosion and deposition were seen. During June and July, 1972, for instance, deposition occurred, followed by erosion prior to the September profile. Another cycle of deposition preceeded the November survey. These cycles are clearly not sympathetic with lake level fluctuations. The surficial sediment on the beach contained large amounts of gravel, the gravel frequently being washed entirely free of sand.

One-half mile to the north, at Site D, significant change occurred in the beach profile primarily due to the extensive erosion of the back edge of the beach. In August, 1971, the distance from the bottom of the stabilized sand bluff at the back edge of the bluff to the water line was 18 feet. Gravels generally devoid of sand comprised the beach, with bimodal gravelly sands just above, at, and below the water line. During the fall and early winter months, October, 1971 - January, 1972, over six feet of bluff was eroded, as evidenced by the loss of a fence stake from the bluff. (See Table 5-2). That erosion had indeed taken place was further shown by numerous large trees embedded in the ice covering the beach. (Figure 5-2). In April, 1972, even though the profile starting point was moved back to the bottom of the now existing bluff, the distance to the water line was only 14 feet. In addition, the lake level was down 0.76 feet since August, 1971. The gravel found in August, 1971 on the beach had been replaced by sands and bimodal gravelly sands. Bimodal gravelly sands were also found below the water line.

Again, erosion of the sand bluff in excess of 6.5 feet occurred between April, 1972 and June, 1972. As before, a marker from the bluff was eroded away. The profile measured in June, 1972, again from the newly formed base of the bluff, was considerably larger (38 feet) than previously. Gravels and bimodal gravelly sands formed the beach above the water line. A distinct berm had been formed at PP1225.

In July, September, and November, 1972, very long profiles were measured with distances from the bluff to the water line measuring 60, 55, and 52 feet respectively. While no erosion of the bluff was documented, it cannot be ruled out. Sands and bimodal gravelly sands formed the beach.

At Profile Site E, bimodal gravelly sands surfaced the beach above and below the water line in August, 1971, April and June, 1972. While no significant change in beach length was noted between August, 1971 and April, 1972, by June, 1972, the length was shortened by 5 feet. The rise in lake level, from +2.3 feet in April to +3.01 feet in June can account for the change. By July, 1972, further shortening of the width by another 5 feet occurred, possibly due to the small (0.17 foot) rise in lake level, but also perhaps to real loss of beach material. Between July and September, 1972, the old boat launch on top of the bluff which was being used as a bench mark had washed away. At least three feet of bluff erosion was thus measured. In September, 1972, the beach profile was five feet larger than in July, 1972, although the beach material had not changed markedly.

Between October and November, 1972, 6.8 feet of the bluff eroded. The profile measured in November was 12 feet longer than before. Part of this lengthening was due to the erosion of the bluff but some of it must be due to deposits of sand and gravel on the beach.

At Site F, sands and bimodal gravelly sands were found both above and below the water line, in August, 1971. By April, the profile lengthened 18 feet with a drop in lake level of 0.76 foot. While the lake level change can account for some of the lengthening, some deposition of additional material must have occurred. By June, 1972, 8 feet of shortening occurred with the lake level up 0.17 foot. A small rise (0.71 foot) in lake level by July was accompanied by a decrease of 21 feet in the length of the beach. More than 7 feet of erosion of the sand bluffs was documented between July and September, 1972. Even though the profile in September was begun at the newly formed foot of the bluff, 3 feet of beach was lost since July. Also, gravels were not found in September, although they had been common in the four preceeding surveys. Prior to November 1972, the beach had lengthened by 14 feet.

One and one-quarter miles south of Point Beach Power Plant, at Site G, the back edge of the beach is formed by a drift bluff. No erosion of the bluff was noted here during the study period. While in August, 1971, a fairly uniform slope was found to a length of 21 feet, the profile had lengthened to 35 feet and became somewhat flatter by April, 1972. During this period the lake level had gone from a high of +3.06 feet in August, 1971, to a low of +2.08 feet in late winter and had risen to +2.30 by April, 1972. In June, 1972, when the lake level was up to +3.01 feet a steep erosional face had formed as the water line came closer in towards shore. During the summer and fall, a significant widening of the beach occurred as the result of deposition of sediment on the beach.

Three-quarters of a mile south of Point Beach Power Plant, at Site H, a sand bluff was again encountered. In August, 1971, a wide (41 ft.) beach was composed of sand grading to bimodal gravelly sands above and continuing below the water line. By April, 1972, when the water level had fallen 0.76 foot, the beach had become significantly narrower, having a width of only 11 feet. The pattern of sand above bimodal and gravelly sand below the water line remained. Erosion of beach material is the only explanation. Between April and June, 1972, a small (0.5 foot) edge of the sand bluff eroded. That erosion was indeed taking place is evidenced by the steep erosional face found in the June profile. Bimodal materials covered the entire profile indicating that the entire beach had been subjected to intense wave action. By June, the lake level had risen 0.71 foot over the April level. In July, the profile had shortened to 20 feet with an attendant use of lake level of 0.17 foot since June. Between July and September, erosion of the sand bluff exceeded 4 feet, as evidenced by the washing away of the profile marker on the bluff. In spite of the fact that the profile was begun at the newly formed bluff base, the profile is even shorter than in July. The lake level in September was 0.26 foot above the July level. Sand found at the head of the profile is no doubt due to slumping from the sand bluff behind. Deposition must have preceeded the November survey since the beach had lengthened to 46.5 feet with a lake level drop since September of only 0.22 foot. The November profile shows an erosional face just above the water line indicating an end to the depositional phase.

North of Point Beach Power Plant, one-quarter mile, a drift bluff is again encountered. A 23-foot distance was measured in August, 1971, the beach being composed of sand, grading to bimodal sediments above and below the water line. By June, 1972 a small amount of deposition had occurred as the beach above the water line lengthened 5 feet with no attendant lake level change. The distribution of sediments on the beach remained the same. Prior to July, erosion of the beach sediments occurred. Only a 10 feet wide strip of beach remained above the water line. The lake level rise of 0.17 foot by July, from June, does not account for this much change. Over 4 feet of bluff was eroded between July and September. Nevertheless, an even narrower beach (5 feet) was exposed in September, with sand on the upper beach and bimodal materials above and below the water line. Prior to November, the beach underwent a depositional cycle as the beach widened to 34 feet.

Further north profiling was begun in June, 1972. While in June a distance of 33 feet was measured from the bluff to the water line, and in July this distance was 49 feet. Since the lake level rose 0.17 foot during the time between these two profiles, deposition must have occurred on the beach. By September, the beach was being eroded, as evidenced by the steep erosional face and the narrower beach. A small amount of bluff erosion, 0.5 foot, occurred between October and November, 1972, but by November, the beach had widened as compared with the September profile. Sands and gravelly sand comprised the beach in all profiles.

What, then, does this sequence of beach profiles tell us about the character of the lake-land interface in the study area? First, significant changes in the width, slope, and materials of the beach were noted at every site during the period of study. The width of the beach, from the stabilized material at its back edge to the water line, varied as the result of erosion of the stabilized material and depositional/erosional cycles on the beach itself. Texture of the material found at the surface of the beach varied with the intensity of wave action washing over the beach. High intensities will deposit gravels and winnow away the finer fraction. Slope changes are related to the type of material present and whether deposition or erosion is taking place.

By comparing the sequence of beach profiles to the table of lake level fluctuations (Table 2-3) it is obvious that the erosional/depositional cycles are not simply a function of water level change. Clearly, intense wave action plays a dominant role in the form of the beach. This is well documented by the instances of eroding beaches and bluffs during periods of lower lake levels.

At site A, for instance, an erosional face was found during the April, 1972 profile. In the week prior to sampling, northeast winds predominated (up to 25 miles per hour). The September profile at Site C indicated erosion and northeast winds (up to 15 miles per hour) predominated prior to sampling. Between July and September, significant erosion occurred at Sites G, H. I, and J. While wind data are not presented for the entire summer, the northeast and southeast winds (up to 15 miles per hour) preceeding the September profiling period are an indication of the wind levels.

Second, it is apparent that erosion is not uniform along the shoreline. Erosion of 4 feet or more occurred at one site while 1/2 mile to the north and south, no erosion whatsoever was found. While there are obvious differences, unconsolidated but stabilized sand versus drift, in the nature of the material at the back of the beach, both types of materials were eroded. Thus, the non-uniform erosion must be ascribed to other causes - the angle of wave attack on the curvilinear shoreline and differences in offshore topography.

Third, prior to bluff erosion, the beach is cut back, decreasing the effect of this moderating feature. This process, then, can enhance the effect of the angle of wave attack and a steep offshore slope. A stretch of shoreline exposed to intense wave action will first lose material from the beach and continuing wave forces will then attack the bluff, undercutting them and causing erosion. A wide beach, then, acts as a deterrent to land erosion.

Finally, it appears that the beaches always tend towards an equilibrium width after erosion of the sand and drift bluff. Following this erosion the beach readjusts to a profile similar to the pre-erosion situation. When the erosional process of lake level rise and wave action are not satisfied by sediment removal from the beach, these processes begin eating away at the bluffs.

It becomes apparent then, that a wide beach, well supplied by sediment, is beneficial to the stability of the shoreline. Interference in the littoral zone by man which causes depletion and erosion on the beaches will only enhance the natural erosional process of the lake.

DYED SAND EXPERIMENT

To characterize the sand movement in front of the outfall, colored sand was placed on the lake bottom in three locations east of Point Beach Nuclear Power Plant. Yellow-orange sand was placed north of the Unit I outfall between buoys 13 and 14 and between buoys 1 and 2 (See Fig. 3-8). Blue sand was placed between buoys 7 and 8. To measure the rate of sand movement, all the sand of one color should have been placed in one spot. That this was not done was due to a misunderstanding on the part of the crew in the small boat. Figures 5-14 through 5-21 show the surficial sediment distributions during each sampling sequence. The lakeward edge of the sand zone in front of the outfall appears to be about 1500 feet from shore. Samples recovered from buoys 3 and 5 alternated between clay and very fine sand. Such variations in the sediment type are due to either real changes in the surficial sediment at these buoys, with thin layers of very fine sand being moved in and out, or to patches of very fine sand near the edge of a continuous sand zone. Inshore of these two buoys, very fine and fine sand were always found. Near the intake crib, red clay was the predominant sediment type, with patches of sand and granules. Along the shore coarser sediments, very coarse to medium sands and granules, and red clay were found.

Several measurements of longshore currents in the upper 4 feet were taken during this experiment. Table 5-3 lists the velocities and directions measured. At buoy 7, south of the outfall, velocities of 6.75 and 6.24 cm/sec. were measured. North of the outfall, at buoy 2, velocities of 4.18 and 4.23 cm/sec. were recorded. Of particular interest is the decrease in velocity on the downwind side of the plume. The interaction of the discharge water and the receiving waters reduced the longshore current velocity by 1/3. Its direction was always south to north during this experiment.

Only four samples were recovered which contained blue grains. They were samples DS472, DS545, DS1015, and DS1023. Sample DS472 was recovered from the pole on July 19 at 1434 and contained 9 blue grains. On July 20, another sample at the pole, DS1015, taken at 1104 contained 3 blue grains. A third offshore sample, DS1023, 10 feet north of buoy 18 contained 7 blue grains. It was taken July 20 at 1355. One nearshore sample, DS545, contained 3 blue grains. It was taken on

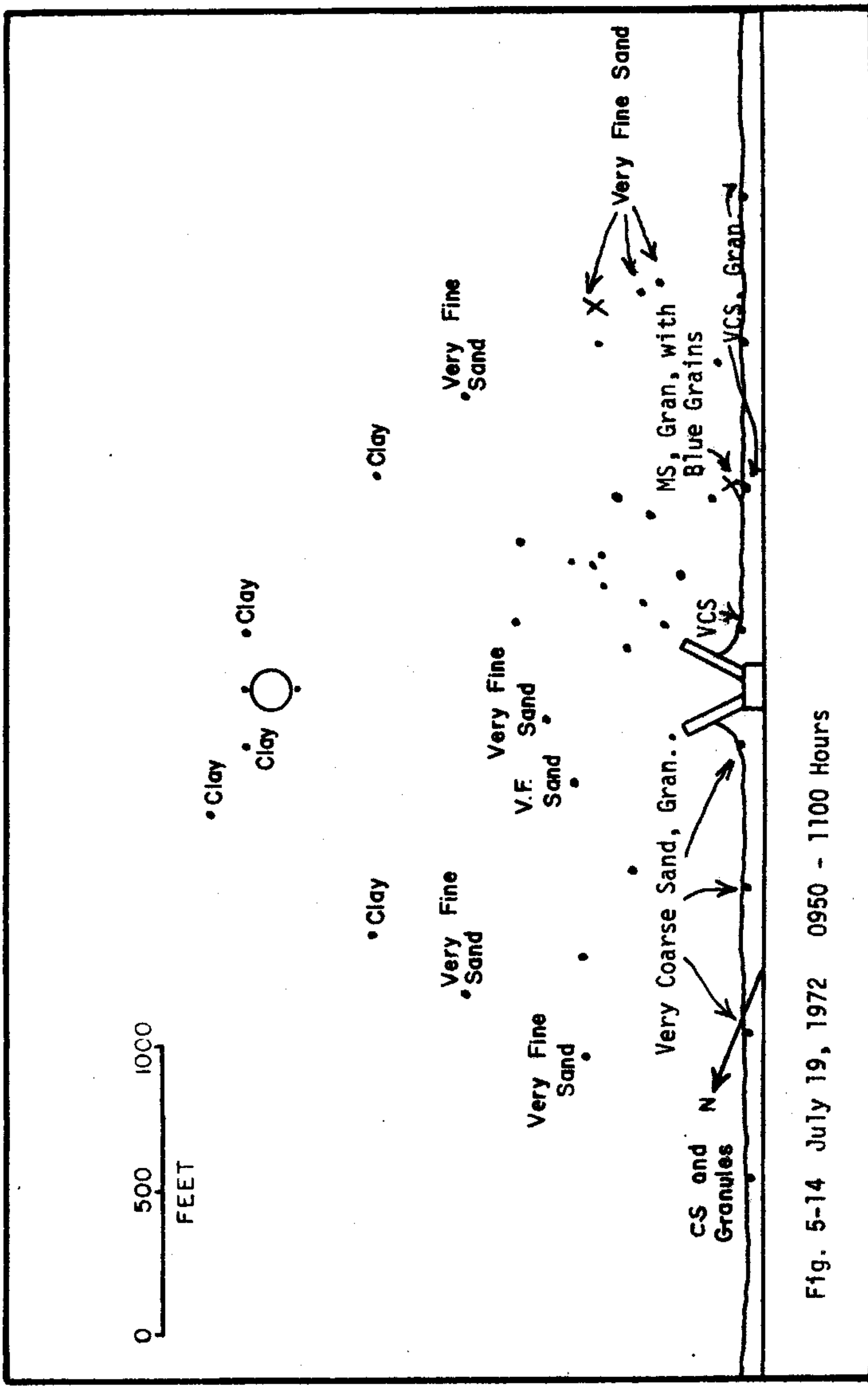


Fig. 5-14 July 19, 1972 0950 - 1100 Hours

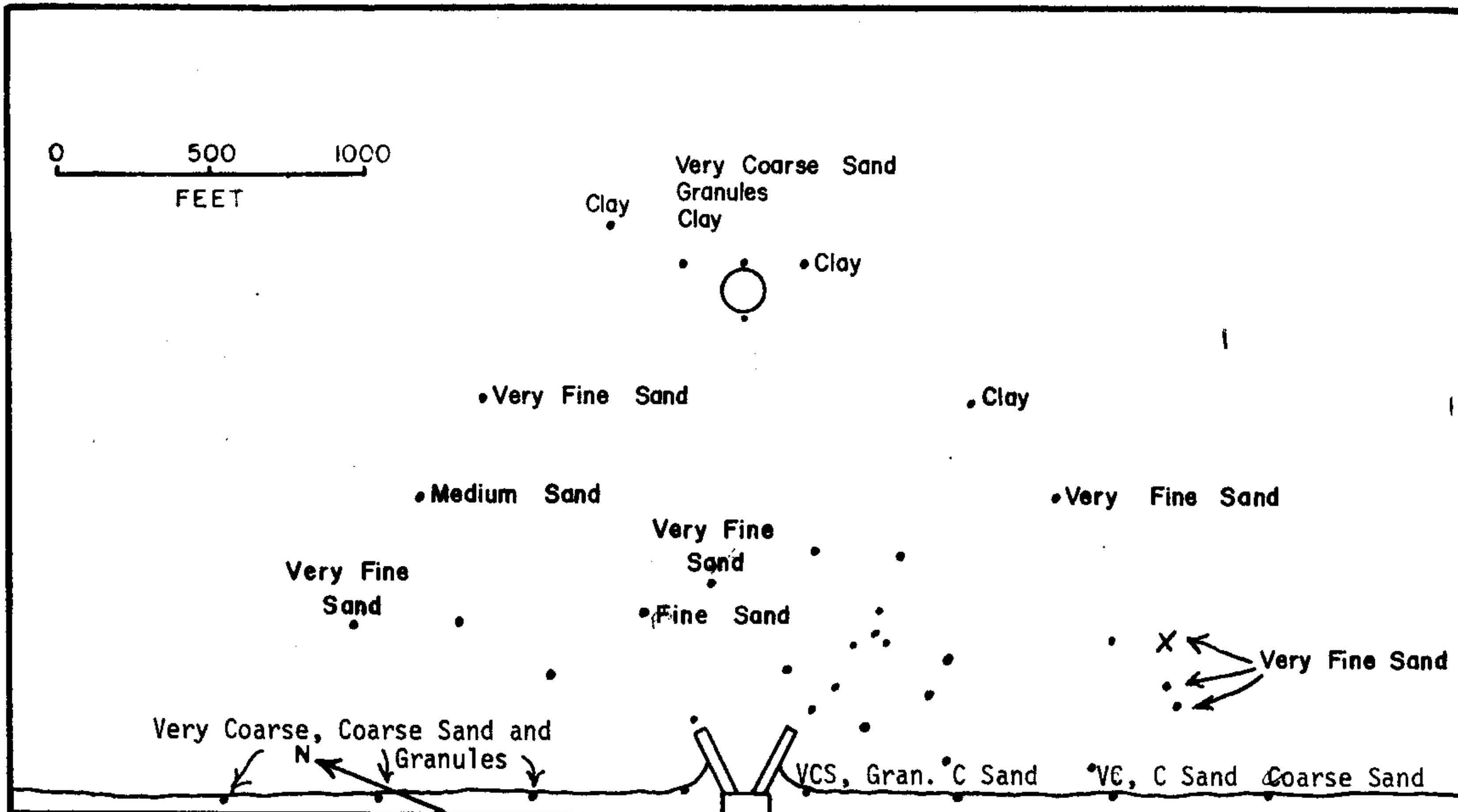


Fig. 5-15 July 19, 1972 1100 - 1235 Hours

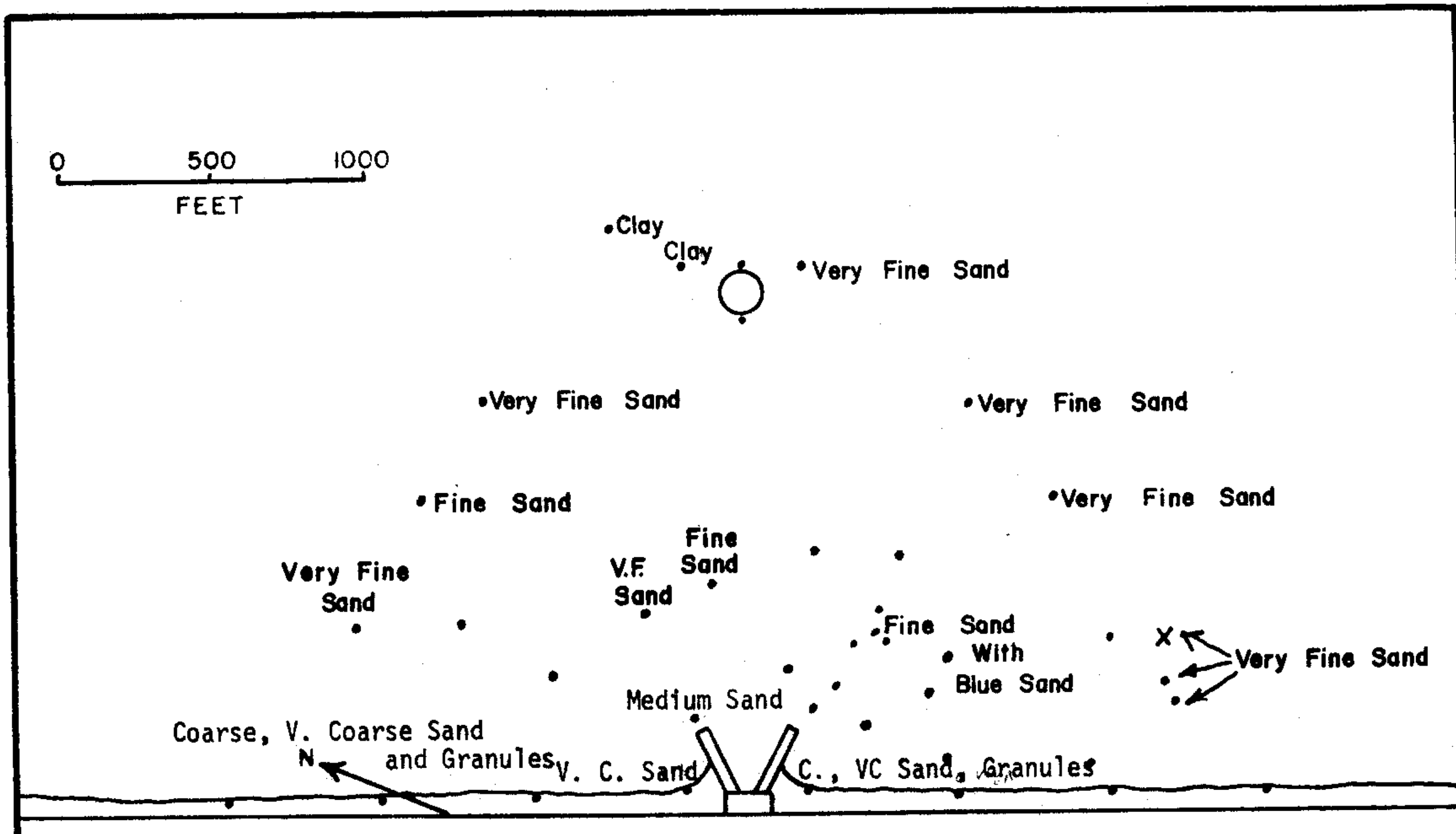


Fig. 5-16 July 19, 1972 1400 - 1505 Hours

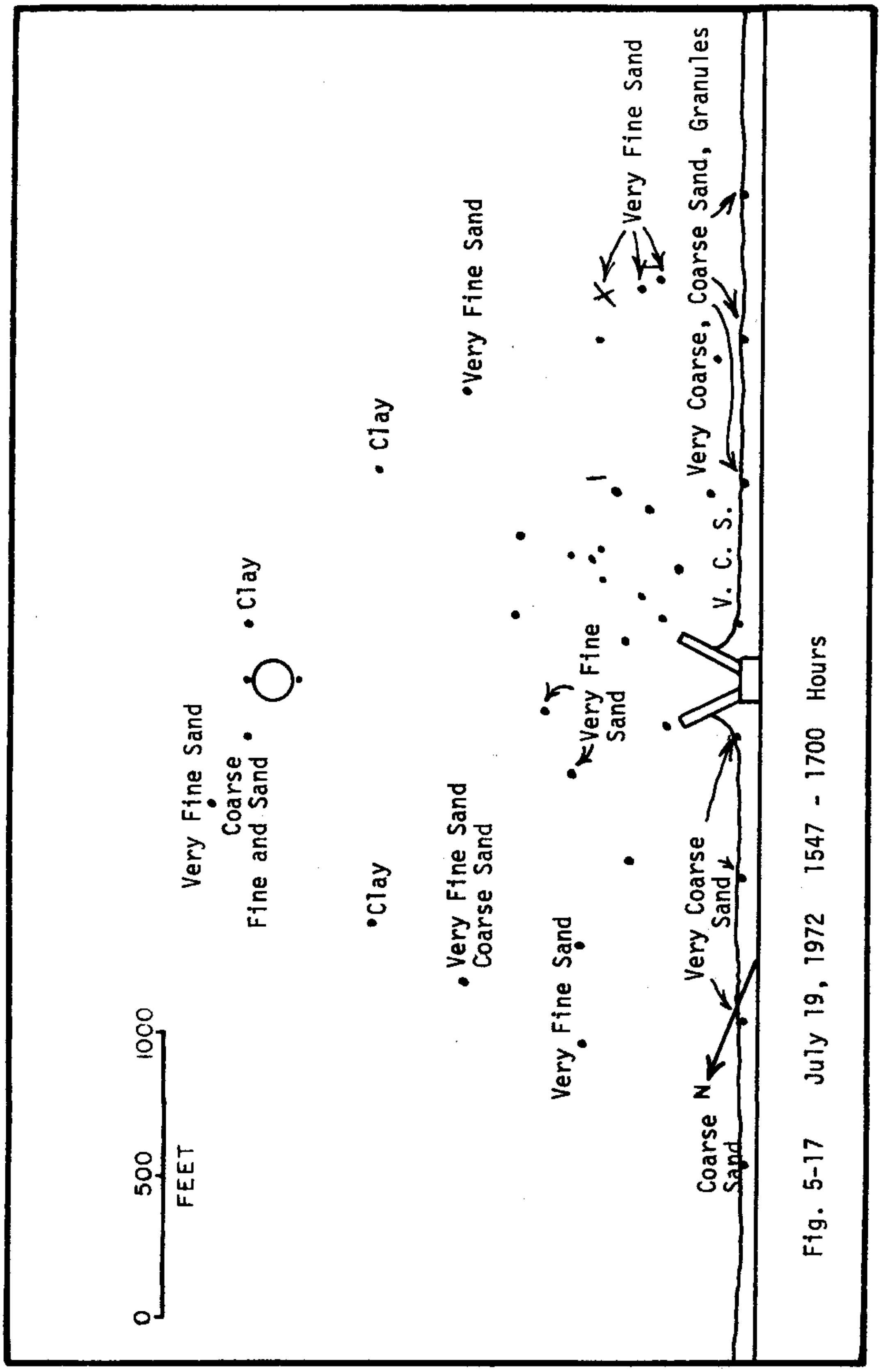


Fig. 5-17 July 19, 1972 1547 - 1700 Hours

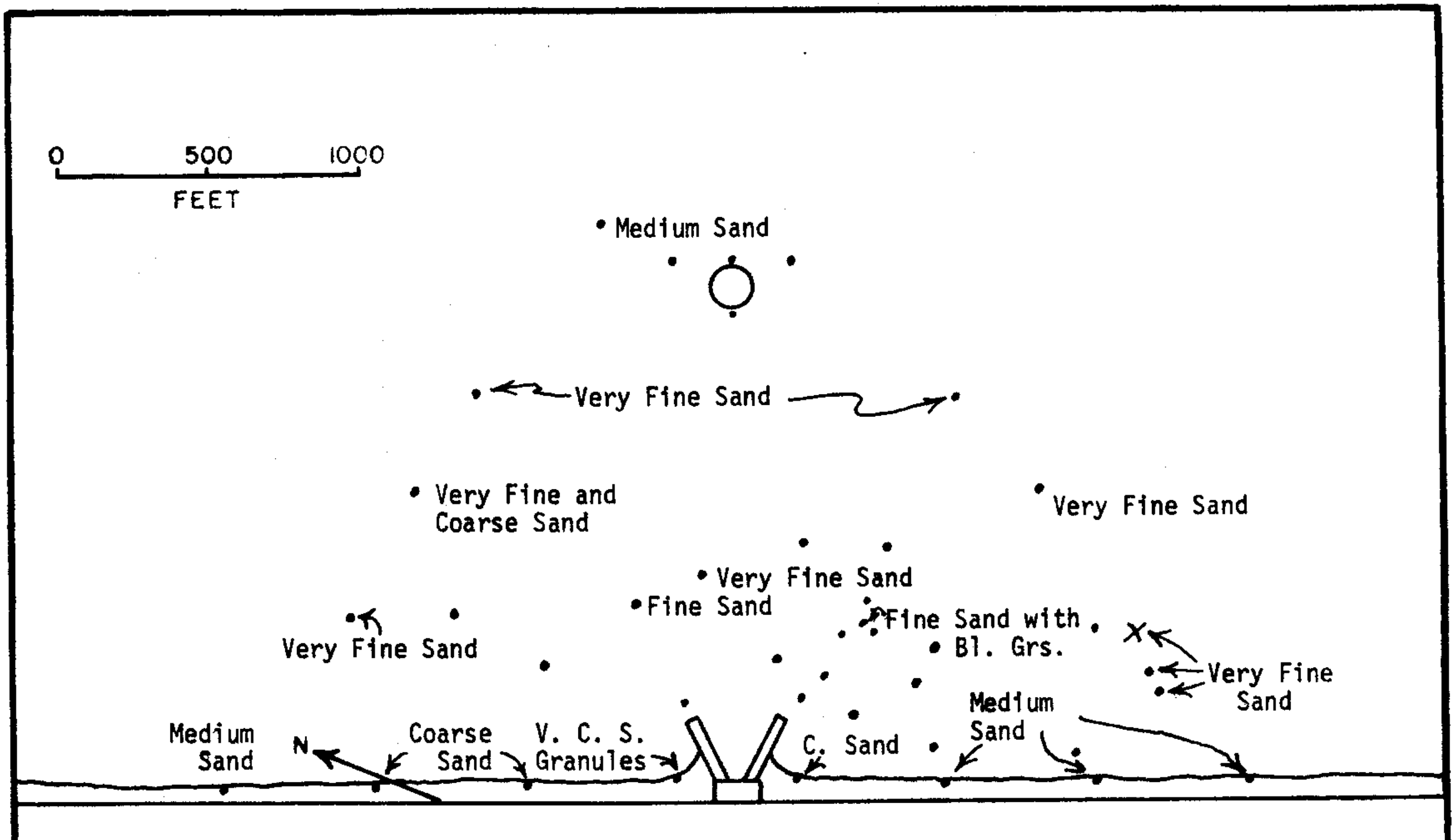


Fig. 5-18 July 20, 1972 1033 - 1125 Hours

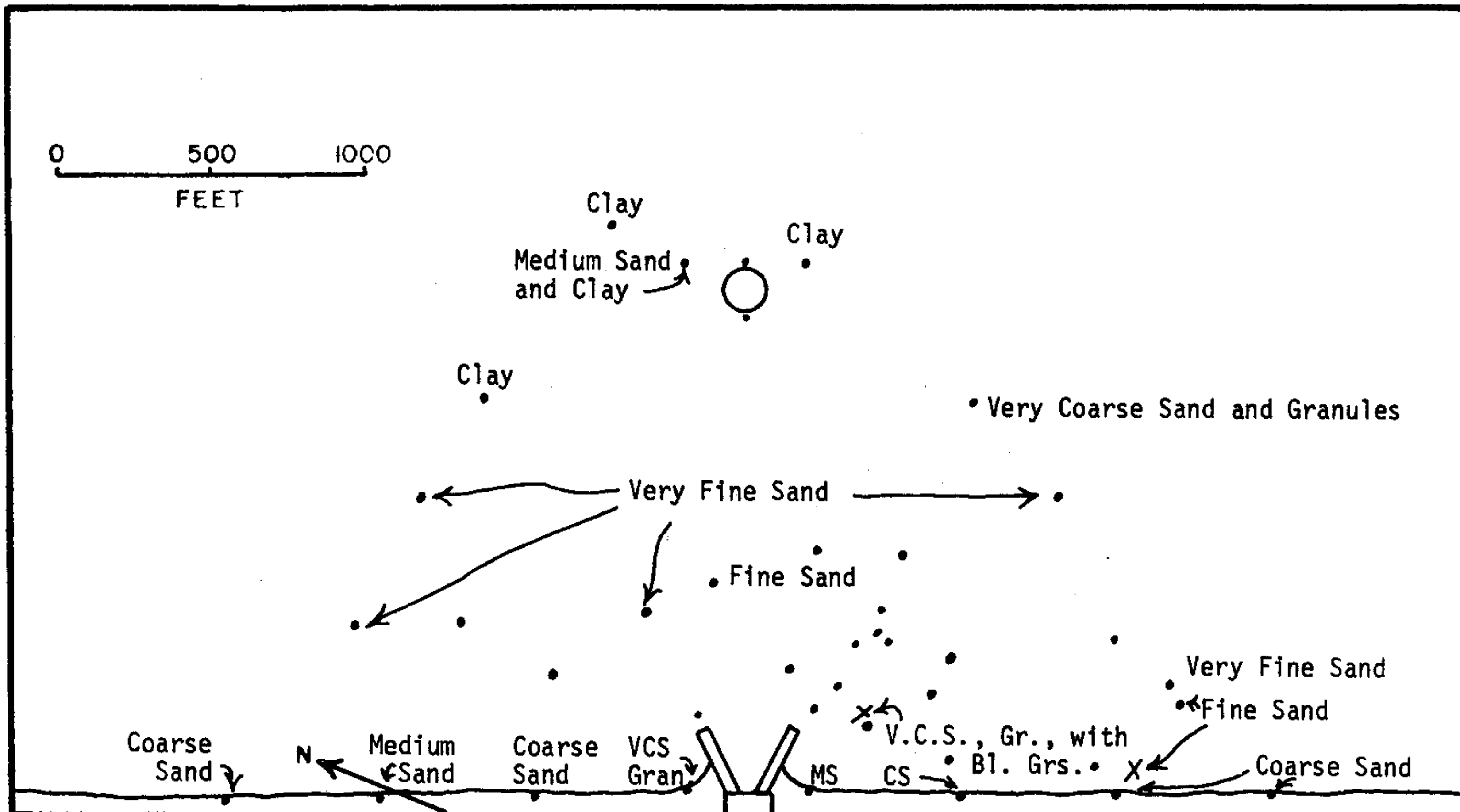


Fig. 5-19 July 20, 1972 1230 - 1355 Hours

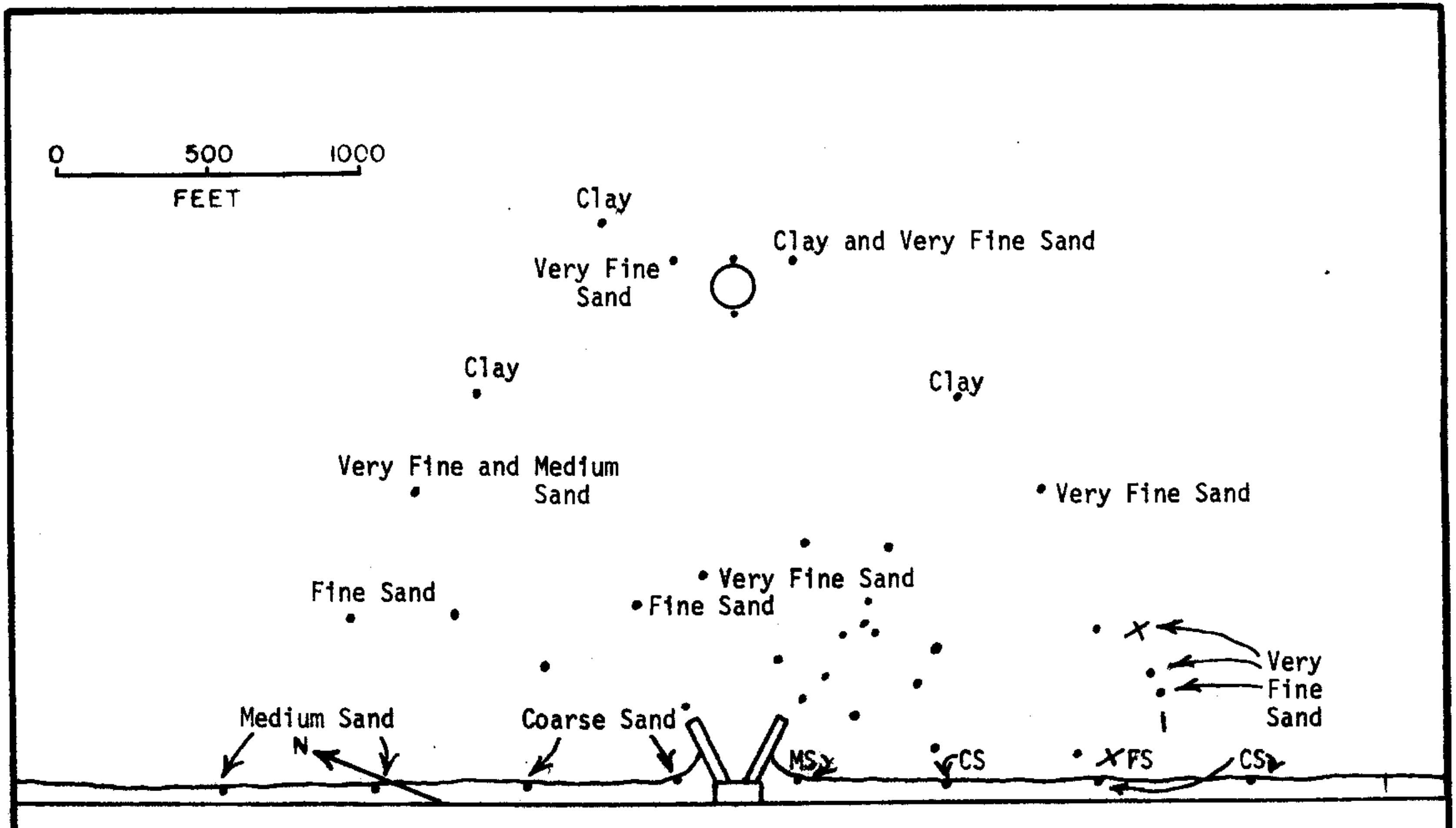


Fig. 5-20 July 20, 1972 1400 - 1530 Hours

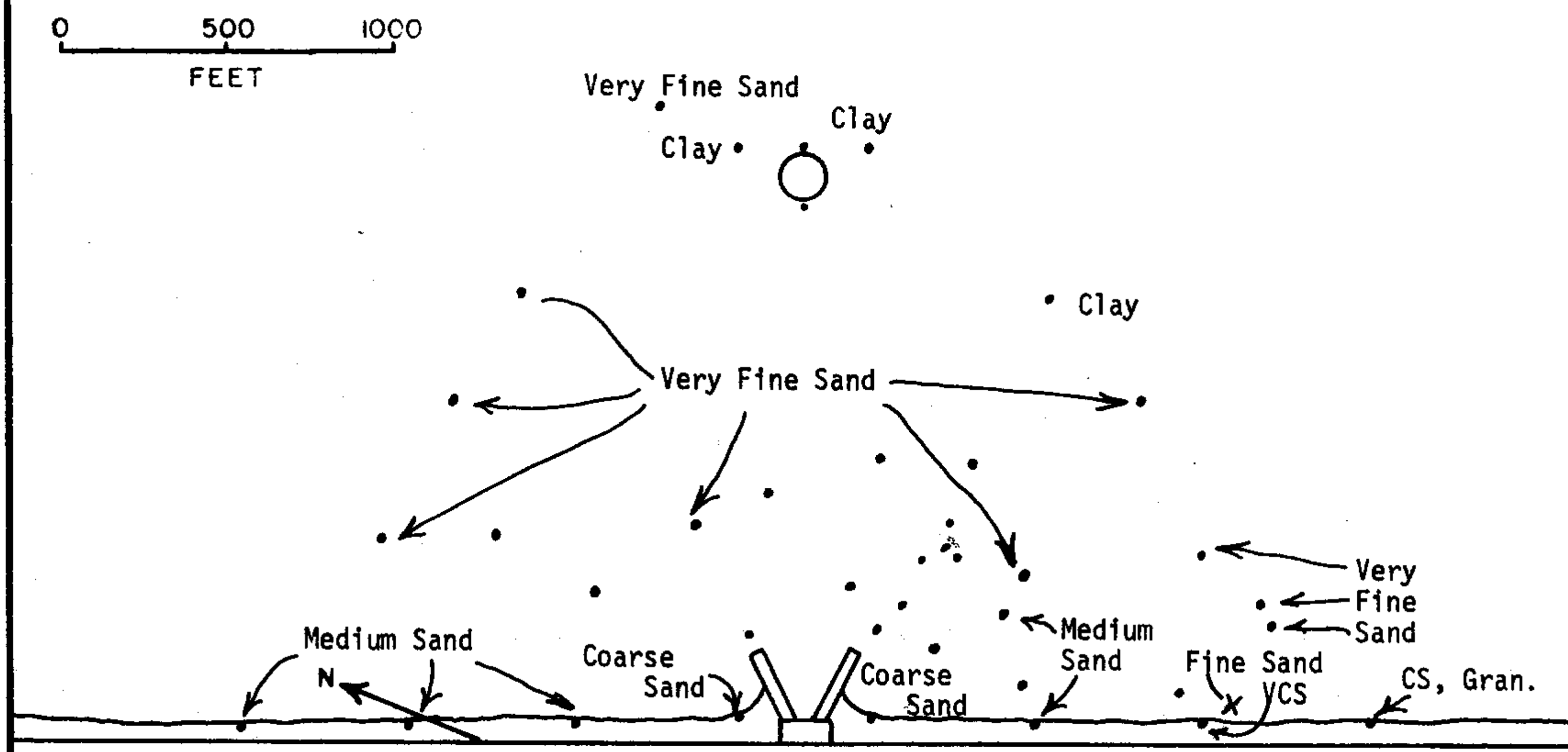


Fig. 5-21 July 21, 1972 0945 - 1040 Hours

TABLE 5-3

LONGSHORE CURRENT MEASUREMENTS

Date & Time		Buoy Number	Velocity	Direction
7/19/72	1515	7	6.75 cm/sec 2.65 in/sec	S--→N
7/19/72	1540	2	4.18 cm/sec 1.65 in/sec	S--→N
7/20/72	1335	7	6.24 cm/sec 2.45 in/sec	S--→N
7/20/72	1350	2	4.23 cm/sec 1.67 in/sec	S--→N

July 19, at 1023, 10 feet lakeward of the water line at beach location F (500 feet south of the Unit I outfall). Unfortunately the yellow-orange sand was not readily identifiable in the samples. Many of the grains had a naturally yellow-orange color which made identification of the dyed grains questionable. As a result no data are available on the movement of this sand. The blue sand spread generally northward in the nearshore zones and towards the beach. The quickest movement measured was 775 feet in 1-1/2 hours (to 10 feet lakeward of beach station F). This is rate of movement of 8.6 feet/minute. Offshore, the blue sand spread to the pole, a distance of 875 feet, in 5-1/2 hours. This is a rate of 2.6 feet/minute. A northward movement of blue sand was substantiated by the two other samples.

Because of the very few grains recovered in only four samples, no volume of transport can be calculated. However, it can be concluded that only a small number of the blue grains were transported from the point of deposition. These are two possible explanations of this. First, because of the calm sea during the experiment, as indicated in Figure 2-11, the energy of the transporting medium along the shoreline was at a minimum. The average velocities measured in the upper four feet of water, do not exceed the threshold velocities of the most easily eroded sand size, very fine sand. A few grains moved, however, so that some energy greater than the threshold velocity must have been available in the fluid regime. Second, it is possible, considering the development of the sand patch in front of Point Beach Power Plant, that the dyed sand was placed in an area of deposition and that it was covered before substantial movement could take place.

VI. RESOURCE ANALYSIS

INTRODUCTION

The rapid population growth in the Great Lakes states, coupled with a high degree of industrialization in the region, requires the identification of new resources to supply the advancing economy. From 1960 to 1970, the population of Wisconsin increased by 11.8%, while Illinois and Michigan grew by 10.2% and 13.4% respectively (U.S. Bureau of the Census, 1972). During this same period, the metropolitan areas of Milwaukee and Chicago increased in total population by 9.8% and 12.2%, respectively (Ibid.). Throughout the entire country, the value of new construction in 1971 was $110 billion (Ibid.). As our land-based stock of resources dwindles, our economic leaders are turning toward the Great Lakes as a new resource base.

Focusing on the coastal sediments and the land-lake interface, this study has revealed the existence of two resource reserves. Sand, critical to the construction and foundry industries, is abundant in the coastal waters of Lake Michigan. The beach and coastal lands are ideally suited as recreation sites for a growing population.

SAND RESOURCES

Two areas can be identifed as sand reserves: offshore from Rawley Point and in the nearshore waters lakeward of Point Beach Nuclear Power Plant. Lakeward of Rawley Point, a huge volume of sand covers the bottom. Considering only the offshore sand zone north of Rawley Point, a conservative estimate of the areal extent is 3.5 by 3.5 nautical miles. If one assumes that the depth of this sand is only one foot, the sand reserve is 14,700,000 cubic yards. As the maximum water depth overlying this sand resource is 100 feet, it is readily accessible to dredge removal.

The second sand reserve identified, nearshore eastward of Point Beach Nuclear Power Plant, is estimated to be 250,000 cubic yards. This estimate is based on a length parallel to the shoreline of 3,000 yards, and average width of 300 yards, and an average depth of 1 foot. These are the dimensions of the sand zone in June, 1972. The depth is particularly problematical. However, anchor weights for a number of buoys have been placed on the bottom within the zone of sand deposition and were subsequently covered with sand. A depth exceeding 2 feet is therefore indicated for the inner areas of the sand zone and an estimate of one foot for an average depth is clearly reasonable. It is especially important to note that this resource is renewable, given the mechanism of its formation, as described earlier. Hence, the reserve estimate is somewhat misleading, as it is not the total reserve but only an annual supply.

ECONOMIC POTENTIAL

Both of these areas contain moderately and moderately well sorted material in the coarse to fine sand sizes. The silt and clay sizes constitute less than 2% of the total weight. Quartz is the predominant mineral with shells and organic matter appearing only rarely. Economic uses of this quality sand include:

1. as a constituent of concrete, mortar, and plaster; 2. foundry use in iron and steel casting; 3. as an abrasive or filter; 4. construction use in roofing, flooring, and grouting; and 5. beach replenishment.

Demand for sand and gravel is high in any industrial area, and depends on the population growth, income, and rate of industrialization and urbanization (Davenport, 1971). In 1970, the U.S. consumed 982 million short tons of sand and gravel which was worth $1,116 million (U.S. Bureau of the Census, 1972). In Wisconsin during the same year, 41,103,000 short tons were consumed, at a value of $35,107,000. Kewwaunee and Manitowoc Counties produced $637,000 and $2,295,000 worth of these materials, respectively (Broderick, 1972).

While sand and gravel occur abundantly in Wisconsin, two factors retard the full utilization of the reserves. These commodities are low value-high volume items for which transportation charges constitute a large portion of the delivered price (Davenport, 1971). Zoning laws, urbanization, and depletion drive quarries further and further from the point of demand, lowering potential earnings (Ibid.). Thus, when sand and gravel are located far distances from points of demand, they cannot be profitably exploited.

The second factor retarding exploitation of aggregate reserves arises from the growing awareness of environmental and aesthetic values. City and surburban dwellers alike are demanding the removal of metropolitan quarrying operations. As leisure time increases and country settings become more popular for vacation homes and recreational activities, mining operations in these areas encounter growing opposition.

Offshore marine and lake sources are thus becoming increasingly attractive. A large reserve off the northeastern United States has been identified (Schlee, 1968). Great Britain has a viable offshore sand and gravel industry in its coastal waters, with about 13 million long tons produced in 1969 by 56 dredges. In western Lake Erie, four commercial reserves were identified by the State of Ohio (Hartley, 1960) and are presently being exploited. There is then, demand for commercial sand and precedents for the feasibility of marine and lacustrine recovery operations. As the sand reserves in the coastal waters of the study area lie near the urban and industrial areas of the Fox River Valley, Two Rivers, Manitowoc, and Milwaukee, they have economic potential.

ENVIRONMENTAL IMPACT

Any potential recovery operation of the sand reserve in Lake Michigan will have to be scrutinized for its environmental impact. Considering the large sand reserve lakeward of Rawley Point, it would be ill-advised to remove this material under present economic conditions. As reviewed earlier, shoaling offshore topography and wide beaches reduce the erosional intensity of incoming waves. Sand removal would therefore lower the offshore profile and most likely result in increased rates of coastal erosion. Because there is a rising concern about shore erosion and because the coastal lands north and south of Rawley Point are occupied by a state forest providing highly prized recreational facilities, exploitation of this sand reserve would be environmentally unsound at this time.

The sand patch just east of Point Beach Nuclear Power Plant appears to be a renewable resource. This conclusion is justified by the considerable growth of this reserve during the study period and by the proposed formation mechanism.

As a renewable resource, any material removed would be naturally replaced. If the rate of removal is equal to the rate of renewal, exploitation could continue indefinitely.

What would be the environmental impact of such exploitation? It must first be pointed out that this is an unnatural deposit, not in equilibrium with the natural lake regime. Because of its concentration near the power plant outfall, the best method of removal would be a movable suction line extended out from shore. Using this method, sand would only be removed from the nearshore waters directly in front of the power plant. No shore erosion would result because only a very small area of the shallow nearshore topography would be altered and the shore in this area is well protected by rip-rap. Vacuumming the excess sand from this area would cause very little or no increase in turbidity as there would be no waste or tailings disposed.

The adverse consequence of such removal would be a decrease in the volume of material available for littoral transport. The magnitude of any adverse environmental effects resulting from such removal are indeed difficult to assess. In order to properly evaluate the consequences of this removal, a measurement of total volume of littoral drift and its rate would be necessary. If the volume removed is only a small component of the littoral drift, then the environmental effects, most notably shore erosion, would be insignificant in relation to the rapid erosion due to high lake levels and intense wave action. The removal may, in fact, reclaim excess littoral material which would be eventually lost to deeper waters. The sand reserve identified in the nearshore zone lakeward of Point Beach Nuclear Power Plant should therefore be further investigated for possible economic exploitation.

LAKESHORE LAND RESOURCES

The second resource identified during the course of this study is the land resource of the beach and adjoining property. This is an economic resource because of the high price put on aesthetic and recreational values and coastal property. Rapid shore erosion decreases the availability of the beach for recreation and the desirability of owning coastal property. The best use of these lands, then, would be to devote them to public recreation through State and Federal ownership. In this way, they would be available to large numbers of users and individual property owners would not suffer the losses of erosion.

VII. FAUNAL LIST

Only three varieties of aquatic life were encountered during the sediment sampling. First, living amphipods were recovered in several bottom samples. Second, empty gastropod shells comprised part of the sediment at three stations. Finally, one pelecypod valve was found in the bottom sediment at one station. No plant life was encountered during the offshore or beach sampling.

AMPHIPODS

The living benthic organisms were identified as amphipods on the basis of their laterally compressed segmented bodies. Figure 7-1 shows one of the specimens collected. The body is made up of a cephalothorax, formed by the head fused with the first thoracic segment, seven free thoracic segments, an abdomen with six segments and a small telson (Pennak, 1953; Chase, et al. 1959). Two pairs of antennae are present and the first three abdominal segments hold paired pleopods (abdominal locomotor appendages adapted for swimming). These amphipods were ascribed to the genus and species Pontoporeia affinis Lindström because of the following features: The fifth periopod (abdominal appendages used for crawling and walking) is much shorter than the fourth with its second segment greatly expanded; the first antenna is shorter than the second. When first recovered, the organisms had a pinkish-cream color and appeared to be resting on the sediment surface or swimming just above it. Figure 7-2 shows the position of this species in the zoological classification system.

Amphipods both swim above the substrate and crawl along its surface, using their appendages for locomotion. It is therefore a benthic or bottom living organism. They are scavengers and feed on both animal and plant material. Pennak (1953, p. 436) wrote that "freshly killed animals are consumed readily," and "only rarely do they attack and feed on living animals." The females carry the fertilized eggs for 1-3 weeks before the young are released. Pontoporeia affinis Lindström is believed to have a life cycle of 30 months or more (Pennak, 1953). While amphipods generally live in a wide variety of unpolluted streams and lakes, Pontoporeia affinis Linstrom has been recovered only from deep, cold, oligotrophic, northern lakes (Pennak, 1953). The principal predator on the amphipods are fish, but birds and amphibians also feed on them.

This species has been reported to have a wide distribution and great abundance in Lake Michigan. Henson (1966) has reviewed the findings of several investigators and reports that up to 14,000 individuals per square meter have been found in the lake but an average number is between 1,500 and 2,000 individuals per square meter. Powers and Robertson, (1965) show that from 3,000 - 11,000 amphipods per square meter were found between Rawley Point and Kewaunee. These amphipods seem to prefer intermediate depths, 80-140 feet, and temperatures from 8-12°C. (Henson, 1966).

In this sediment study, Pontoporeia affinis Lindström was recovered at stations PP393 and PP1500. The water depths at these stations were 49 feet and 12 feet respectively. At both stations, fine sand was the surficial sediment.

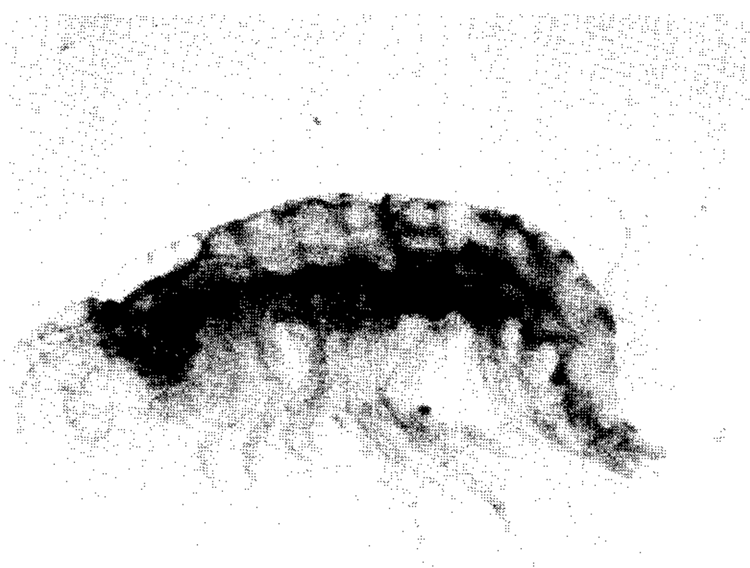


Fig. 7-1 _Pontoporeia affinis_ Lindström. Specimen is 7 mm long.

FIGURE 7-2

AMPHIPOD CLASSIFICATION

Phylum	-	Arthropoda
Class	-	Crustacea
Subclass	-	Malacostracea
Order	-	Amphipoda
Family	-	Haustoriidae
Genus & Species	-	*Pontoporeia affinis* (Lindström, 1855)

From: Pennak, 1953

GASTROPODS

Empty gastropod shells comprised part of the sediment at stations PP561, 567, and 568. Two or three shells per sample were recovered. One of the gastropod shells is shown in Figure 7-3. Because no operculum was present, the coiling was spiral and dextral, the shells were small, and cream to brown colored, they were identified as being of the genus Lymnaea. The species was not resolved. If an operculum was present, but was lost with the soft parts, these gastropods would be contained in the order Ctenobranchiata and would not be identifiable to the genus level. The identification is therefore only tentative. Figure 7-4 shows the position of the genus Lymnaea and the order Ctenobranchiata within the Mollusca Phylum.

Gastropods move along a substrate by means of a muscular protrusion called a foot. Some species, including Lymnaea, can move by means of "spinning". A thin mucus thread is excreted and the organism can move up or down on it. Upward motion is facilitated by the gastropod reducing its specific gravity (Pennak, 1953). Gastropods generally have a vegetable diet, but Lymnaea is omnivorous and a good scavenger. They have also been observed feeding on living animal tissue. (Pennak, 1953). Reproduction is hermaphroditic, with the eggs being deposited in a gelatinous mass on the substrate. Nine to fifteen months is the life span for most gastropods but those in the family Lymnaeidae live at least three years. Like the amphipods, fish are the chief predators on the gastropods.

One ecological parameter which seems to be most important to gastropods is a high level of calcium carbonate, from which they construct their shells. Lymnaeidae occur principally in waters with at least 15 parts per million of bound carbon dioxide (Pennak, 1953).

Because the gastropod shells found at stations 561, 567, and 568 were empty, they most probably had been transported into these locations. Because the shells are delicate, transportation from a remote source seems impossible. While they might have originally lived in one of the many streams or swampy areas along the shore, this family has been reported in the benthic population of Lake Michigan (Henson, 1966).

PELECYPODS

At station PP844, one valve of a pelecypod was contained in the sediment sample. While positive identification is impossible because of the incomplete shell, the pelecypod can tentatively be classified in the family Sphaeriidae. (See Fig. 7-5). This was done on the basis of the presence of cardinal teeth, anterior and posterior lateral teeth, the somewhat fragile shell, and the length of 11 millimeters (Pennak, 1953).

Pelecypods are benthic and burrowing organisms which move over and into the substrate with a muscular foot. They are filter feeders, filtering plankton and organic debris from the water. While reproduction differs from family to family, the Sphaeriidae are hermaphroditic, the immature young being released from the parent fully formed. This family is preyed upon by fish. A wide variety of habitants are occupied by the pelecypods and the Sphaeriidae can be found on all sorts of sediments except clay and rock (Pennak, 1953). In the

Fig. 7-3 Gastropod. Specimen is 10 mm from top to bottom.

FIGURE 7 - 4

GASTROPOD CLASSIFICATION

Phylum - Mollusca

Class - Pelecypoda

Class - Gastropoda

Order	-	Pulmonata	Order	-	Ctenobranchiata
Family	-	Lymnaeidae			
Genus	-	*Lymnaea*			

From: Pennak, 1953

FIGURE 7-5

PELECYPOD CLASSIFICATION

Phylum - Mollusca

Class - Gastropoda

Class - Pelecypoda

Order - Eulamellibranchia

Order - Heterodonta

Family - Sphaeriidae

Genus - <u>Pisidium</u>

Genus - <u>Sphaerium</u>

From: Pennak, 1953 and
Chace <u>et</u> <u>al</u>, 1959

study area, the valve was associated with very fine sand. Two genera from this family, Pissidium and Shpaerium are common in Lake Michigan (Henson, 1966).

Benthic life in the study area, then, is not abundant. Local populations of Pontoporeia affinis Lindström were found but these were the only live organisms recovered. Trace evidence of gastropods and pelecypods denote some other biological life in the area but, judging by the few shells encountered, it must be slim indeed.

VIII. DISCUSSION

Interpretation of the results of this investigation has permitted the sedimentary regime in the area of study to be defined. Likewise, the sedimentary transport patterns and the short-term changes in the regime due to the cooling water discharge at Point Beach Nuclear Power Plant have been revealed. The knowledge gained concerning the natural regime together with it natural variability and background raioactivity has provided a baseline for future study of possible long-term alterations in the sedimentary regime. From study of the short-term changes in the area, a prediction can be made concerning these long-term effects. Finally, the method of discharge can be evaluated along with a discussion regarding power plant siting and industrial waste discharge in general.

THE OFFSHORE SEDIMENTARY REGIME

Four surficial sediment types were found in this area of Lake Michigan; desiccated, consolidated red clay; rocky gravel and gravelly sand; sand; and muddy sand. Found predominately in the nearshore waters north of the Point Beach Power Plant, the desiccated red clay has been identified as relict material deposited during the Valders substage of the Wisconsin stage of the Pleistocene epoch. Such identification was possible through visual and mineralogical techniques. While recent sediments were found to be transported over this surface and were thus intermittently found in a thin veneer on the red clay, recent materials are not being permanently deposited in these areas.

Rocky gravels and gravelly sands were found to be a combination of relict material and recent sediments. Relict materials were identified by signs of having been plucked from the surface of the desiccated red clay. On the other hand, the recent sediments were unconsolidated and therefore subject to transport. The rocky gravels and gravelly sands appear predominately in a lobate area in the intermediate depths of the northern zone of the study area.

Sand, chiefly in the most mobile size classes - medium to very fine - covered the zone south of Point Beach Power Plant from the shoreline to depths exceeding 100 feet. A band of sand also extended northward east of the lobe of coarser sediments. Finally, muddy sand was found at the lakeward edge of the study area.

Comparing these results with Emery's (1951) description of this area of Lake Michigan, a major disparity is noted. While Emery cataloged the bottom in the area as being rocky, only a very small zone could be thus classified from the results of this study. Even in the areas where rocks occurred, gravels and gravelly sands predominate. Further, sand and clay are widespread surficial sediments. The recovery of glacial till, either swept clean of recent sediment or covered with a veneer of this material compliments Hough's (1935) findings of similar material along the eastern and western shores in other areas of Lake Michigan.

Sediment transport patterns have emerged from the distribution of surficial sediment types and the textural parameters. Throughout the intermediate depths of the study area, the net transport is from north to south. From deposits formed near the outfall at Point Beach Power Plant, however, it appears that the nearshore sediment is transported from north to south at times, and from south to north at others.

Mineralogical analyses indicated that the recent sands were mainly quartz, with potash feldspars being more abundant than plagioclase feldspars, as predicted by Goldich's mineral stability series in weathering (1938). No mineralogical dispersion pattern of these constituents was found within the study area. The sands were classified as being a quartzose or feldspathic sand, falling on the borderline between these two varieties, as defined by Krumbein and Sloss (1963). Predominate minerals in the high density fraction are diopside, augite, enstatite, hypersthene, hornblende, and magnetite.

X-ray analyses of both the silt- and clay-size fraction and the high specific gravity fraction have led to the glacial drift bluffs, bordering the back of the beach along the shore of the study area, being identified as the source of the lake sediments. Further, the desiccated red clay exposed offshore was identified as the same material as contained in the drift bluffs, using the method of x-ray diffraction.

The glacial drift deposited in the area during the Pleistocene thus exercises control over the recent sediments by acting as a source for the sediments and by providing the surface over which they may be transported and on which they are deposited. The great difference between the surficial materials in the northern zone and the recent sands found in the south is due to the configuration of the surface of the glacial drift. This surface, over which recent sediments are transported is exposed at a higher elevation in the north than in the south. As a result, in the north, this surface was swept clean of deposits of all but the coarsest material. Sediment transported over this surface was deposited in the southern area.

NATURAL VARIABILITY

An important part of any description of a sedimentary regime is its natural variability. Storm influence is a prime parameter. That large amounts of sand can be pushed from deeper water toward shore by a storm from the east was well documented during the June, 1972 survey. This means that sand transported to deeper waters and deposited during periods of quiescence can be returned to the normal transport system, rather than being lost. This natural process of reclaiming sand is significant in that the net volume of sand normally passing out of the area of transport is reduced.

A second natural variable in the offshore area is the intermittent veneer of sand and gravel surrounding the lobe of coarse material in the north. This was composed of sediment in transport and its extent changes during the transportive process.

Finally, the muddy sand patches off Rawley Point were subject to natural variability. The existence of this type of surficial sediment is due to the settling out of suspension of the finer material during quiescent periods. When the fluid regime over these areas becomes more energetic, this fine material is transported out of the area.

The beach, too, displays natural change, perhaps even more obviously than the offshore areas. Variations in the form and materials of this interface are due to changes in the level of the lake and intense storm action. Erosion of the material forming the back edge of the beach is nonuniform along the shore of the study area. This erosional process is a response to the offshore regime being in temporary disequilibrium as predicted by Bruun's theory of sea level change (1962) and also due to the loss of sedimentary material from the immediate area by transport along the coast and to deeper water. Erosion of the shoreline of Lake Michigan has been well documented since 1850 and should be viewed as a natural process, rather than with alarm. It should be noted, however, that while the beaches change form and erosion of the land proper continues, the beach itself tends toward an equilibrium configuration.

CHANGES DUE TO THE DISCHARGE OF WATER

Along with the conditions of natural variability, this study has revealed a short-term consequence of the water discharged by the Point Beach Power Plant. Directly in front of the outfall, a significant sand patch developed during the course of the study. Deposition in this area is due to the interruption of the littoral and longshore currents by the water being jetted perpendicular to it. The sand patch has been identified as an anomalous area of deposition and, as such, is a renewable sand reserve. Because mobile sand has been removed from the transport system, areas of gravelly-sand and clean clay are developing offshore shoutheast of the power plant where formerly sand was deposited.

No environmental damage due to this anomalous zone of deposition has been recognized. The shoreline directly to the north and south of Point Beach Nuclear Power Plant has eroded no more than any of the other profile sites. Also, the rate of erosion documented along the shore of the study area is no greater than the rates of erosion measured since 1850 along the Wisconsin shore of Lake Michigan.

BASELINE FOR FUTURE STUDIES

This delineation of the sedimentary regime in this area of Lake Michigan can now serve as a baseline for investigations of possible long-term effects of the water discharged at the Point Beach Power Plant. The natural variability of the area, including the natural shoreline erosion, is of particular importance in a baseline for long-term study. Because this plant is fueled by nuclear materials, the background radioactivity levels of the sediment are important parameters in the baseline.

Significant differences were found in the levels of background radioactivity in the different types of sediment - sand, clay, and muddy sand. It is therefore important that future analyses, by government agencies, for example, describe the sediment type along with the associated radioactivity level. If a series of sand samples taken in one year were compared to a set of clay samples taken during the following year, the overall background radioactivity of the sediments could be said to be increasing markedly. This, however, would be a misrepresentation.

PREDICTION OF LONG-TERM CHANGES

Considering the short-term changes in the natural sedimentary regime of the study area as the result of the water discharge, what might happen after several years of operation of the power plant? While only Unit I of the Point

Beach Power Plant was operating, significant deposition of sand occurred in the nearshore areas in front of and on either side of the outfall. When both Unit I and Unit II are put into full operation, twice as much water will be jetted perpendicularly through the nearshore zone. Although it would be too simplistic to assume that the barrier to longshore transport would then be twice as intense, certainly this greater volume of water would make it more difficult for sediment to be transported along the shoreline. If, while only Unit I was operating, only a portion of the sediment normally transported along the shore was deposited, with the remainder passing the barrier by transport in the area lakeward of the plume influence, the operation of both units may make passing the barrier that much more difficult. This would result because of the greater intensity of the unnatural flow regime.

This being the case, sediment would be deposited at a greater rate. As the nearshore areas fill in and become shallower, the zone of transport would move lakeward, as happens when groins are constructed along a shoreline. Hence, the zone of deposition would be moved further out from shore. The long-term effect then, would be an everwidening zone of sediment deposition. At some point, a steady-state might be reached, in which no new deposition would occur and the volume of sediment normally transported along the shoreline would be transported lakeward of the area of plume influence.

EVALUATION OF THE METHOD OF DISCHARGE

Because the outfalls at Point Beach Nuclear Power Plant direct the discharge water in a plume into the lake, the natural flow of sediment along the shore is interrupted. As the velocity of the discharge water is perpendicular to the littoral and longshore currents, the plume acts somewhat like a groin - perhaps more comparable to a permeable groin than an impermeable groin. Also, the water is discharged at a particularly vulnerable place in the sedimentary regime, the littoral zone, which, in the natural situation, has adjusted itself into a finely tuned equilibrium. Alterations to the sedimentary regime would be greatly decreased if the discharge water was diffused rather than jetted out, and the location of the outfall was moved into deeper water.

This observation is worthy of note in regard to the design of other industrial water discharges. While a most simple engineering design is employed at Point Beach Power Plant, a more sophisticated plan, utilizing diffusers and piping the effluent to deeper water away from the littoral zone, should be considered as a worthwhile capital investment. If such an initial investment is made, future increased operating costs in the form of environmental monitoring and extended litigation will be avoided.

One further observation comes to light from the results of this investigation. Point Beach Nuclear Power Plant is built right on the edge of the shoreline. Because erosion of this shoreline is a natural, continuing phenomenon and because a nuclear power plant is planned as a long-term investment by the utility, a site so close to the present shoreline shows a lack of good planning. While the joint owners of this plant have installed rip-rap to protect the shoreline directly in front of the plant, the shoreline on either side will continue to erode. In a matter of 50 years, the power plant may be located on a point of land jutting out into the lake. Allowances should have been made for natural erosion of the lake shore when planning the plant. Furthermore, had the plant been built one-half mile or so from the coast and the effluent discharged offshore, the plant would be less visible as a coastal structure and would have been more appealing to those who feel the natural qualities of the shoreline should be preserved.

CONTINUED INVESTIGATION

Continuing studies of the effects of the water discharged at Point Beach Power Plant should focus on the movement of sediment along the shoreline and its deposition in front of the outfall. Further, the rate of littoral transport along the shore by the natural regime to the north and south should be examined more closely. Finally, the offshore regime should continue to be monitored, as yet undetected changes in this zone may occur, along with unrevealed natural variations when the plant is running at full capacity for several years.

Further investigation of the efficiency of the two jets of discharge water will be a significant contribution to those involved in the planning of industrial effluent structures. The knowledge of sedimentology will be advanced if the stability of the zones of deposition under the influence of the natural and man-induced flow regimes can be determined. The feasibility of the economic utilization of the renewable sand resource lakeward of the outfall may be demonstrated as the character of the littoral transport is fully delineated. Also, the long-term relationship between nearshore, man-induced change and its impact on the offshore environment will be demonstrated.

IX. CONCLUSIONS

1. The offshore sedimentary regime is composed of four types of sediment. Desiccated red clay of Valderan age (Pleistocene) is exposed, with little or no overlying recent sediment, primarily in the nearshore waters north of Point Beach Nuclear Power Plant. Because this material is of Pleistocene age, it has been identified as a relict sediment. Rocky gravels and gravelly sand predominately occupy a lobate zone in the intermediate depths north of the power plant. While most of this material is recent, some of the larger rocks were resting within the surface of the Valderan drift and are therefore relict materials. Sand, mainly in the fine sand class, dominates the area south of Point Beach Nuclear Power Plant, from the shoreline to depths exceeding 100 feet and extends northward in a band east of the rocky gravels and gravelly sands. Muddy sands are found beneath the deepest waters of the study area and in intermittent patches off Rawley Point.

2. The net transport of sediments offshore is north to south. This was indicated by the increase in sorting and decrease in grain size from north to south through the study area. Along the shoreline, the transport direction reverses, but the net trasport is from north to south.

3. Quartz being the principal mineral composing the sand grains, the sands offshore were classified as a quartzose or feldspathic sand. Potash feldspars were generally more abundant than the plagioclases. The heavy mineral suite is composed primarily of diopside, augite, enstatite, hypersthene, hornblende, and magnetite.

4. Pleistocene drift deposits form bluffs at the back edge of the beach north of Point Beach Power Plant and exert an influence on the offshore sedimentary regime in the study area by acting as a source for the modern sediments. Further, deposits of Valderan age are exposed offshore with no recent sediments overlying them. Finally, the same Valderan age deposits underlie the modern sediments of the area and provide a surface for their transport and deposition.

5. Background radiation measurements revealed that the clays and muddy sands contained the highest radioactivity levels. Gravelly sands had the lowest levels with sands having intermediate values.

6. The natural variability of the beach material and configuration was recognized. While cycles of erosion and deposition of sediments were observed at the land-lake interface, the beach configuration tends to return to an equilibrium condition. Erosion results from a rise in lake level and/or intense storm action. Erosion of the material forming the back edge of the beach, whether it be sand deposits or glacial drift, was found to be a continuing natural phenomenon.

7. An anomalous zone of sand deposition was established along the shoreline to the north, in front of, and to the south of the Unit I cooling water outfall at Point Beach Nuclear Power Plant during the course of the study period. This sand patch is characterized by well sorted, very fine sand at its outer edges, grading to poorer sorted, coarser sediments directly lakeward of the outfall. The unnatural fluid regime resulting from the cooling water discharge is causing an unnatural zone of deposition along the shoreline by decelerating and deflecting the littoral drift.

8. During the course of the study, no environmental degradation, as measured in the form of increased shore erosion was found due to the anomalous area of sand deposition associated with the power plant discharge. While this deposition removes sediment from the littoral transport, to date this removal has produced no adverse effects.

9. It cannot be assumed, a priori, that the removal of material from the littoral transport will result in environmental damage. Removal may only reclaim material normally lost from the immediate area by transport along the shoreline or to deeper waters. It must be concluded, then, that although Point Beach Nuclear Power Plant is interfering with the natural transport of sediment along the shoreline, resulting in an unnatural zone of deposition, it is not, at present, damaging the environment.

10. Two resource reserves were identified. Sand reserves, critical to the construction and foundry industries, occur off Rawley Point and in the zone of deposition lakeward of Point Beach Nuclear Power Plant. It would be environmentally unsound to exploit the reserves off Rawley Point under present economic conditions as it would lead to increased shoreline erosion. However, the reserve near the power plant is a more favorable prospect. It is an unnatural deposit, not in equilibrium with the natural lake regime.

11. Benthic life, as observed during the sediment sampling, is not diverse. The one species found to be living on the sediment surface is Pontoporeia affinis Lindström, an amphipod.

12. The sedimentary regime in the area should continue to be monitored. More significant changes in the sedimentary environment may be detected after both units of Point Beach Nuclear Power Plant have been running for a year or more. Further the stability of the anomalous zones of deposition near the outfall structure should be determined. Finally, the rate of littoral transport along the shore should be fully delineated so that the feasibility of economic utilization of the renewable sand resource may be evaluated.

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