HEAVY MINERALS IN PLEISTOCENE AND CRETACEOUS SEDIMENTS ALONG THE NASSAU-SUFFOLK COUNTY BORDER, LONG ISLAND, NEW YORK

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Abstract

Abundance and distribution of heavy minerals in Long Island sediments near the ground-water divide and at the southern shore were examined in an effort to identify sources and sinks of dissolved iron and other ground-water constituents along a deep ground-water flow path. Heavy-mineral data from boreholes near the ground-water divide and at downgradient sites near the southern shore in western Nassau and eastern Suffolk Counties were used to document and compare the relative abundance of heavy minerals within and among geologic units.

Major heavy minerals in the Cretaceous sediments at the study sites include muscovite, leucoxene, ilmenite, rutile, staurolite, chloritoid, and aluminosilicates (Al_2SiO_5); those in the overlying Pleistocene deposits at the study sites include iron oxides, leucoxene, zircon, garnet, ilmenite, aluminosilicates, and hornblende. Pyrite or marcasite, garnet, hornblende, and tourmaline were found locally in the Cretaceous sediments, but pyrite or marcasite were not detected in the borehole samples from near the ground-water divide, probably because the ground water there is more highly oxygenated than it is in sediments farther along the ground-water flow path. Glauconite was present in both Cretaceous and Pleistocene deposits, but only in the marine units. Of the iron-bearing minerals, leucoxene, iron oxides, and pyrite or marcasite were found to be the most abundant and potentially reactive.

INTRODUCTION

Definition of the geochemical reactions that predominate in the Long Island aquifer system requires study of the reactive minerals in the sediments. The low dissolved-solids concentrations of ground water of Long Island, reflect the paucity of reactive minerals in the sediments that form the major aquifers. These sediments consist mostly of quartz sand; heavy minerals constitute generally less than a few percent by weight. Iron is one of the most reactive dissolved constituents (Brown and Schoonen, 1994) and is derived from iron coatings on sediment grains and the heavy-mineral fraction of sediments. The heavy minerals in the Cretaceous and Pleistocene sediments that overlie bedrock on Long Island are derived mainly from weathered crystalline and metamorphic rocks of New York and New England (Perlmutter and Todd, 1965).

The distribution of heavy minerals within an aquifer along a ground-water flow path, and the residence time of water (or distance travelled), affect concentrations of dissolved constituent at any given location along that flow path. Ground-water chemistry evolves along a flow path through interaction with the minerals and organic carbon, and as a function of the predominant terminal electron-accepting process (Lovley and Goodwin, 1988). The abundance of heavy minerals in Long Island sediments has been studied by several workers (see Previous Studies section), but the spatial distribution of these minerals has not been examined in detail. Such information is needed for geochemical modeling and in studies of iron geochemistry along this flow path.

In 1994, the U.S. Geological Survey (USGS), in cooperation with Suffolk County Water Author-

ity (SCWA), began a study of iron geochemistry and chemical evolution of ground water along the southward flow path from the ground-water divide to the southern shore at the Nassau-Suffolk County border (fig. 1). The initial phase of the study included delineation of heavy-minerals distribution in the upper Cretaceous deposits, including the Matawan Group and Magothy Formation undifferentiated (Magothy aquifer), and in the saturated part of the overlying Pleistocene deposits (upper glacial aquifer). The core samples were examined for grain-size distribution, mineralogy, and degree of chemical weathering as an indication of their reactivity. Heavy minerals from core samples collected near the ground-water divide (the area of deepest recharge) were studied and compared with mineralogical data from previous studies on Long Island to help define geochemical reactions along the flow path shown on section A-A´ (fig. 2). Unpublished heavy-mineral data from a borehole in Tanner Park near the southern shore (Sirois and others, 1986) and elsewhere along the southern shore (Perlmutter and Todd, 1965), were used for comparison.
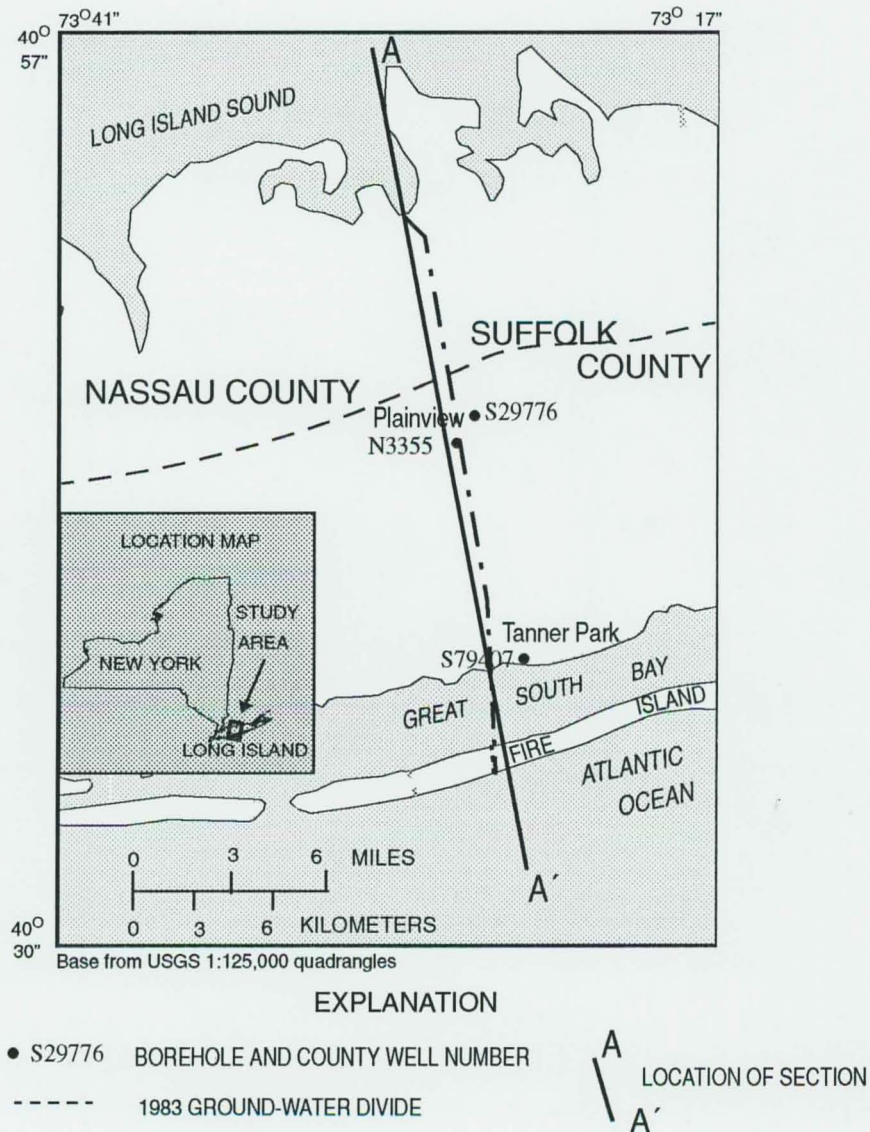

Figure 1. Location of hydrogeologic section along Nassau/Suffolk County border with Plainview and Tanner Park Borehole locations.
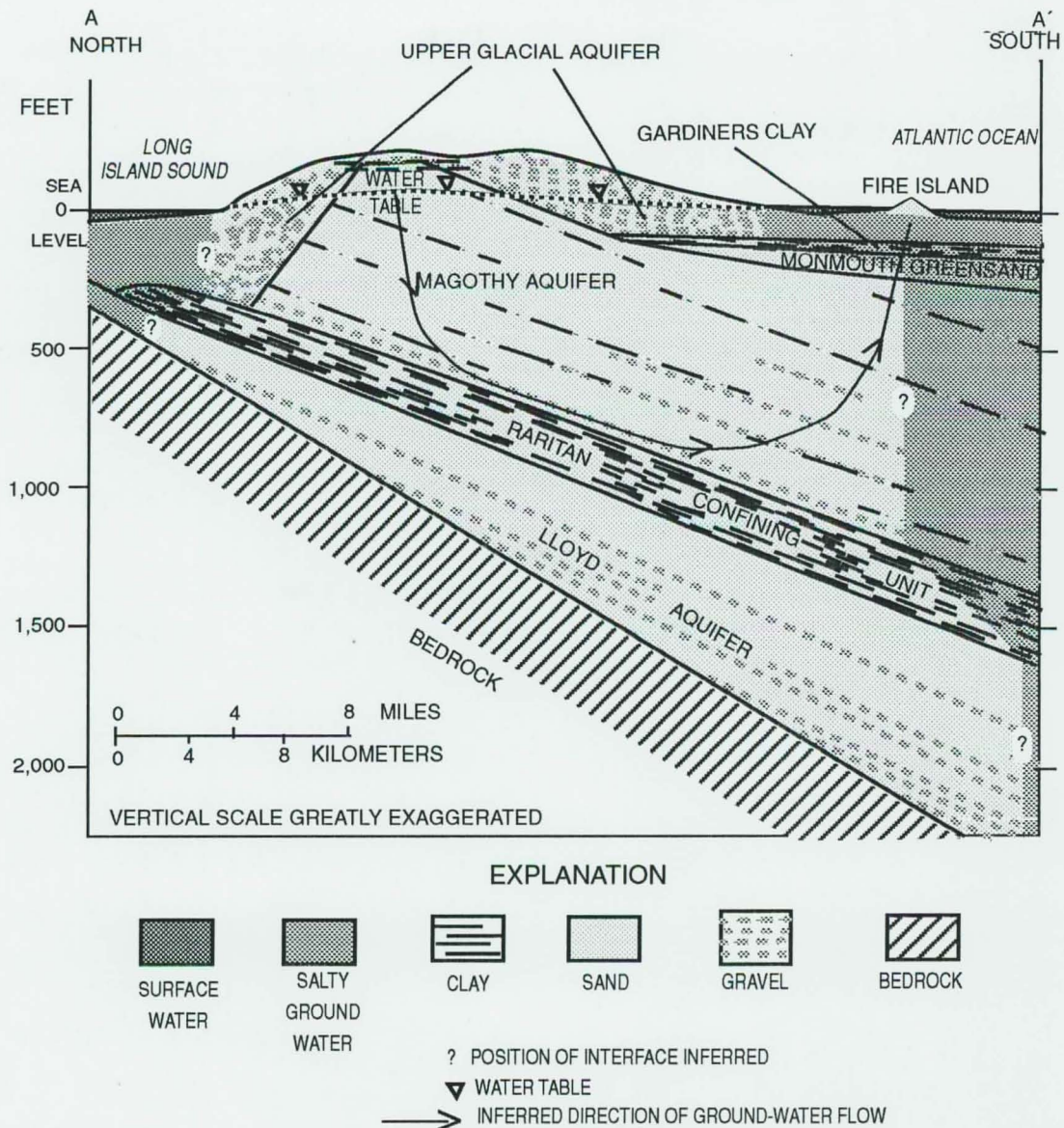
Figure 2. Hydrogeologic section A-A′ along Nassau-Suffolk County border, Long Island, N.Y. (Modified from Franke and Cohen, 1972, fig. 2.)

Purpose and Scope

This report describes the occurrence, general abundance, and distribution of heavy minerals in the Pleistocene and upper Cretaceous deposits at Plainview, New York, about 0.6 mi south of the groundwater divide, and compares this data with data from a site on the southern shore (Tanner Park), farther along the flow path (fig. 1 and 2); it also cites data from other Long Island studies.

Previous Studies

Several studies on Long Island have included mineralogical analyses. Suter and others (1949) listed the major and trace mineral constituents in the Cretaceous and Pleistocene deposits. Faust (1963) found that the Pleistocene outwash sand in central Suffolk County contains greater quantities and a greater variety of heavy minerals, rock fragments, alkali feldspars, and hornblende than the upper Cretaceous deposits, which are limited in heavy-

mineral content but contain lignite and pyrite. Perll-mutter and Todd (1965) found that upper Creta-ceous sand in southern Suffolk County contained the full suite of heavy minerals that is generally characteristic of the marine Cretaceous beds of Maryland, Delaware, and New Jersey (Groot and Glass, 1960). This suite includes epidote, pyrite, ilmenite, garnet, zircon, sillimanite, staurolite, chlo-ritoid, chlorite, muscovite, tourmaline, and glauco-nite. Sirois and others (1986) reported similar heavy-mineral occurrences in core samples from a borehole at Tanner Park.

Aronson and others (1983), in a study of tex-tural characteristics and heavy-mineral content in the upper glacial (Pleistocene) and Magothy (upper Cretaceous) aquifers, observed that (1) andalusite was present in the Magothy deposits but absent from upper glacial deposits, whereas hornblende and clinozoisite were common in upper glacial deposits but absent from Magothy deposits; and (2) zircon, sillimanite, rutile, kyanite, garnet, and trem-olite were present in considerably greater quantities in the upper glacial aquifer than in the Magothy aquifer. Foord and others (1970) used heavy-min-eral, clay-mineral, and grain-size characteristics of cores from several deep boreholes in north-central Long Island to distinguish several units of upper Cretaceous and Pleistocene age and found that the largely nonmarine upper Cretaceous sediments were marked by a limited heavy-mineral suite and a lack of secondary minerals, such as glauconite. Lie-bling and Scherp (1975) reported a zone with abun-dant chlorite overlying the nonmarine Raritan Formation; Sirois and others (1986) found similar abundances of chlorite in the Tanner Park cores, as did Faust (1963) in upper Cretaceous samples from central Suffolk County.

Groot and Glass (1960), in a study of New Jer-sey coastal-plain sediments (Cretaceous and Ceno-zoic), observed two heavy-mineral suites—a full suite (listed above) consisting of a variety of igne-ous and metamorphic minerals in marine sediments, and a limited suite characterized by highly stable minerals (tourmaline, zircon, rutile, and staurolite) in nonmarine sediments. The limited suite in the nonmarine sediments did not contain garnet, epi-dote, chloritoid, or hornblende (Dryden and Dry-den, 1956). Dryden and Dryden (1946), in a comparison of heavy-mineral weathering rates in source rocks of Lower Cretaceous sediments in

Maryland, found zircon, tourmaline, and sillimanite to be much more resistant than kyanite, hornblende, staurolite, and garnet. Owens and others (1960) showed through X-ray analysis that "ilmenite" from the Miocene and Post-Miocene formations near Trenton, N.J., 80 miles southwest of the study area, is a mixture of ilmenite and ferric and titanium oxides.

Sirois and others (1986), examined several samples of cores extending to a depth of 1,176 ft in well S79407 (fig. 1), and Perlmutter and Todd (1965) examined several boreholes along the south-ern shore of Long Island.

Methods

Six Pleistocene (upper glacial) to upper Creta-ceous (basal Magothy) unit borehole cores at S29776 and N3355 (fig. 1) were analyzed. Core samples and depths from N3355 include N1 (75 to 76 ft), and those from S29776 include S1 (145 to 146 ft), S2 (206-207 ft), S3 (366-367 ft), S4 (466-467 ft), and S5 (726-727 ft).

A subsample of each core sample was disaggre-gated, and grain coatings were removed by sonic treatment in a 10-percent sodium bicarbonate solu-tion according to the method of Cremeens and oth-ers (1987). Each sample was separated by mechanical sieves into five grain-size fractions, including material greater than 2 mm (granules and pebbles), 0.5 mm to 2 mm (coarse and very coarse sand), 0.125 to 0.5 mm (medium sand), 0.00625 to 0.125 mm (very fine and fine sand), and less than 0.0625 mm (silt and clay). The silt and clay frac-tions were not analyzed in these cores, but results of a previous study of silt and clay mineralogy is dis-cussed further on. Heavy minerals (minerals with density > 2.75 g/cm^3) were separated from each fraction with heavy liquids. Mineralogy of heavy-mineral fractions was determined by elemental analysis with energy-dispersive spectroscopy on an electron microprobe analyzer.

GEOLOGIC FRAMEWORK

Long Island is overlain by a sequence of upper Cretaceous and Pleistocene sediments that were deposited on a southeastward dipping bedrock sur-

face (fig. 2). The deposits thicken toward the southeast and reach a maximum thickness of about 2,000 ft in southeastern Long Island.

Upper Cretaceous deposits include the Lloyd Sand Member (Lloyd aquifer) and the clay member of the Raritan Formation (Raritan confining unit), which are unconformably overlain by the Matawan Group and Magothy Formation (Magothy aquifer), undifferentiated. Along the southern shore of Long Island, the Matawan Group and Magothy Formation, undifferentiated, are unconformably overlain by the Monmouth Group (Monmouth greensand). Cretaceous sands on Long Island generally consist of chemically stable minerals or the highly altered equivalents of less stable minerals (Suter and others, 1949); in addition to angular quartz grains, they also contain tourmaline, rutile, zircon, kaolinite, kaolinized muscovite, weathered chert grains, and pyrite or marcasite associated with lignite. The Monmouth Group, a marine deposit, typically consists of greenish-black glauconitic and lignitic clay, silt, and clayey to silty sand (Jensen and Soren, 1971). Upper Cretaceous marine clays of Long Island are primarily illite and montmorillonite with variable amounts of chlorite, kaolinite, and mixed layer clays, and upper Cretaceous nonmarine clays are primarily kaolinite with variable amounts of illite (Lonnie, 1982). The upper surface of Cretaceous deposits ranges from over 300 ft above sea level in the northern part of the study area, in an area known as the high Cretaceous terrace (Suter and others, 1949), to 100 ft below sea level at the southern end of the study area.

In the southern part of the island, the Cretaceous deposits are unconformably overlain by the Gardiners Clay, an interglacial unit. North of this unit, they are unconformably overlain by deposits of Pleistocene age (upper glacial aquifer). The Gardiners Clay is a dark-gray or greenish-gray silty clay or fine sand that may contain woody material, diatoms, foraminifera, and shell fragments (pelecypods). The mineral assemblage of the Gardiners Clay commonly contains biotite, chlorite, glauconite, hornblende, muscovite, and quartz (Perlmutter and Todd, 1965), and a complete clay mineral suite of illite, chlorite, mixed-layer clays, and minor kaolinite (Lonnie, 1982). Pleistocene marine clays, including the Gardiners, are illitic with variable amounts of chlorite, kaolinite, montmorillonite, and mixed-layer clays (Lonnie, 1982).

Upper Pleistocene deposits (upper glacial aquifer) are characterized mainly by clean, coarse sand but also contain sandy clay, clay, and fine sand; they may also contain the same minerals as the Cretaceous sediments but have a greater variety and abundance of heavy minerals such as amphibole, pyroxene, fresh muscovite, biotite, and chlorite, as well as rock fragments and unweathered feldspar (Suter and others, 1949). Pleistocene deposits in central Suffolk County typically contain chlorite-mica schist rock fragments (Faust, 1963). In general, upper glacial (Pleistocene) sands are coarser grained and contain a smaller silt and clay fraction than Magothy (Cretaceous) sands. Aronson and others (1983) found that Magothy aquifer sands in central Nassau County have a higher degree of sorting and a considerably smaller mean diameter than upper glacial sands. The upper glacial aquifer contains interstadial clay units, including the "20-foot" clay, in the southern part of the study area (Doriski and Wilde-Katz, 1983), and the Smithtown clay, farther to the east. The "20-foot" clay has a mineral and fossil assemblage similar to that of the Gardiners Clay (Doriski and Wilde-Katz, 1983).

HEAVY MINERALS

Core samples from boreholes at Plainview were analyzed for heavy minerals. Data from previous studies to the south—at Tanner Park (Sirois and others, 1986) and near the Nassau-Suffolk County border (Perlmutter and Todd, 1965)—were compared with the Plainview data. Unless discussed specifically, site locations for data from Sirois and others (1986) and Perlmutter and Todd (1965) are collectively referred to as "south-shore" deposits. Data from other previous studies are included in the following discussion for comparison of spatial trends and of heavy-mineral distribution among specific geologic units.

Quartz is the most abundant mineral in upper glacial and Magothy sand and typically constitutes at least 90 percent of the fine- to coarse fraction; the heavy-mineral fraction generally constitutes less than 5 percent. Muscovite is more abundant in upper Cretaceous sand than it is in Pleistocene sand. The most commonly observed heavy minerals from

boreholes near the ground-water divide (S29776 and N3355, fig. 1) are shown in table 1A; the most abundant heavy minerals from boreholes along the southern shore (Sirois and others, 1986; Perlmutter and Todd, 1965) are listed in table 1B

Vertical Variations

The abundance of heavy minerals in sand fractions of core samples is somewhat dependent on the geologic unit and, therefore, the depth. The relative abundances of heavy minerals differ from unit to unit (table 1). These differences are probably a function of the extent of rock weathering (Faust, 1963) as well as the depositional environment. For example, Cretaceous sands have undergone more weathering and contain a smaller variety of heavy minerals than have Pleistocene sands. These relative differences in heavy-mineral weathering may be smaller in poorly permeable units than in sand because the lower rates of ground-water flow would retard weathering rates. The depositional environment also can be important; for example, the Gardiners Clay and Monmouth greensand were deposited in a marine environment and contain abundant glauconite, a mineral typically absent in nonmarine sediments.

Several heavy-mineral differences between Pleistocene and Cretaceous sands are evident at Plainview. Relatively unstable minerals, including iron oxides, garnet, and unstable rock fragments are common in the Pleistocene sands and less abundant or absent in Cretaceous sands, whereas muscovite, which is generally considered to be stable, is more abundant in Cretaceous sediments than in Pleistocene sediments. Chloritoid and staurolite were also observed in Cretaceous sands but not in Pleistocene sands.

Heavy-mineral prevalence at the southern shore also changes with depth. Pyrite or marcasite is generally present (and locally abundant) in Cretaceous sediments, commonly in association with lignite, but is absent in Pleistocene deposits. Muscovite and chlorite are more abundant in Cretaceous sediments than in Pleistocene sediments, and, at Tanner Park, tourmaline and staurolite are more abundant in Cretaceous sands than in Pleistocene sands. Biotite is rare or absent at all sites within the study area. The presence of glauconite in only the Monmouth.

Table 1. Most abundant heavy minerals in sand-size (0.0625-mm - 2-mm diameter) fractions in borehole cores from study area, Long Island, N.Y.

[South-shore data from Sirois and others (1986) and Perlmutter and Todd (1965). Locations shown in fig. 1]

Series	Hydrogeologic unit	Heavy minerals
A. Boreholes S29776 and N3355 near ground-water divide		
PLEISTOCENE	Upper glacial aquifer	Iron oxides, leucoxene, garnet (almandine), ilmenite, aluminosilicates, zircon
CRETACEOUS	Magothy aquifer	Muscovite, leucoxene, ilmenite, rutile, staurolite, chloritoid, aluminosilicates, chlorite, zircon
B. Boreholes along southern shore		
PLEISTOCENE	Upper glacial aquifer	Hornblende, ilmenite, zircon, garnet, staurolite, kyanite, iron oxides, tourmaline
PLEISTOCENE	Gardiners Clay	Glauconite, hornblende, ilmenite/leucoxene, zircon, garnet, staurolite
CRETACEOUS	Monmouth greensand	Ilmenite, leucoxene, muscovite, glauconite, zircon, pyrite, staurolite, garnet, tourmaline
CRETACEOUS	Magothy aquifer	Ilmenite/leucoxene, muscovite, hornblende, pyrite, garnet, tourmaline
CRETACEOUS	Raritan confining unit	Hornblende, staurolite, tourmaline, kyanite, muscovite, garnet, ilmenite/leucoxene
CRETACEOUS	Lloyd aquifer	Ilmenite/leucoxene, hornblende, staurolite, muscovite, tourmaline

greensand (Cretaceous) and the Gardiners Clay (Pleistocene) reflects the marine depositional environment of these units.

Lateral Variations

The lateral distribution of heavy minerals within lithologic units is not uniform throughout Long Island. For example, little or no hornblende was found in Magothy aquifer sediments in Plainview cores (S29667 and N3355) by this author, nor by Aronson and others (1983) in central Nassau County, nor by Faust (1963) in central Suffolk County, nor by Perlmutter and Todd (1965) at the southern shore, whereas significant percentages are reported throughout the Cretaceous sediments at Tanner Park by Sirois and others (1986).

The variation in heavy minerals between Plainview and the southern shore along the A-A' study section is significant. Pyrite or marcasite abundance in Cretaceous sediments appears to vary laterally—boreholes near the ground-water divide yielded much less pyrite than samples from boreholes near the southern shore, further along the ground-water flow path. Similarly, garnet and tourmaline are extremely sparse in Magothy sands at Plainview but are reported throughout south-shore deposits (Sirois and others, 1986; Perlmutter and Todd, 1965), whereas rutile is abundant throughout upper glacial and Magothy aquifer sands at Plainview but is rare or absent in southern-shore deposits. Aluminosilicates (used herein to refer to kyanite, sillimanite, and andalusite), are abundant throughout Plainview core samples but could not be distinguished from one another by the author using the Energy Dispersive Spectroscopy method of analysis. Kyanite and sillimanite are reported in high to moderate abundance at the southern shore, but andalusite is not. Glauconite is abundant in the Monmouth greensand and the Gardiners Clay (marine deposits beneath the southern shore) but does not extend to the northern part of the study section.

The most abundant heavy mineral at Plainview is typically leucoxene, an altered iron titanium oxide that is found throughout borehole S29776. The leucoxene at this borehole appears similar to the "ilmenite" of the Miocene and post Miocene formations in southern New Jersey, which is

reported as a mixture of ilmenite and ferric and titanium oxides (Markewitz and others, 1958). Abundant leucoxene and ilmenite are also found along the southern shore by Perlmutter and Todd (1965). Sirois and others (1986) do not distinguish between the opaque minerals, which include leucoxene and ilmenite. Zircon is found in moderate to high abundance throughout the study section.

Grain size

Heavy minerals near the ground-water divide are typically concentrated in the very-fine and fine-sand fractions of Cretaceous and Pleistocene sediments as a result of geological, mineralogical, and sedimentological factors (Rittenhouse, 1943). In central Suffolk County, Faust (1963) reports a greater abundance of heavy minerals in Pleistocene sediment fractions less than 0.125 mm (fine sand to silt and clay) than in the medium and coarse sand fractions.

The heavy-mineral content of silt and clay fractions at Tanner Park does not appear to differ significantly from that in sand fractions. The presence of Fe, Ti, and S peaks in X-ray fluorescence analyses, in addition to an analysis of sulfur percentages by Sirois and others (1986), suggests the presence of (1) iron oxides or hydroxides, (2) TiO_2 or $FeTiO_2$, such as rutile, ilmenite, or leucoxene, and (3) pyrite or marcasite, in both silt and clay fractions and in sand fractions.

Mineral Reactivity

Mineral reactivity is an important factor in the heavy-minerals contribution to ground-water chemistry. Iron-bearing minerals such as ferrihydrite (poorly ordered ferric oxyhydroxide), goethite, and hematite are fairly reactive, whereas ilmenite, garnet, augite, and amphibole are relatively unreactive (Canfield and others, 1992). Amorphous ferric oxyhydroxide or poorly ordered ferric oxyhydroxide (ferrihydrite) are considered to be reactive or microbially reducible (Chukhrov and others, 1973; Lovley and Phillips, 1986a), whereas other iron forms, including Fe_2O_3 (hematite) and Fe_3O_4, are not readily reducible (Lovley and Phillips, 1986b). Relative mineral reactivity of heavy mineral grains

can be estimated from etch pits and other dissolution features that are observable through scanning electron microscopy. Further work is needed to determine the reactivity of iron-bearing mineral phases, including mineral grains and ferric oxyhydroxide grain coatings, in Long Island sediments, and how this reactivity affects the chemical evolution of ground water along its flow paths.

CONCLUSIONS

Heavy minerals in sediment-core samples collected at borehole sites along a ground-water flow path from the ground-water divide to the southern shore along the Nassau-Suffolk County border were studied to estimate their relative abundance and distribution. Differences in mineralogy and abundance were observed between Pleistocene and Cretaceous units, and some of the apparent trends differed with depth and from north to south. Upper Pleistocene sediments along the section contain more unstable rock fragments and minerals, such as garnet and iron oxides than the Cretaceous deposits, which contain abundant muscovite, staurolite, pyrite or marcasite, and chloritoid. Heavy minerals are typically concentrated in the very-fine and fine-sand fractions of Pleistocene and Cretaceous sediments.

The lateral distribution of heavy minerals within lithologic units is not uniform throughout Long Island or even along the study section. Borehole samples from Plainview, near the ground-water divide, contain much less pyrite or marcasite than do samples from boreholes near the southern shore, farther along the ground-water flow path. Garnet and tourmaline are sparse in Magothy sands at Plainview but are abundant throughout southern-shore deposits, whereas rutile is abundant throughout upper glacial and Magothy aquifer sands at Plainview but is rare or absent in southern shore deposits. Glauconite is abundant in the Monmouth greensand and the Gardiners Clay, which are marine deposits beneath the southern shore but is not present in the northern part of the study section.

Leucoxene, iron oxides, and pyrite or marcasite were found to be the most abundant and potentially reactive of the iron-bearing minerals, with the exception of ferric oxyhydroxide grain coatings. Leucoxene was observed in relatively large abundance, and was continuous with depth. Iron coat-

ings on sediment grains, which typically consist of poorly crystalline ferric oxyhydroxides, are not specifically addressed in this report. Iron coatings are an important source and sink of iron in the aquifer system, however.

Acknowledgments

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