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GEOLOGICAL SURVEY

A HEAVY MINERAL STUDY OF PLEISTOCENE AND HOLOCENE SEDIMENTS NEAR NOME, ALASKA

By

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This report is preliminary
and has not been edited or
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ABSTRACT

A heavy mineral study was carried out for sand-size fractions of onshore Holocene sediments (modern beach and river sediments), nearshore Holocene and Pleistocene relict sediments, and Pleistocene and Pliocene sediments from several nearshore drill-holes. Heavy mineral assemblages of these sediments are dominated by garnet, chlorite, epidote, chloritoid, sphene, and staurolite.

The nearshore region of Nome is mainly underlain by various types of Pleistocene sediments such as relict gravel that mantles glacial drift, relict gravel over Nome River outwash fan, relict gravelly sand of submerged beaches, and relict gravel that mantles bedrock. In places these relict sediments are covered by Holocene sandy and muddy sediments. The high concentration of heavy minerals is expected for various relict sediments, because the latter were winnowed by several transgressions and regressions of the sea during Pleistocene time. Concentration of heavy minerals, however, is greater for Holocene sand than relict gravel, which mantles glacial drift and relict gravelly sand of submerged beaches. The high concentration of heavy minerals in Holocene sand suggests the winnowing of sand by strong bottom currents. The low concentration of heavy minerals in the relict gravel on glacial drift and relict gravelly sand of submerged beaches is probably due to the heterogenous nature

of relict sediments. Sand fractions of the relict sediments probably have been introduced during the Holocene time. Also, contamination of samples of relict gravel from underlying glacial drift is suspected.

A greater concentration of coarse gold particles (1 mm. or larger) is found in nearshore relict gravel that mantles glacial drift than in any other sediment type. Relict gravel on glacial drift, which carries high gold values, does not show a high concentration of heavy minerals or a high concentration of garnet. Two factors account for the lack of correlation between concentration of gold and the other heavy minerals: (1) contrast between hydraulic properties of the gold particles and other heavy minerals, and (2) the heterogeneous nature of relict sediments. Because of their extremely high specific gravity, coarse gold particles are not moved by longshore currents or bottom currents from relict gravel which mantles glacial drift, whereas the heavy minerals which are mostly medium to fine sand in size, are transported by longshore currents and strong bottom currents. The Holocene sand winnowed by strong bottom currents shows a high concentration of heavy minerals.

Heavy mineral assemblages are more or less similar for the various sediments. Minor compositional variations mainly reflect the effect of sorting of mineral grains according to size and specific gravity. The frequencies of

garnet and staurolite are slightly higher than average for modern beach and river sediments. In nearshore sediments, garnet is most abundant in Holocene sand winnowed by strong bottom currents. Holocene silty sediment which occurs in small patches is characterized by high concentration of micaceous minerals and low concentration of garnet, because the weak currents which deposit fine sediments usually carry light micaceous minerals in great abundance and minerals of high specific gravity like garnet in small amounts. Samples of Pleistocene glacial till and Pliocene marine silt from several nearshore drill-hole locations show high concentrations of micaceous minerals and low concentration of garnet.

Holocene, Pleistocene, and Pliocene sediments of Nome are mostly derived from the same general metamorphic source rocks of the inland region. The majority of the minerals found in heavy mineral assemblages, such as garnet, chlorite, epidote, chloritoid, sphene, staurolite, hornblende, and tremolite-actinolite, are reported to occur in the metamorphic rocks of Nome and the adjacent region.

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INTRODUCTION

PURPOSE

The Nome region of Alaska became well known after the discovery of placer gold deposits in the latter part of the nineteenth century. Recently, during the summers of 1967 and 1968, as part of the U.S. Geological Survey's Heavy Metal Program, 141 bottom samples were collected in the nearshore region of Nome and 51 bore holes were drilled in this region. This program also included detailed sampling of Nome beaches and the collection of samples of river beds of this region. The investigation near Nome is a part of the U.S. Geological Survey's exploration program carried out in the Chirikov Basin (that part of the Bering Sea bounded by the Seward Peninsula, the Yukon Delta, St. Lawrence Island, and the coast of the Chukotka Peninsula, Siberia (Fig. 1)) to study the distribution of gold and general geology of the region.

The purpose of this investigation was two-fold: (1) to study nonopaque heavy minerals (Sp. gr. 2.85) in sand-size fractions and to interpret mineralogical variations in terms of source areas, depositional environment, transportation agents and age of sediments, and (2) to

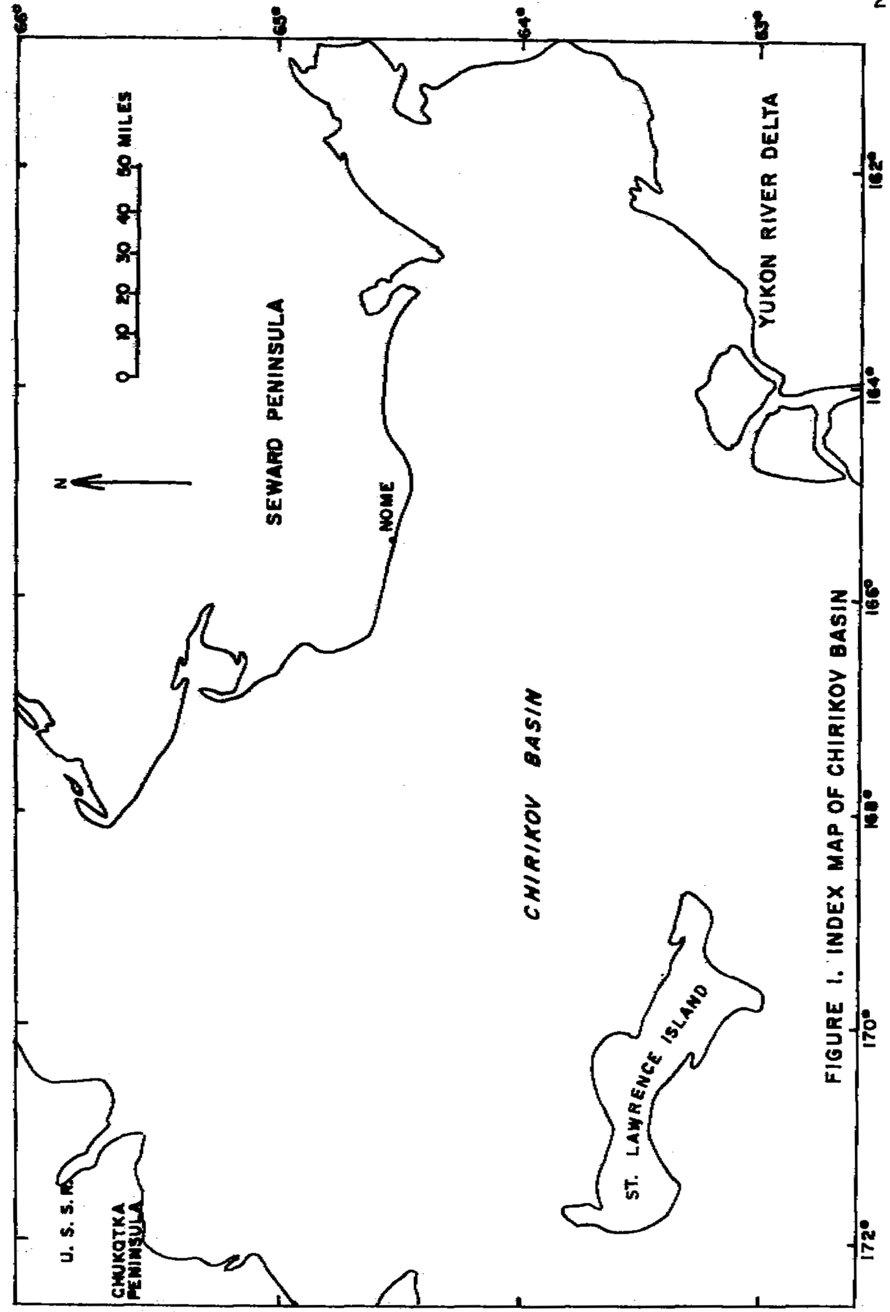


FIGURE 1. INDEX MAP OF CHIRIKOV BASIN

relate the distribution of gold to heavy minerals.

LOCATION

The area of investigation is located in the northeastern part of the Chirikov Basin, off the coast of Nome, Seward Peninsula, Alaska (Fig. 1). The samples selected for the heavy mineral analysis came from a 216 square mile area, which lies between Cripple River and Cape Nome and extends about eight miles in offshore direction (Fig. 2).

PREVIOUS WORK

Placer gold deposits of the Seward Peninsula were first reported in 1865 by members of a party sent by the Western Union Telegraph Company during the construction of telegraph lines to connect the United States with eastern Asia. The Nome gold rush took place between 1898 and 1900. During the height of the excitement, it is estimated that about 2000 men were engaged in gold mining along the beach near Nome. Although only the most primitive means were employed, over a million dollars worth of gold was obtained in a period of about two months, and the richest deposits of the present beach were practically exhausted. Between 1904-1906, mining operations for placer gold deposits extended to onshore buried beaches and over all parts of the Nome region (Collier and others, 1908, pp. 19-39).

The interest in placer gold deposits of the Nome

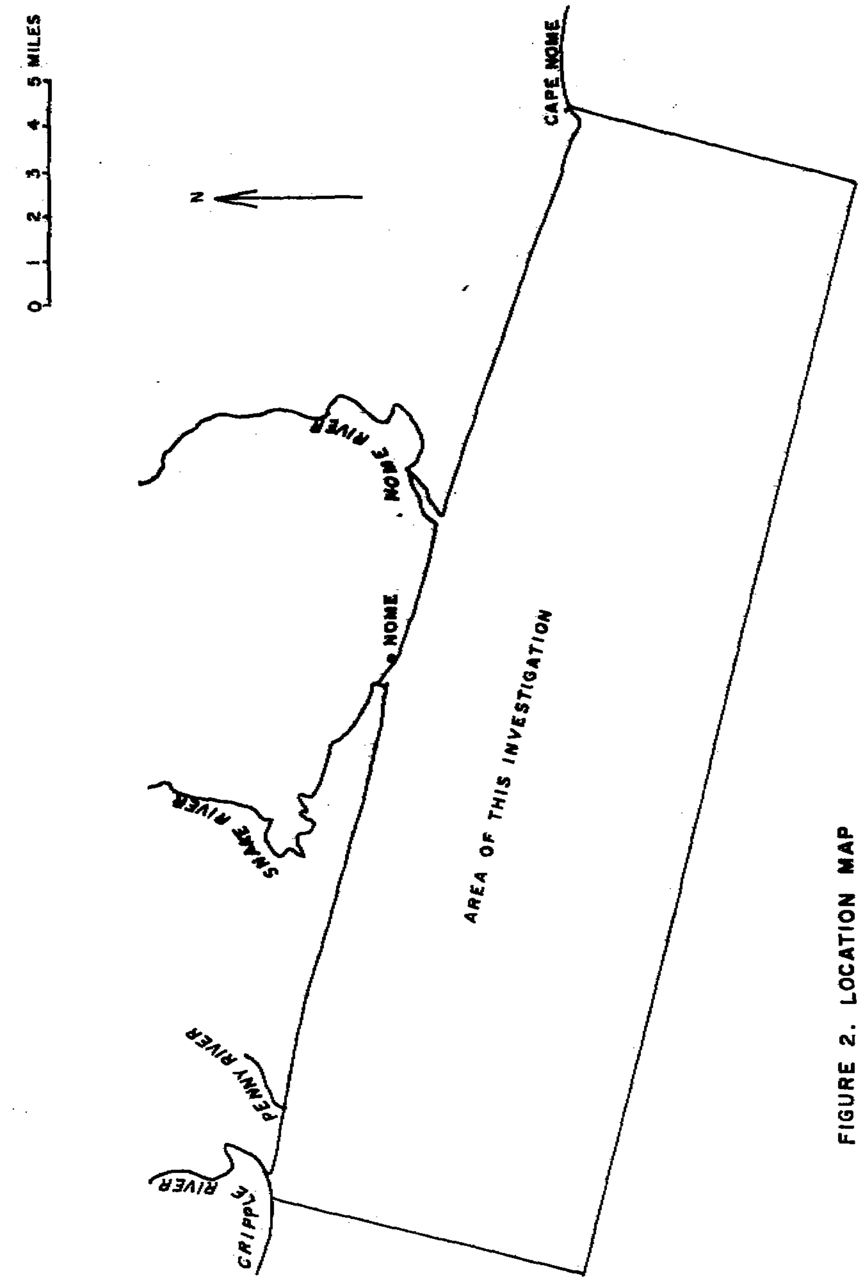


FIGURE 2. LOCATION MAP

region led to systematic geological investigations of the area by the U.S. Geological Survey (Brooks and others, 1901; Collier and others, 1908; Moffit, 1913). The report by Brooks and others (1901) included the first description of Nome beach sediments and buried beach sediments of the near-by coastal plain. Recently an important contribution about the distribution of nearshore bottom sediments of Nome came from Nelson and Hopkins (1969) of the U.S. Geological Survey. Their report primarily deals with the distribution of gold in the northern Bering Sea. Also, the investigation by Greene (1970) has helped in understanding sedimentary processes of the Nome beaches.

The heavy minerals in sediments of the northern Bering Sea were studied by K. Venkatarathnam (1969) of the University of Washington, Seattle. In his paper, he described the heavy minerals in the sediments farther offshore from the area presently under investigation. However, no detailed study of heavy minerals has been done in the near-shore or onshore sediments of Nome prior to this thesis.

GEOLOGICAL SETTING

General Geology

Most of the southern Seward Peninsula is underlain by metamorphosed sedimentary rocks (Fig. 3). In the Kigluik Mountains, which are situated about 30 miles north of Nome,

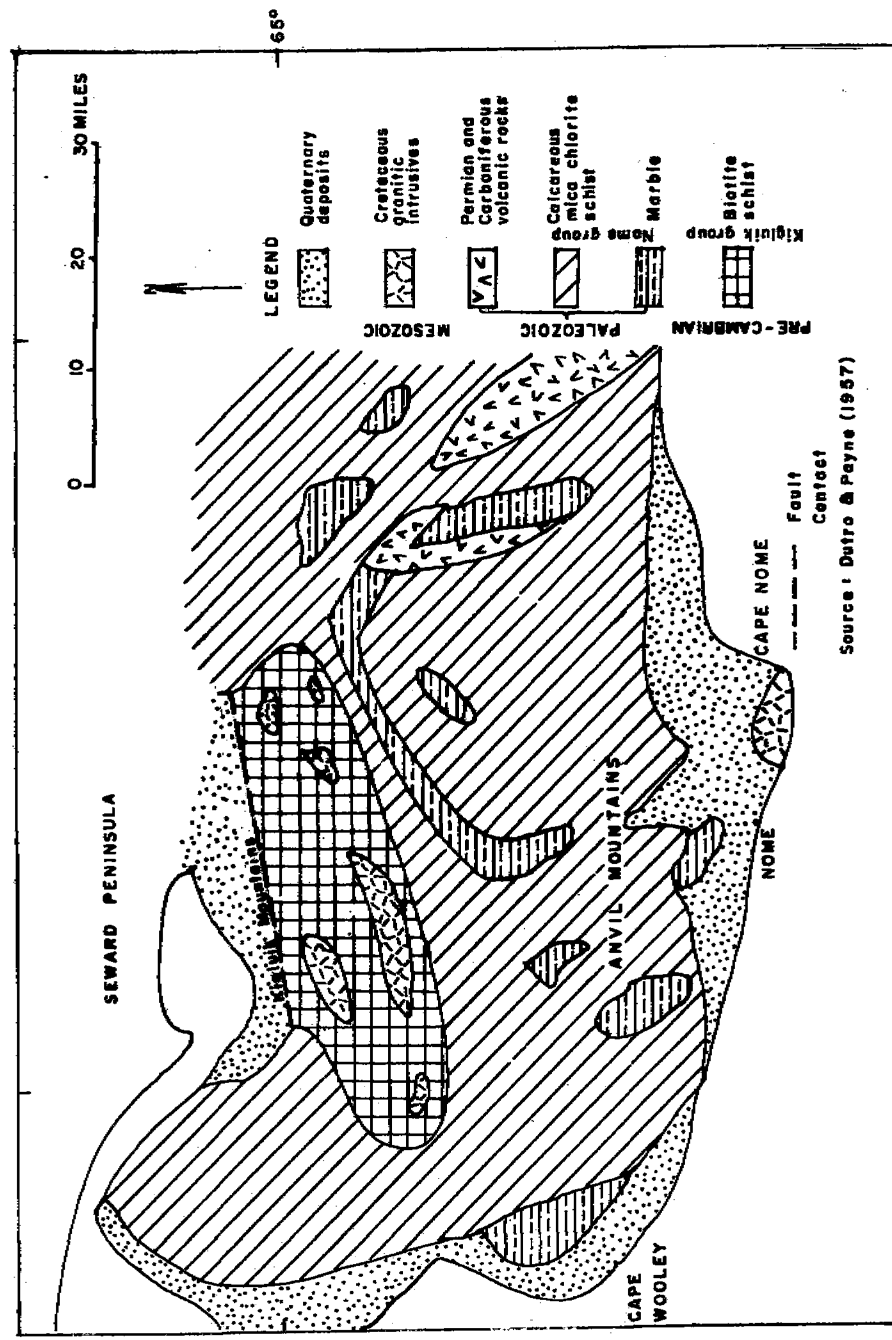


FIGURE 3. GENERALIZED GEOLOGIC MAP OF THE SOUTHERN SEWARD PENINSULA, ALASKA

164°
166°

rock types such as biotite gneiss, biotite schist, and coarsely crystalline marble crop out (Moffit, 1913, p. 33). These rocks are known as Kigluik group. The rocks of the Kigluik group are intruded by dikes and sills of granite, diorite, and diabase. Overlying the Kigluik group is a series of rocks that consist chiefly of chloritic and feldspathic schist and altered limestones. These rocks are known as Nome group and are exposed in the Anvil Mountains, a few miles north of Nome. Similar chloritic schists form the basement beneath Tertiary and Quaternary sediments on the coastal plain and the nearshore sediments. The rocks of the Nome group are intruded by granite, granodiorite, and greenstone. The largest area of granite is present at Cape Nome (Moffit, 1913, p. 33).

The rocks of the Kigluik group are mostly of early Paleozoic age, but may include some rocks of the pre-Cambrian age (Dutro and Payne, 1957). The rocks of the Nome group are of early Paleozoic age. Intrusive rocks of both groups are probably of late Paleozoic (Permo-Carboniferous) and Mesozoic age (Dutro and Payne, 1957).

Coastal Plain Stratigraphy

The bedrock beneath the Nome coastal plain is mantled by Pliocene and Pleistocene beach sediments interstratified with glacial deposits (Hopkins, in press). These marine and glacial sediments are covered by modern beach sediments, alluvium, colluvium, wind blown silt and peat of Holocene

age. Four major marine units representing different sea level stands during late Pliocene and Pleistocene time have been recognized. They are locally known as Pliocene beach, Submarine beach, Third beach, and Second beach (Hopkins, in press). The Submarine beach and Third beach are separated by glacial drift of the Iron Creek glaciation, and the Third beach and Second beach are separated by the Nome River glacial drift (Illinoian). A geologic cross-section across the coastal plain area at Nome is shown in Figure 4.

Beach Sediments

The Nome beach sediments vary from coarse gravel to fine and medium sand. Fine sand predominates near water, but in the higher part of the beaches, gravel is more abundant. The pebbles of the gravels do not exceed 1 or 2 inches in their greatest dimension. The gravels on the beach surface are mostly rounded quartz with a considerable amount of schist and a little granite. In places the surface material is almost entirely composed of red garnet or "ruby sand" (Moffit, 1913, p. 110).

According to Greene (1970), the beach sediments are poorly sorted with no direction of increasing or decreasing median diameter, sorting coefficient, or sand-gravel ratio. The sorting coefficient (Trask's sorting coefficient) varies from 1.20 to 5.10, and median diameter varies from 0.52 mm to 13 mm. Generally, the sand found in the swash zones shows the best sorting. The foreshore and backshore

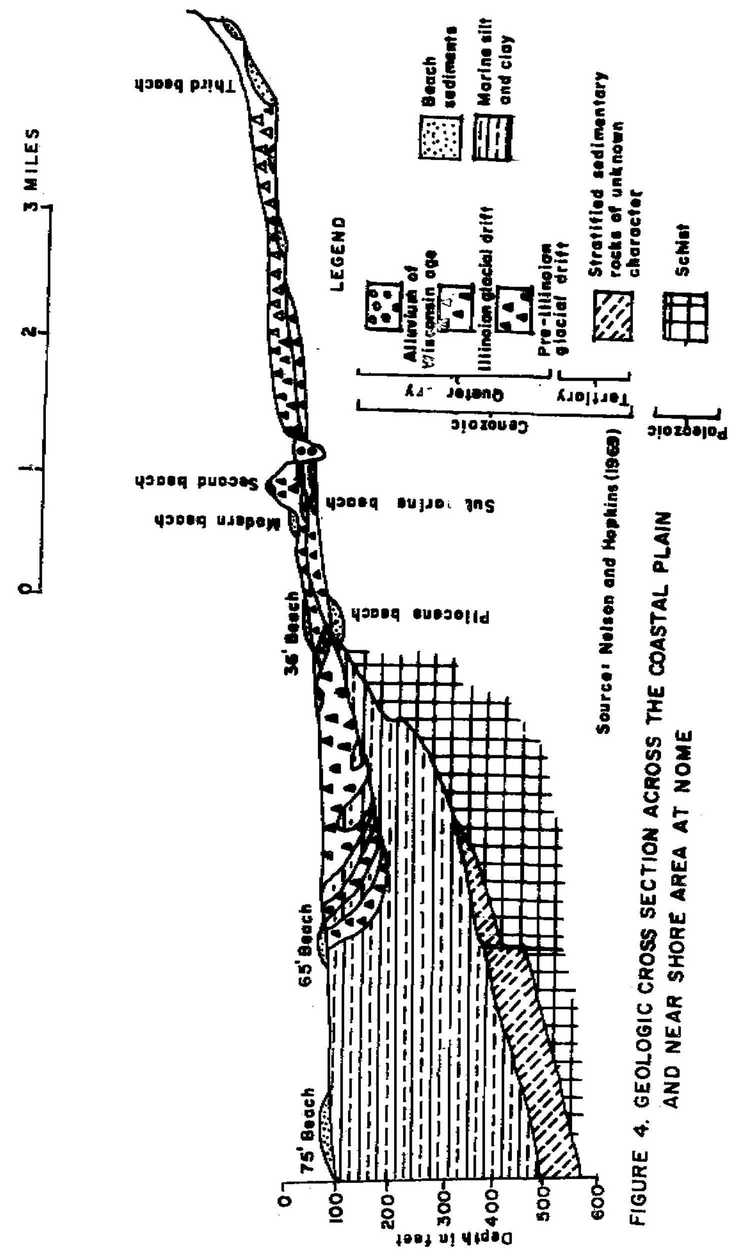


FIGURE 4. GEOLOGIC CROSS SECTION ACROSS THE COASTAL PLAIN AND NEAR SHORE AREA AT NOME

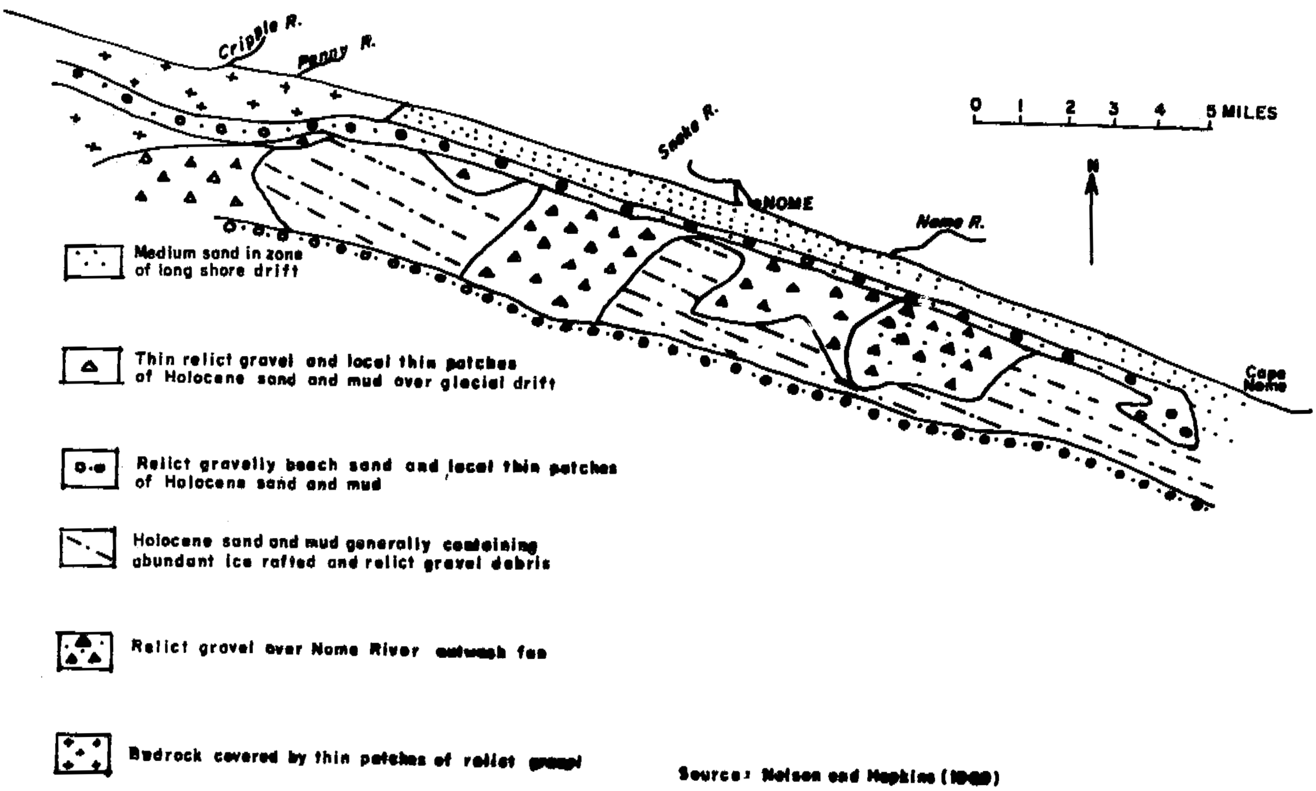
sediments are gravelly and poorly sorted.

Moving ice covers the sea and beaches for about seven months every year. Thus, beaches are isolated from surface waves, longshore drift, and tidal currents during this period. Further, sea ice in contact with the ocean bottom picks up gravel and sand and pushes them ashore (Greene, 1970). In Greene's opinion, the isolation of the beaches for about seven months from wave energy, and the disturbance of sediments by movement of the sea ice is responsible for the poor sorting of the beach sediments.

Nearshore Bottom Sediments

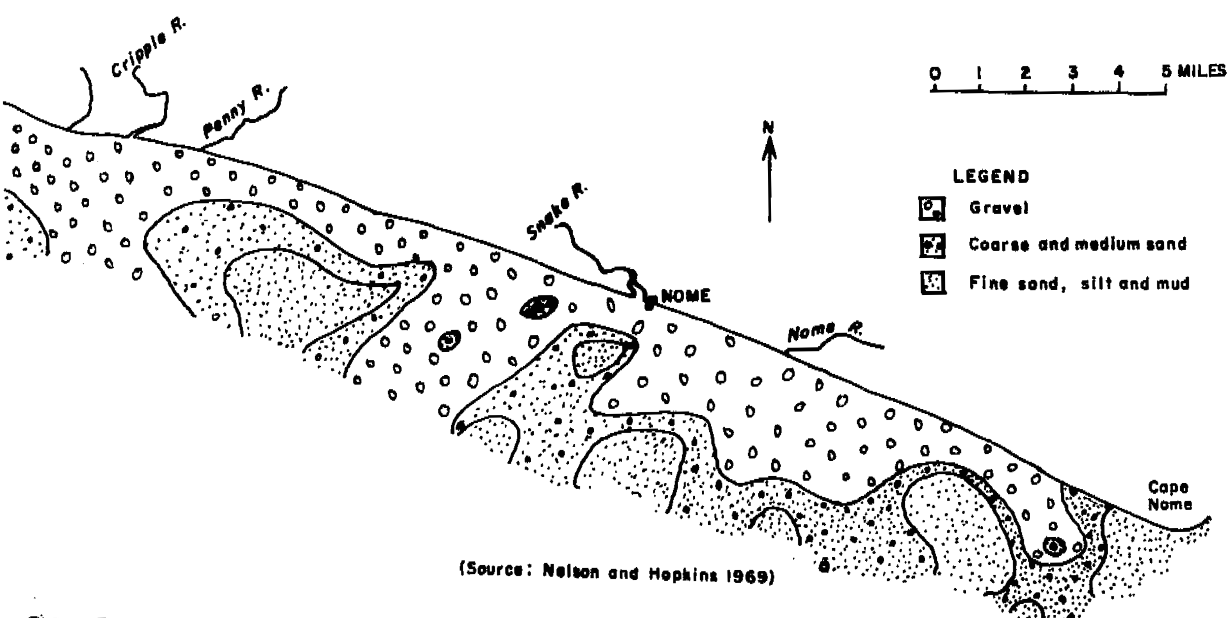
Most of the nearshore region of Nome is underlain by Pleistocene relict sediments (Fig. 5). The relict sediments consist of a variety of materials such as ancient beach, deltaic and onshore glacial sediments which are now submerged as a result of the eustatic rise of sea level during the past 19,000 years (Emery, 1968, p. 445). The relict sediments of the Nome region are mainly gravels which are found in an irregular belt parallel to the shore. The gravel pattern is interrupted by tongues of Holocene sand, silt, and mud. Silty and muddy sediments occur in topographic depressions. The map of the mean size of surface sediments shows the irregular distribution of sandy, silty, and muddy sediments of the Holocene age (Fig. 6).

Two submerged beaches, called inner and outer, have been recognized at depths of -35 to -42 feet and -65 to -72



Source: Nelson and Hopkins (1969)

FIGURE 5. SEDIMENT TYPES IN THE NOME NEAR SHORE REGION



(Source: Nelson and Hopkins 1969)

FIGURE 6. MEAN SIZE OF NEAR SHORE BOTTOM SEDIMENTS

feet. The submerged beaches occur in more or less regular belts parallel to the shore. The age of these submerged beaches is uncertain, but according to Nelson and Hopkins (1969, p. 10), the outer beach may have formed during the rise of the sea level about 40,000 to 30,000 years ago, and the inner beach may have formed during the Holocene rise in sea level between 15,000 and 5000 years ago.

The following is a summary of general geology and sediment types of the nearshore region of Nome from the report of Nelson and Hopkins (1969):

(1) Pleistocene relict sediments, which are further classified in four categories:

(a) Relict gravel derived from underlying glacial drift. Glacial marks and other features are often present in gravels of glacial origin. Pebbles are angular and made up of a variety of rock types.

(b) Relict gravel resting on the Nome River outwash fan.

(c) Relict gravelly sand of submerged beaches formed where the sea level was stationary for a considerable period. Submerged beach gravels are generally well rounded and pebbles of quartzite predominate.

(d) Relict gravel derived from underlying bedrock, where bedrock is exposed at a very shallow depth.

(2) Well-sorted and medium-sized transgressive sand of Holocene age containing 10% or less silt and mud found in the present day zone of longshore current movement.

(3) A mixed type of Holocene mud and relict gravel which occurs near the boundaries of the relict gravel areas and where small local depressions in the relict gravel region are covered by a thin mantle of Holocene mud.

(4) Holocene silty and muddy sediments which occur further offshore.

Chapter 2

TECHNIQUES OF INVESTIGATION

SELECTION OF SAMPLES

Fifty-four samples representing all types of sediment in the nearshore region of Nome were analyzed for the heavy mineral study. In order to evaluate the source region of onshore Holocene sediments, nine beach samples and two samples of sand from the Nome River bed were analyzed. Also, nine samples from five drill-holes which penetrated Pleistocene glacial till and Pliocene marine sediments at nearshore locations were studied. Thus a total of 74 samples were examined for this investigation (Fig. 7).

HEAVY MINERAL SEPARATIONS

All samples were analyzed following standard laboratory procedures. Heavy mineral separations were performed by centrifuging sand-sized fraction (1-4 phi interval) in bromoform (Sp. Gr. 2.85 at 25° C.) as suggested by Hutton (1960, p. 642). Nine nearshore samples and one sample of "ruby sand" from the modern beach were sieved into three size fractions, 1-2, 2-3, and 3-4 phi intervals and heavy minerals were separated from each fraction in order to study mineral variations in different size fractions. The weight

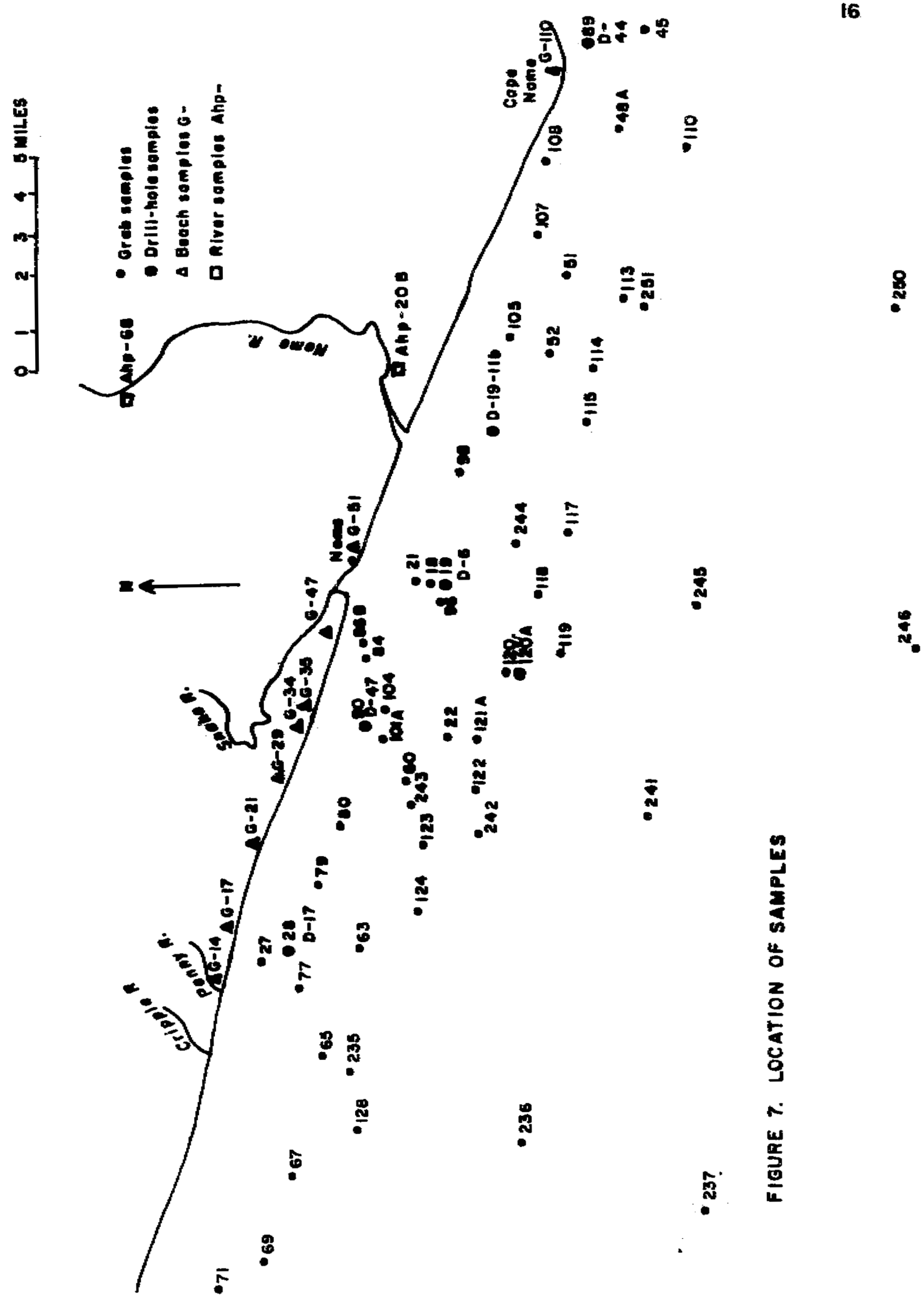


FIGURE 7. LOCATION OF SAMPLES

percentages of heavy minerals are reported in Appendix 1. The ferromagnetic fractions were removed by a hand magnet from the heavy mineral residues of those samples which were sieved into three size fractions. The weight percentages of ferromagnetic minerals in the heavy mineral residues are reported in Appendix 2.

The Electromagnetic fractionation of the heavy mineral concentrates of two samples was performed with a Franz separator, as outlined by Hutton (1959, p. 12). A slope of 15^{o}, and tilt of 10^{o} and a particle size of 3-4 phi was used for these samples.

MINERAL IDENTIFICATION

The identification of mineral grains was performed by studying their optical properties under the petrographic microscope. The oil-immersion technique was used, especially when there were difficult problems of identification. The mineral grains were mounted on gelatin coated slides for the purpose of refractive index determination. Immersion oils were calibrated to ± 0.003.

MOUNTING

After studying the heavy mineral fractions of ten samples which had been separated into three size fractions, it was found that heavy minerals were concentrated in the 2-4 phi grain size fraction. Therefore, heavy mineral

fractions were sieved into two size fractions, 1-2 phi and 2-4 phi. The 2-4 phi size fractions were mounted on microscope slides using hyrax (R. I. 1.71); the 1-2 phi grain size fractions, which contained simple mineral assemblages, such as garnet and micaceous minerals, were mounted with lakeside (R. I. 1.536). The four samples studied for light mineral constituents also were mounted in lakeside.

COUNTING PROCEDURES

Grain counting was carried out by using a mechanical stage mounted on a petrographic microscope. First, all heavy minerals, opaque as well as nonopaque, were counted together. The total counts of each sample included 300-400 nonopaque and nonmicaceous mineral grains. The mineral frequencies were reduced as percents excluding opaque and micaceous minerals. Three micaceous minerals, chlorite, muscovite, and biolite, were counted together, and their frequencies in the nonopaque minerals of heavy residues were also reduced as percents.

Chapter 3

HEAVY MINERALS

AMPHIBOLE GROUP

Hornblende

The frequency of hornblende varies from 1 to 10% of the heavy mineral fractions of the Nome sediments. Hornblende occurs as elongate cleavage fragments with moderately rounded edges. The greenish to bluish green variety is very common; the brown variety is comparatively less common. The following optical properties were determined:

(1) A refractive index of 1.665 was obtained for the γ direction, which is also the direction of elongation. The determination of refractive index was made for three grains of the greenish blue variety.

(2) Pleochroic scheme:

	Green hornblende	Brown hornblende
α	light green	light yellow
β	olive green	yellowish brown
γ	deep bluish green	brownish yellow

(3) Biaxial (-), with rather large 2V of 65^{o}-75^{o} (estimated), $Z \wedge C = 15^{o}$-25^{o}

Glaucophane

Glaucophane is less common than hornblende. Its

frequency varies from 0-4%. Glaucophane mainly occurs as cleavage fragments with moderately rounded edges. The following optical properties were found:

(1) Refractive indices: $\alpha = 1.635$
$\beta = 1.640$

The refractive indices were measured on one grain of glaucophane.

(2) Pleochroic scheme: α = colorless
β = lavender
γ = deep blue

(3) Biaxial (-), 2V = 50^{o}-60^{o} (estimated),
$Z \wedge C = 16^{o}$,
dispersion: D_x - $r < v$, moderate.

Tremolite-actinolite

These two minerals were counted together. Their combined frequency varies from 0 to 4%. Tremolite and actinolite occur as cleavage controlled fragments with moderately rounded edges. There are all gradations from the colorless, nonpleochroic (tremolite) to the pale green pleochroic variety (actinolite).

APATITE

Although apatite was found in a number of samples, its frequency rarely exceeded 3% in any sample. It occurs as rounded, well-worn, egg-shaped grains. Stumpy, prismatic crystals, rounded at the edges are also found. The grains are mostly colorless but dusty in appearance.

CHLORITOID

The frequency of chloritoid varies from 1 to 8%. It mainly occurs as tabular grains parallel to 001. Such sections generally give a Bxa figure. Elongate cleavage fragments are less common, and these crystals show marked pleochroism. Many grains contain numerous inclusions of quartz and opaque materials. The following optical properties were determined:

(1) Refractive indices: α = 1.710

β = 1.716

The determination was made on one grain lying on the 001 cleavage plane.

(2) Pleochroic scheme: α = greenish gray

β = bluish gray

γ = colorless

(3) Biaxal (+), $2V = 60^{\circ} - 70^{\circ}$ (estimated),

dispersion: D_z-r > v, strong.

Included with the chloritoid are rare grains which are tentatively considered to be a variety of chloritoid. The optical properties of this mineral differ from normal chloritoid as follows:

	Normal Chloritoid	Variety of Chloritoid
(1) Shape	Tabular grains lying on 001 cleavage plane	Usually occurs as elongate crystals
(2) Pleochroism: α	= greenish gray	yellow
β	= bluish gray	greenish yellow
(3) Interference figure	Bxa (+), $2V = 60^{\circ} - 70^{\circ}$ dispersion: D_z-r > v, strong	Bxa, $2V = 70^{\circ} - 80^{\circ}$ marked by a strong crossed dispersion. Optical sign could not be determined because of a crossed dispersion.
(4) Birefringence	low-order	low-order

Like normal chloritoid, the variety of chloritoid also separates at Fr. 2. by the Franz separator (Appendix 3).

EPIDOTE GROUP

Epidote

After garnet, epidote is the second most abundant mineral in the heavy mineral suite of this region. Its frequency varies from 3 to 39%. Epidote commonly occurs as elongate, rectangular shaped grains with edges showing varying degrees of roundness. Highly rounded grains are also found, but rectangular cleavage-controlled grains are more abundant. The grains are characterized by predominant cleavage in the direction of elongation, with somewhat discontinuous fractures (?) at right angle to the cleavage. Epidote usually has a greenish yellow color and shows weak pleochroism, but colorless, nonpleochroic grains are also found.

The rectangular shaped grains commonly give an optic-axis figure and less commonly a centered Bxa (-) figure with a large axial angle (2V = 80^o-85^o estimated). Dispersion is somewhat strong, D_x-r > v. The direction of dispersion is often anomalous showing D_x-r < v. The refractive index of 1.738 was obtained for β direction on three grains.

Clinozoisite

Clinozoisite is a rare mineral in the heavy mineral suite of this region. It was detected in 11 samples and its frequency never exceeds 1% in any sample. Clinozoisite is characterized by its anomalous ultrablue interference color. It is biaxial positive and has strong dispersion, D_z-r < v.

GARNET

Garnet is the most abundant heavy mineral in the Nome sediments. It has been recognized in almost every size fraction and in every sample. Its frequency varies from 15 to 90%. Different varieties of garnet were not distinguished, but from refractive index determination on a number of grains (R.I. 1.78 - 1.81), and from Franz separation data, spessartite-almandine seems to be the most abundant garnet in all samples studied.

Garnet ranges in color from colorless to pale pink, pink, and salmon brown, but the pink variety is the most abundant. Garnet is found in three forms: (1) euhedral grains slightly rounded at edges, (2) well rounded grains, and (3) irregular shaped grains with edges showing varying degrees of roundness from sharply angular corners to well

rounded ones. The euhedral grains are rare, but irregular shaped grains are very common. Inclusions, mainly colorless, needle-shaped or prismatic, are abundant (refractive indices of inclusions are usually lower than that of the host mineral, but inclusions of higher refractive indices than the host mineral were also noticed). Garnet grains are more or less clear, although grains stained with iron-oxide are present in all samples.

GOLD

Although fine gold (less than 0.25 mm) is widely dispersed in sediments of the Nome region (Nelson and Hopkins, 1969, p. 41), it was detected only in the fine-size fraction of one sample of "ruby sand" of the Nome beach. Gold from this sample occurs as thin irregular shaped flakes that show a characteristic golden-yellow color in reflected light. It separates at the anti-magnetic fraction of Franz separator (Fraction: 6 rejected at 1.2 Amp.).

KYANITE

Kyanite is a very rare mineral in the heavy mineral assemblage of this region. It was identified in eight samples, but its frequency never exceeded 1%. Kyanite is characterized by cleavage-controlled rectangular shaped crystals with moderately rounded edges. Many grains show an extinction angle of 30^o between Z and the 001 plane. Such sections also give a centered Bxa (-) figure with a large axial angle.

MICACEOUS MINERALS

Chlorite

Chlorite is the dominant micaceous mineral in the Nome sediments. It was found in almost every size fraction and in every sample. Chlorite occurs as flat, rounded cleavage flakes. It is characterized by a pale grass-green color with faint pleochroism and abundant opaque inclusions. Oxidized grains with yellowish brown color are very common.

Muscovite

After chlorite, muscovite is the next most abundant micaceous mineral. It is characterized by large basal plates that give a centered Bxa (-) figure with an optic axial angle of 45^{o}-50^{o}. Inclusions of opaque minerals, quartz, and minute needle shaped crystals are common.

Biotite

Biotite is less common than chlorite and muscovite. It occurs as irregular cleavage fragments and is characterized by a red-brown color. Cleavage fragments give a centered Bxa (-) figure with a very small axial angle. Inclusions of prismatic-shaped minute crystals, probably of zircon, were noticed in few grains. Grains of biotite are often opaque because of alteration to iron oxides.

OPAQUE MINERALS

The identification of opaque minerals was difficult because it requires an optical system adapted to reflected light techniques. Magnetite and ilmenite are the dominant opaque minerals. A minor amount of hematite, which is characterized by deep blood-red color in reflected light was noticed. The maximum weight percentage of ferromagnetic minerals was observed in "ruby sand" of the Nome beach (25%). The distribution of ferromagnetic minerals in different size grades is described in Chapter 4.

PYROXENE GROUP

Clinopyroxene is of minor importance in the heavy mineral assemblage of this region. It never constitutes more than 2% of the heavy minerals and occurs as cleavage fragments with moderately rounded edges. It is characterized by a large extinction angle ($2V = 38^{o}$-40^{o}). Orthopyroxene was not identified in any of the samples.

SILLIMANITE

Sillimanite was found in a number of samples but its frequency rarely exceeded 3% of the heavy minerals. It mainly occurs as minute fibers, needles, and felted masses. Elongated prismatic grains are comparatively rare. Sillimanite is marked by parallel extinction and positive elongation.

SPHENE

Sphene is a rather persistent mineral. Its frequency varies from 1 to 7%. Sphene commonly occurs as irregular shaped grains with edges showing varying degrees of roundness. Grains of sphene are generally colorless, but slightly pleochroic grains in shades of light yellow to brown were also found. Sphene is characterized by its high order of birefringence and extreme dispersion. Many grains give a centered Bxa figure and the following optical properties were observed: biaxial (+), $2V = 30^{\circ}$ (estimated); dispersion: D_z - $r > v$ extreme.

STAUROLITE

Like sphene, staurolite is also a persistent mineral. Its frequency varies from 0 to 7%. Staurolite commonly occurs as irregular shaped grains with ragged edges, but euhedral grains are rare. Inclusions, mostly of quartz, are abundant, and impart a porous or "sieve" structure appearance to grains. The following optical properties were determined:

(1) Refractive indices: $\alpha = 1.730$
$\gamma = 1.746$
$\gamma - \alpha = 0.016$

The determination was made on one grain of staurolite.

(2) Pleochroic scheme: α = pale yellow
β = pale yellow
γ = orange yellow

(3) Biaxial (+), $2V = 80^{\circ}$-85° (estimated);
dispersion: D_z - $r > v$, moderate.

TOURMALINE

The frequency of tourmaline ranges from 0 to 5%. It usually occurs as small prismatic crystals with slightly rounded edges. Inclusions of opaque materials are very common. The observed dichroic scheme for tourmaline is as follows:

	E	O	
(1)	Brownish and purple	black	very common
(2)	Colorless	brown	very common
(3)	Colorless	green	less common

ZIRCON

The maximum frequency (20%) was observed in fine-size fractions (3-4 phi) of the "ruby sand" of the Nome Beach. In the remaining samples, zircon never constitutes more than 2%. Three varieties of zircon were found: colorless, slightly yellowish, and a purple-colored variety known as hyacinth, but the colorless variety is by far the most common. All three varieties show gradation from slightly rounded crystals to well-rounded oval-shaped grains. Also, irregularly broken prismatic cyrstals were found. All varieties show normal birefringence.

The ratio of length and breadth for perfect euhedral crystals ranges from 1.75 to 3.0, with the majority of grains lying between 2.0 and 2.5.

LIGHT CONSTITUENTS

The light minerals in the sediments were not studied. However, for three nearshore grab samples of Holocene sediment, the mineral composition is as follows: quartz, 90%; microcline, 3%; chert, 2%; rock fragments, 3%; and micaceous minerals, 2%.

Chapter 4

HEAVY MINERAL VARIATIONS

HEAVY MINERAL DISTRIBUTION IN DIFFERENT GRAIN SIZE FRACTIONS

Ten samples were analyzed for heavy mineral variation in three sand-size fractions, 1-2, 2-3, and 3-4 phi. The histograms of the heavy mineral weight percentage distribution in three grain size fractions indicates a maximum concentration of heavy minerals in the 3-4 phi fraction (Fig. 8). Ferromagnetic minerals in heavy mineral residues are also concentrated in this fraction (Fig. 8). The variations of mineral composition in three size fractions were studied by plotting graphs of grain size against the percentage of each mineral species. The mineral composition variations, due to grain size preference of mineral species, were found to be of little importance, although garnet shows preference for the 1-2 phi range (Fig. 9), whereas epidote and chloritoid are more concentrated in the 2-4 phi than in 1-2 phi (Fig. 10, 11). In general, the heavy mineral assemblage of the 2-4 phi size fraction was found to contain the maximum variety of mineral species; consequently the compositional variations were studied for this fraction only.

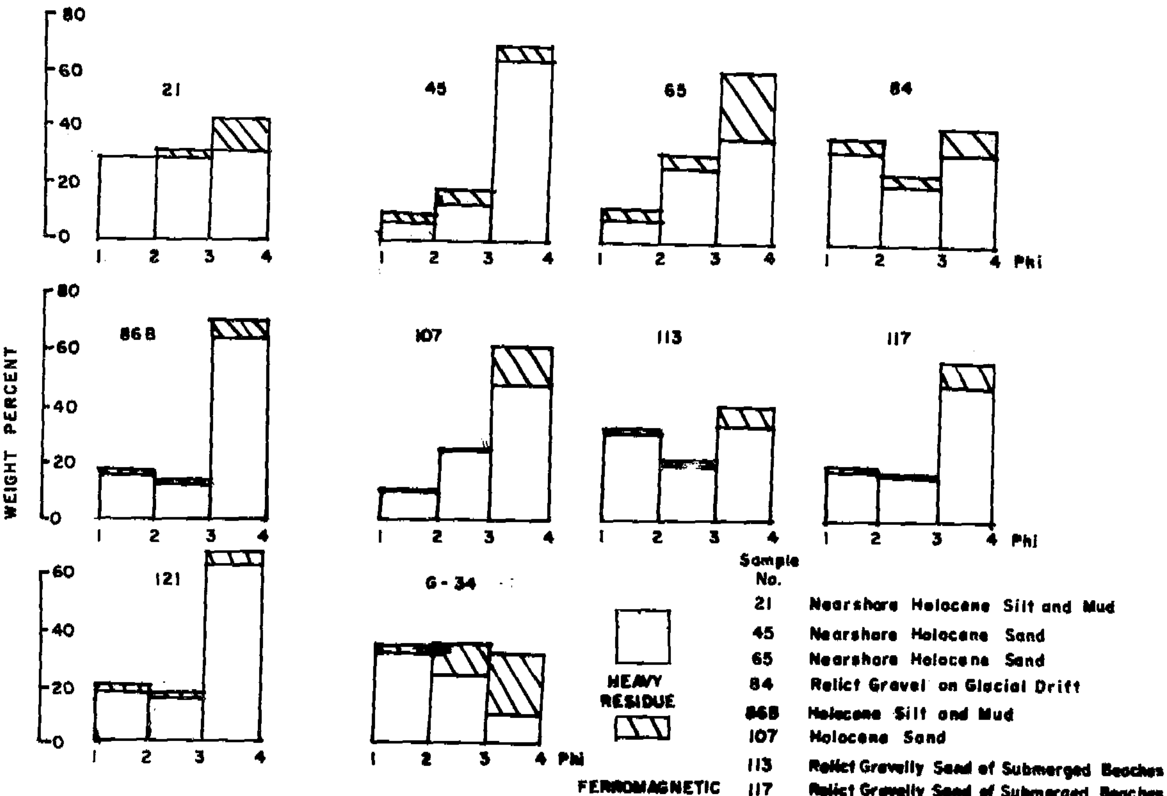


FIGURE 8. HISTOGRAMS OF HEAVY MINERAL WEIGHT PERCENTAGE AND FERROMAGNETIC MINERALS THEREIN

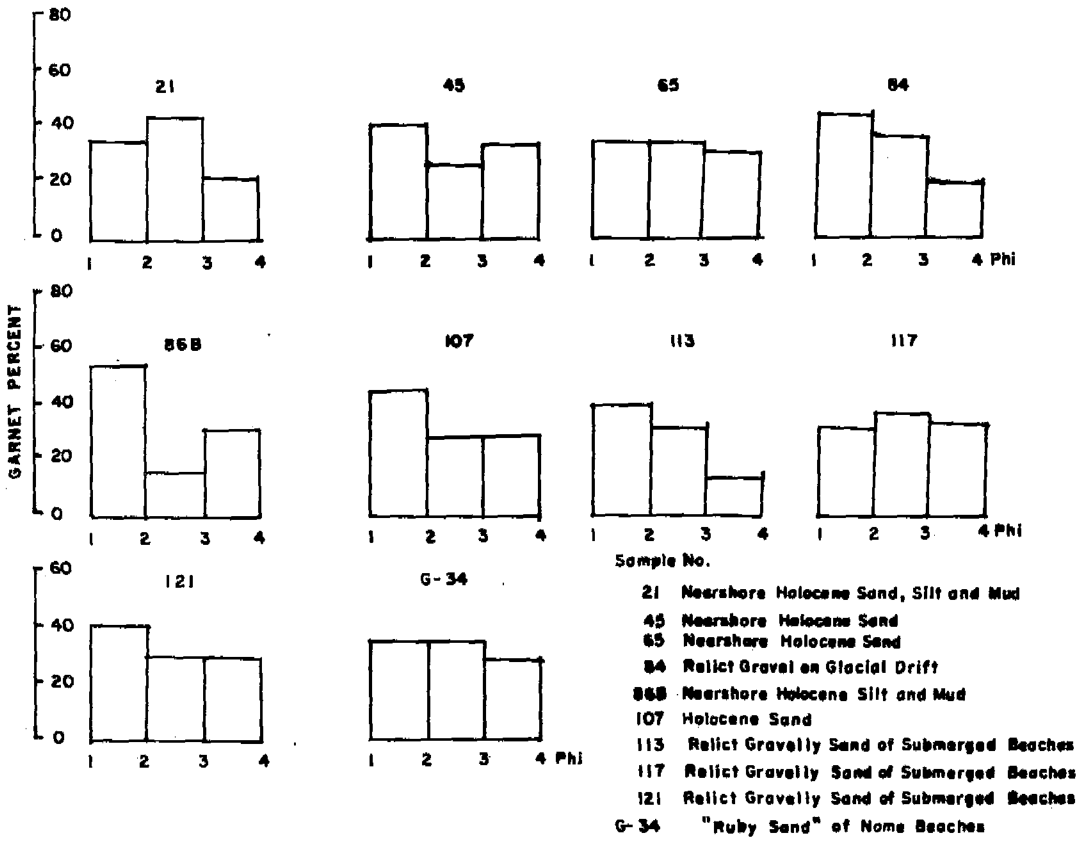
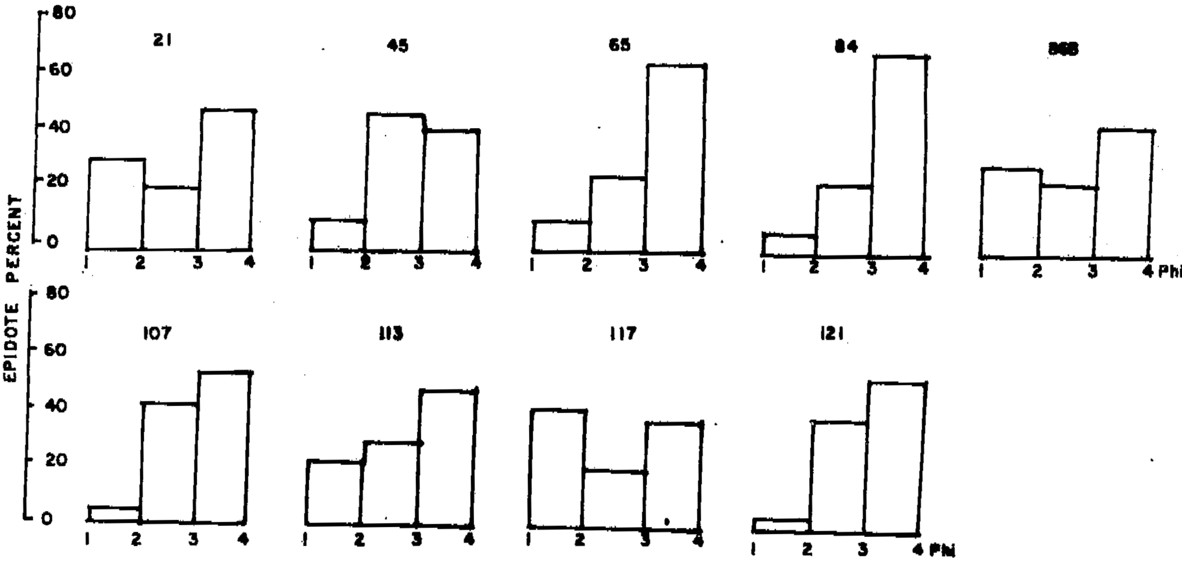


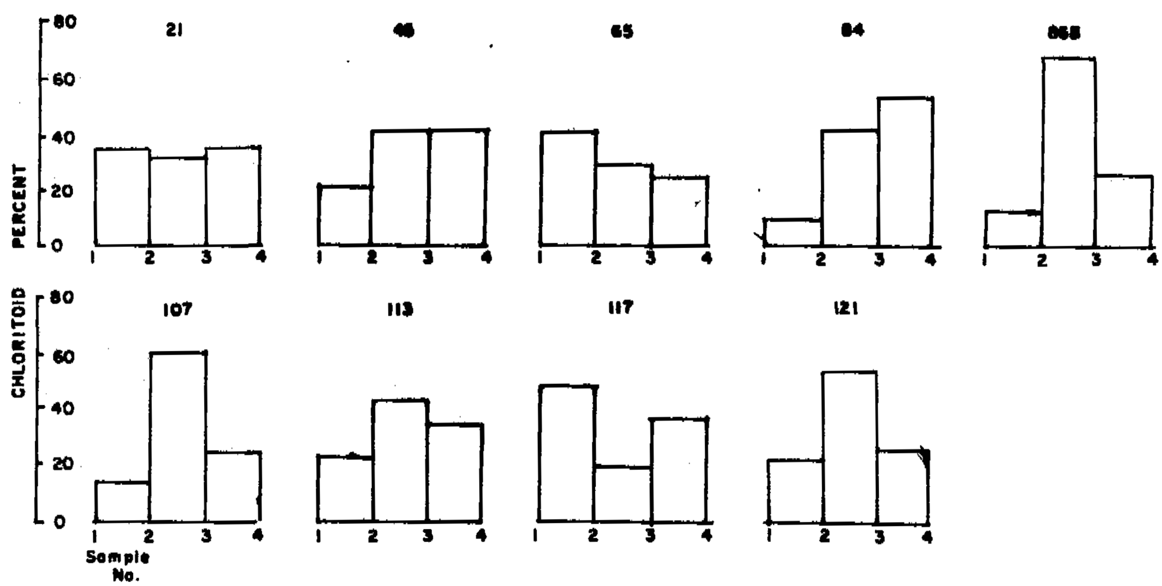
FIGURE 9. SIZE DISTRIBUTION OF GARNET AS A PERCENTAGE OF TOTAL FRACTION



Sample No

21 Nearshore Holocene Sand, Silt and Mud
45 Nearshore Holocene Sand
65 Nearshore Holocene Sand
84 Relict Gravel on Glacial Drift
86B Nearshore Holocene Silt and Mud
113 Relict Gravelly Sand of Submerged Beaches
117 Relict Gravelly Sand of Submerged Beaches
121 Relict Gravelly Sand of Submerged Beaches

FIGURE 10. SIZE DISTRIBUTION OF EPIDOTE AS A PERCENTAGE OF TOTAL FRACTION



21. Nearshore Holocene Silt and Mud
45. Nearshore Holocene Sand
65. Nearshore Holocene Sand
84. Relict Gravel on Glacial Drift
86 B. Nearshore Holocene Silt and Mud
107. Nearshore Holocene Sand
113. Relict Gravelly Sand of Submerged Beaches
117. Relict Gravelly Sand of Submerged Beaches
121. Relict Gravelly Sand of Submerged Beaches

FIGURE 11. SIZE DISTRIBUTION OF CHLORITOID AS A PERCENTAGE OF TOTAL FRACTION

HEAVY MINERAL WEIGHT PERCENTAGE VARIATIONS

Heavy mineral weight percentages in various sediments are reported in Table 1.

Heavy Mineral Weight Percentage in Onshore Holocene Sediments (Fig. 12a)

The maximum concentration of heavy minerals (90%) is found in "ruby sand" which occurs as small pay-streaks on the Nome beaches. These pay-streaks are not more than a few inches thick and extend in a horizontal direction for a short distance only. They are almost entirely made up of pink garnet and opaque minerals (Moffit, 1913, p. 110). According to Hutton (1960, p. 7), such pay-streaks of heavy minerals are formed by strong winnowing action of wind storms. The weight percentage of heavy minerals is also high for sand samples from swash zone (15%) and a bar at Penny River (30%). These sands are well-sorted with an average sorting coefficient (Trask's sorting coefficient) 2.4. Sands in the swash zone and river bar are mainly handled by waves and littoral currents. As a result of this, they are better sorted than sediments on other parts of Nome beach (Greene, 1970).

In the sand fractions of beach gravel from the back-shore region, the lowest weight percentage of heavy minerals (8%) was observed. According to Greene (1970), sediments in this region are handled by waves and moving ice, consequently, they are poorly sorted. The average sorting

Table 1

Average Heavy Mineral Weight Percentages for Various Sediment Types

Sediment types	Mean phi	Weight percent in 1-4 phi size fractions
ONSHORE HOLOCENE SEDIMENTS		
Modern beach sediments		
Ruby sand	0.45	90
Sand samples from swash zone	0.54	15
A sand sample from a bar at Penny River	0.45	30
Gravel samples from back-shore region	-1.5	8
*Gravel samples from Nome River		17
NEARSHORE HOLOCENE AND PLEISTOCENE RELICT SEDIMENTS		
Holocene sand	1.2	18
Holocene silt and mud	4.0	7
Relict gravel over glacial drift	-1.5	12
Relict gravel on Nome River outwash fan	-2.2	18
Relict gravelly sand of submerged beaches	1.5	12
PLEISTOCENE AND PLIOCENE SEDIMENTS FROM NEARSHORE DRILL-HOLES		
*Pleistocene glacial till (Illinoian and pre-Illinoian)	-	8
*Pliocene marine silty sand	-	8

*Grain size data is not available

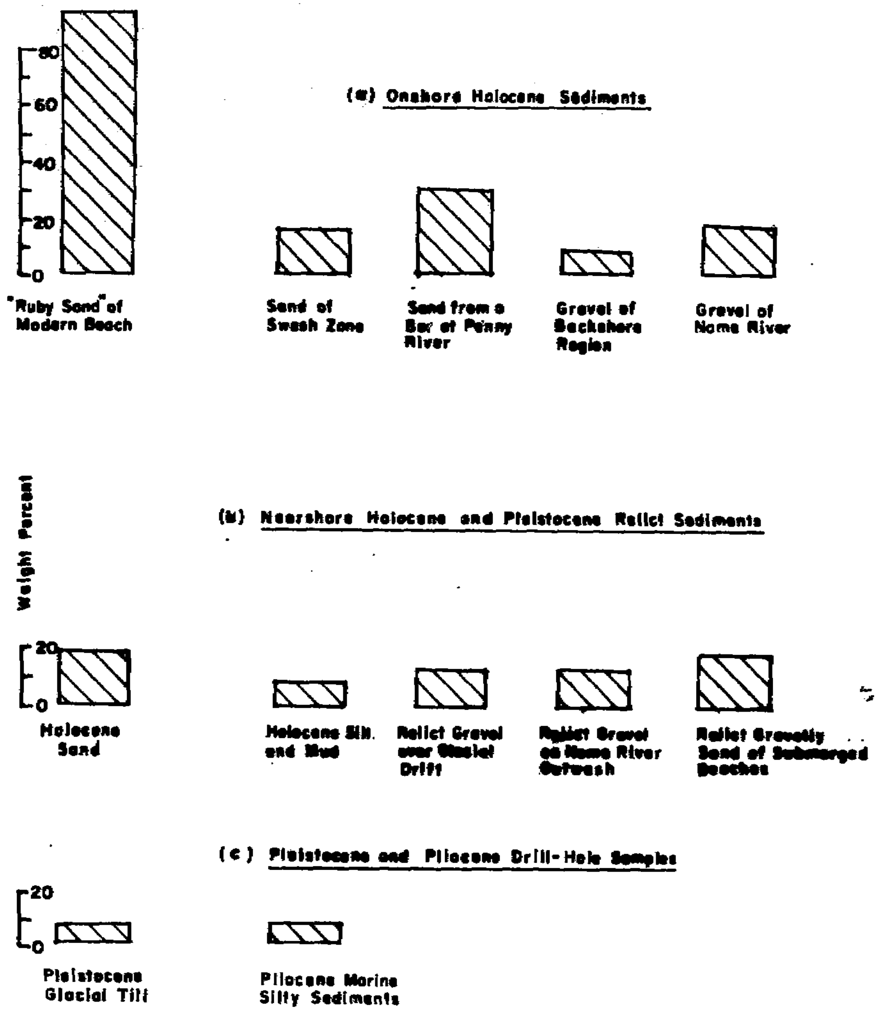


FIGURE 12. HEAVY MINERAL WEIGHT PERCENTAGE DISTRIBUTION IN VARIOUS SEDIMENTS

coefficient for these gravels is 3.89. In beach sediments, high concentration of heavy minerals is associated with well-sorted sand of the swash zone and sand of the river bars. The heavy mineral content is low for the poorly sorted gravel of the backshore region.

In two samples of the Nome River, the weight percentage of heavy minerals is high (17%), apparently because these river sediments have been subjected to strong stream currents.

Heavy Mineral Weight Percentage in Nearshore Holocene and Pleistocene Relict Sediments (Fig. 12b)

Mixed sediments, ranging in grain size from coarse gravel to fine silt and mud, underlie the nearshore region of Nome because relict gravelly sediments of Pleistocene age are interspersed with Holocene sand and mud. Predominantly gravelly sediment often shows nearly the same sorting as predominantly sandy sediment. For this reason, the mean grain size of sediment is used for the purpose of relating the heavy mineral weight percentage variations and the mineral composition variations.

In general, a high concentration of heavy minerals is expected for relict sediments because they were winnowed by several transgressions of the sea during Pleistocene time. However, the maximum concentration (18%) of heavy minerals in nearshore sediments is in the Holocene sand (mean phi 1.2). The relict gravel on glacial drift and relict gravelly sand of submerged beaches have a lower weight percentage of heavy minerals (12%) than Holocene sand. Two samples of relict gravel on the Nome River outwash plain show a high weight percentage of heavy minerals (18%). The map of weight percentage of heavy minerals (Fig. 13) more or less agrees with the map of mean size distribution of bottom sediments (Fig. 6). Patches of Holocene silty and muddy sediments (mean phi 4.0) coincide with the lowest weight percentage of heavy minerals (5-10%) because these silty and muddy sediments are mainly composed of light micaceous minerals.

The high weight percentage of heavy minerals in nearshore Holocene sand suggests the winnowing of Holocene sand by strong bottom currents. However, the direction and magnitude of such currents are uncertain because of the patchy and discontinuous nature of the Holocene sand. The relatively low weight percentage of heavy minerals in relict gravel deposits on glacial drift and relict gravelly sand of submerged beaches probably reflects the heterogeneous nature of relict sediments. Medium to fine-size sand fractions of relict gravelly sediments probably would have been introduced during the Holocene age. Also, the contamination of some samples of relict gravel from the underlying glacial drift is suspected because the relict gravel forms a very thin mantle (1" average thickness) over the glacial drift.

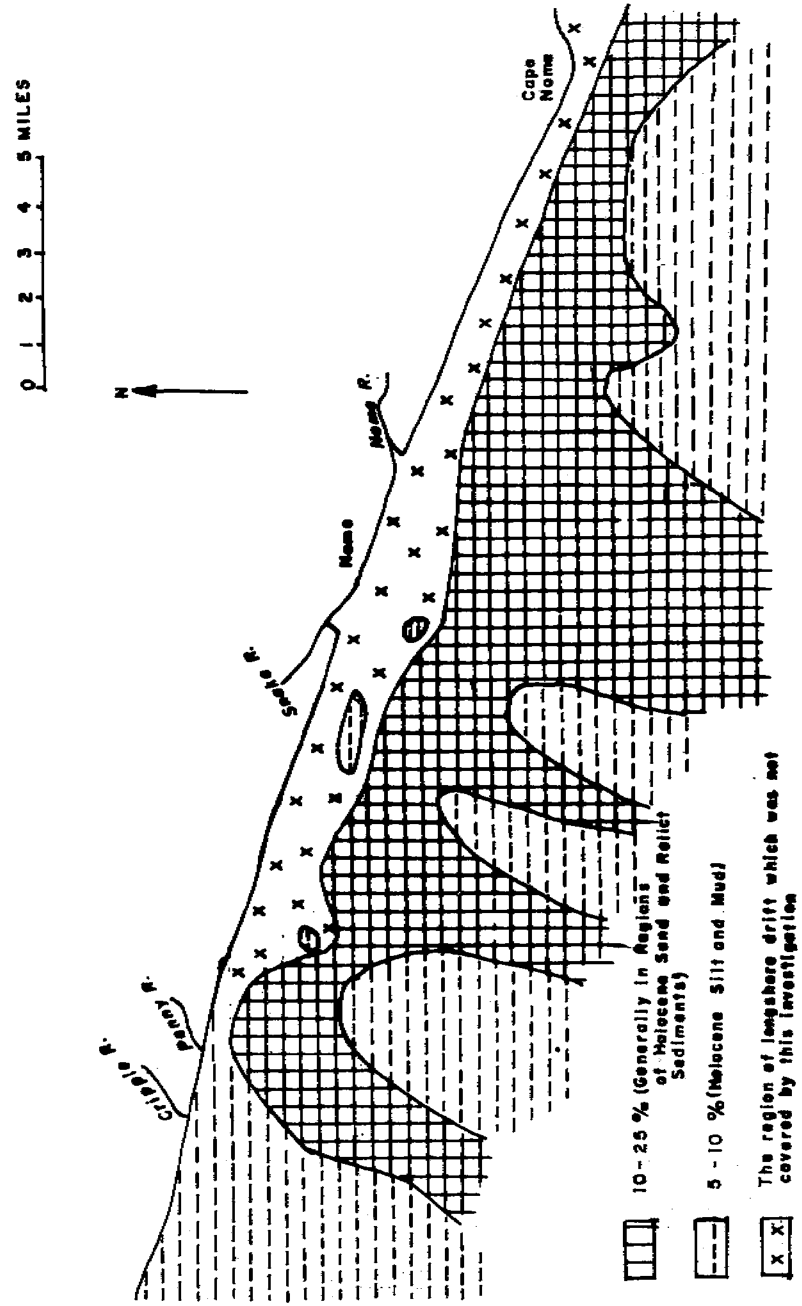


FIGURE 13. HEAVY MINERAL WEIGHT PERCENTAGE MAP

Heavy Mineral Weight Percentage in Pliocene and Pleistocene Sediments (Fig. 12c)

The weight percentage of heavy minerals is low (8%) for three samples of Pleistocene glacial till (Illinoian and pre-Illinoian) obtained from one nearshore drill-hole location. Although grain size data is not available for these samples, low weight percentage of heavy minerals is expected for poorly sorted glacial deposits. The weight percentage of heavy minerals is also low (8%) for three samples of Pliocene marine sediment from three nearshore drill-hole locations. These samples are silty and muddy, and a low weight percentage is expected, as they are mainly composed of micaceous minerals.

RELATIONSHIP BETWEEN GOLD AND HEAVY MINERALS

Distribution of Gold in Sediments of the Nome Region

Three conditions are important in the formation of placer gold deposits: (1) the occurrence of gold in bedrock, (2) the separation of gold from bedrock by weathering, and (3) the concentration of gold particles by stream currents, shore currents, etc. Lode deposits of gold were mined in the Nome region at the time of the gold rush in Nome. Gold occurs in quartz and calcite veins associated with metamorphic rocks of the Nome region (Collier and others, 1908, pp. 114-116). The transportation and distribution of placer gold in sediments of the Nome region is

elaborately discussed by Nelson and Hopkins (1969) in their study. The following is a summary of their data which is relevant to this report.

1. Fine size gold (0.25 mm or less) is widely dispersed in sediments of the Nome region, but the maximum concentration (556.0 parts per billion ppb) of coarse gold particles (1 mm or larger) occurs in relict gravel that mantles glacial drift in the nearshore region. Gold was eroded by glaciers from old gold placers and bedrock of the onshore region, and was transported to its present site with glacial drift. Although the glacial drift carries small values of gold, several transgressions and regressions of the sea during the Pleistocene time winnowed away the fine particles and light minerals, leaving the relict gravel over glacial drift rich in gold. The relict gravel on the Nome River outwash contains relatively little gold (4.0 ppb), because the thin mantle of outwash gravel has covered the glacial drift sources. The concentration of gold in submerged beach gravel (16.0 ppb) is lower than that of relict gravel over drift. Submerged beaches were formed where sea level was steady for a considerable period, and, as a result, beach sediment buried the glacial drift source rock. The relict gravel overlying the drift was formed where the sea advanced rapidly. Nearshore Holocene sediment contains small quantities of fine gold (8.0 ppb). "Ruby sand" of the Nome beaches carries a considerable amount of fine size gold

(2118 ppb). Modern beach gravel samples also carry fairly high values of gold (155 ppb). The average values of gold in different sediment types are reported in Table 2.

2. Coarse-size gold (1 mm or larger), once concentrated in relict gravel on glacial drift, was not moved by normal marine processes such as longshore currents, strong bottom currents, surf waves, etc., although fine-size gold (0.25 mm or smaller) can be transported by these processes.

Relationship Between Gold Value, Heavy Mineral Weight Percentage, Garnet Percentage, and Micaceous Minerals Percentage

Generally, placer gold is associated with minerals of high specific gravity such as magnetite, ilmenite, pyrite, zircon, garnet, and monazite (Bateman, 1959, p. 236). Smaller size grains of gold are hydraulically equivalent to larger grains of lighter minerals, because of gold's extremely high specific gravity (Sp. Gr. = 15-19). The relationship between heavy minerals and gold has been investigated by comparing the average gold values (in parts per billion) for various Nome sediments with (1) heavy mineral weight percentages, (2) garnet percentages (expressed in number frequency excluding micaceous minerals), and (3) micaceous minerals percentages (expressed in number frequency relative to the nonopaque minerals of the heavy concentrates).

Table 2

Average Gold Values, Heavy Mineral Weight Percentages, Garnet Percentages, and Micaceous Minerals Percentages for Various Sediment Types

Sediment types	Mean phi	Av. gold values in parts per billion ppb.(1)	Av. weight percent of heavy minerals	Av. garnet percent (2)	Av. Micaceous minerals percent (3)
MODERN BEACH SEDIMENTS					
Ruby sand	0.45	2118	90	94	0.5
Beach gravel	-1.2	155	8	70	35
NEARSHORE HOLOCENE AND PLEISTOCENE RELICT SEDIMENTS					
Holocene sand	1.2	8	18	68	20
Relict gravel over glacial drift	-1.5	556	12	64	30
Relict gravel on Nome River outwash fan	-2.2	4	18	68	25
Relict gravelly sand of submerged beaches	1.5	16	12	60	40

1. Gold values are of total samples.
   Data was obtained from U.S. Geological Survey.
2. Number frequencies of garnet are expressed in terms of percents excluding counts of micaceous minerals.
3. Number frequencies of micaceous minerals are expressed in terms of percents including counts of all nonopaque minerals in heavy concentrates.

Relationship Between Gold Value and Weight Percentage of Heavy Minerals (Fig. 14)

The bar diagrams of heavy mineral weight percentages and gold values indicate the coincidence of a high weight percentage of heavy minerals and a high gold value only for the "ruby sand" of modern beaches where sand is almost entirely made up of garnet and opaque minerals. **For other sediment** types, high gold values are not related to high weight percentages of heavy minerals. In relict gravel over glacial drift, which carries a high gold value (556 ppb), the weight percentage of heavy minerals is not higher than that of other sediments. Also gravel samples of the modern beaches, which carry fairly high gold values (155 ppb), do not show high weight percentages of heavy minerals (8%). In nearshore Holocene sand and relict gravel on the Nome River outwash, which carry a low gold value (4-8 ppb), the weight percentage of heavy minerals is relatively high (18%).

Relationship Between Gold Value and Garnet Percentage (Fig. 15)

Garnet is the most abundant heavy mineral in the Nome sediments. Only in the "ruby sand" of modern beaches is the garnet percentage related to the high gold value. For other sediments, the gold value is not related to the garnet percentage. In nearshore Holocene sand and in relict gravel over the Nome River outwash plain, which carry low gold values, garnet percentage is high (68-70%). On the other hand, in the relict gravel over glacial drift, which

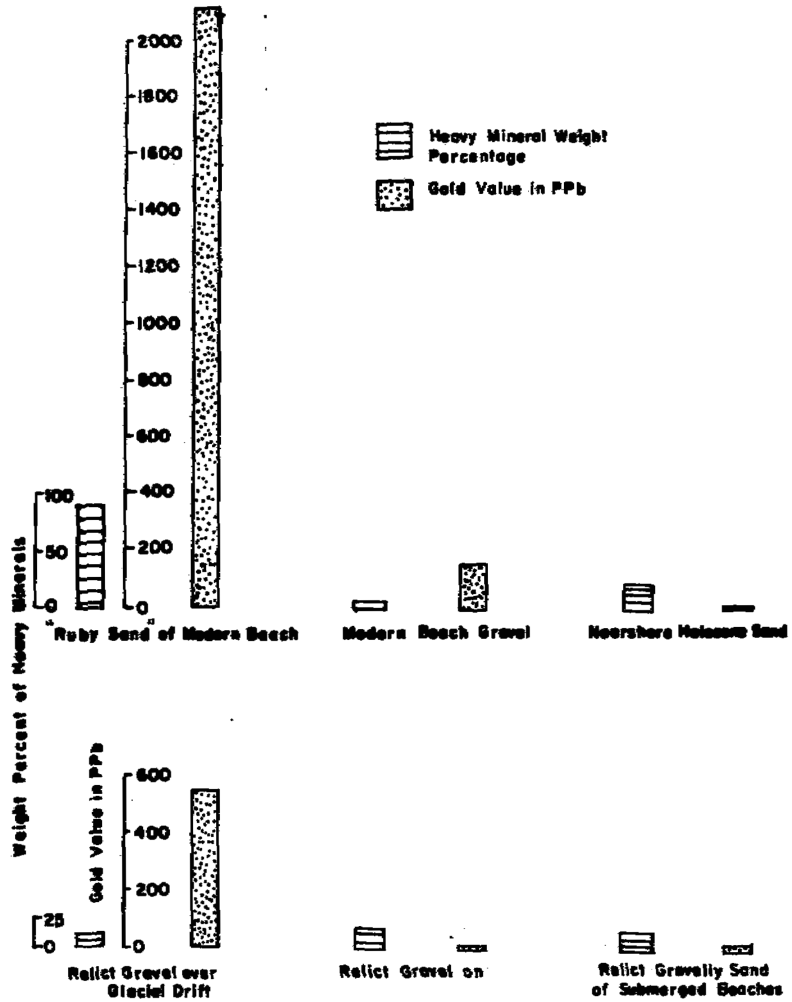


FIGURE 14. RELATIONSHIP BETWEEN GOLD VALUE AND HEAVY MINERAL WEIGHT PERCENTAGE

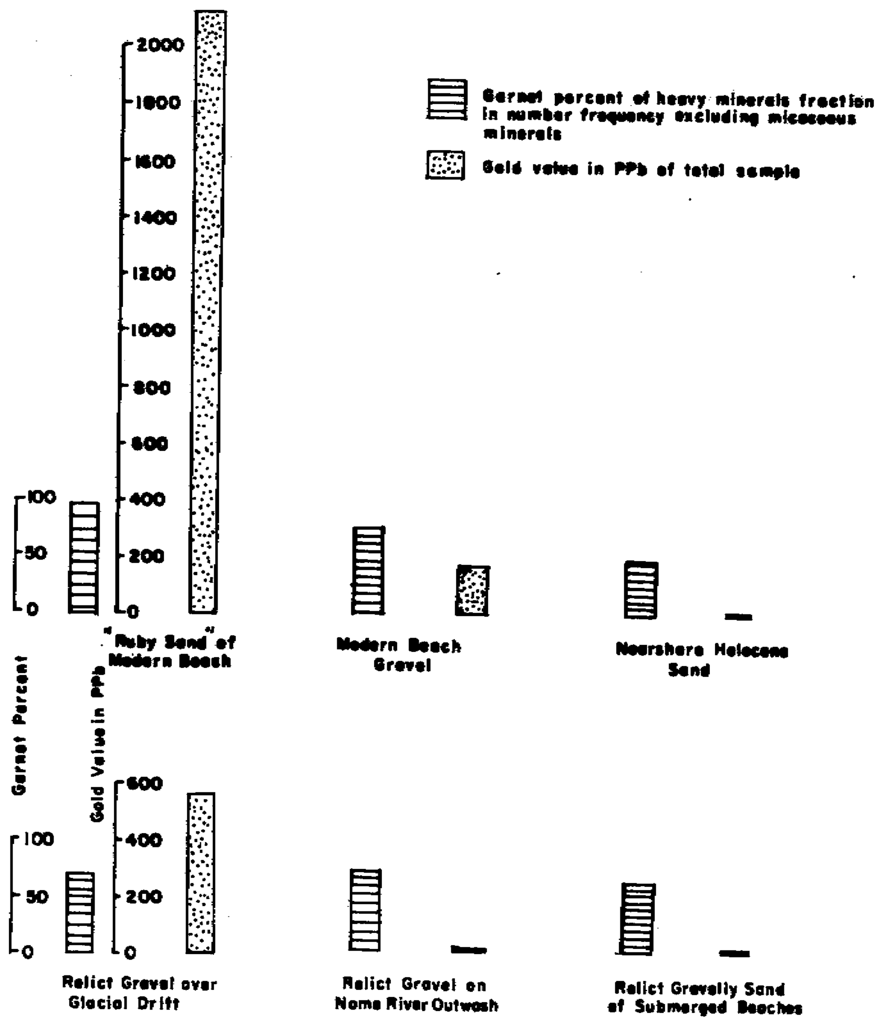


FIGURE 15. RELATIONSHIP BETWEEN GOLD VALUE AND GARNET PERCENTAGE

carries a high gold value, the garnet percentage is slightly lower than that of Holocene sand and relict gravel over the Nome River outwash plain (64%).

Relationship Between Gold Value and Micaceous Minerals Percentage (Fig. 16)

Micaceous minerals are considered to represent low energy environments such as weak wave action, and lack of winnowing. They are usually associated with fine sediment such as silt and mud (Doyle and others, 1968, pp. 381-389). Because of the contrast between hydraulic properties of gold and micaceous minerals (S.G. of micaceous minerals: 2.7-3.3, S.G. of gold: 15-19), an antipathetic relationship is expected between these two. This antipathetic relationship is confirmed for "ruby sand" of the modern beach only, where a high gold value is associated with very low micaceous minerals percentage (0.5%). In nearshore relict gravel over glacial drift that carries a high gold value (558 ppb), the percentage of micaceous minerals is not low (30%). Similarly, in nearshore Holocene sand and in relict gravel on the Nome River outwash, the percentage of micaceous minerals is comparatively low (20-25%), although they carry low gold values (4-8 ppb).

A correlation between a high gold value, a high heavy mineral weight percentage, a high garnet percentage, and a low micaceous minerals percentage exist only for "ruby sand" of the Nome beach. This correlation between gold values

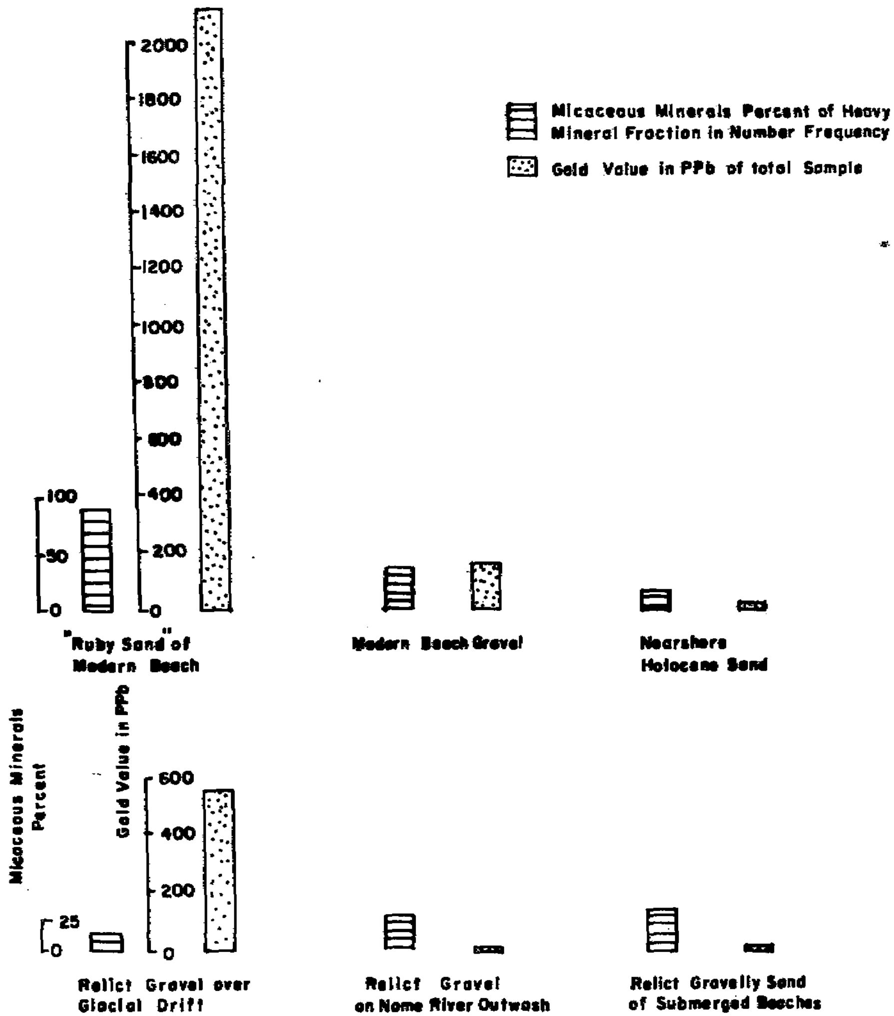


FIGURE 16. RELATIONSHIP BETWEEN GOLD VALUE AND MICACEOUS MINERALS PERCENTAGE

and heavy minerals in "ruby sand" may be due to its exceptionally winnowed nature and the lack of later contamination. The lack of correlation between gold values and heavy minerals for the other sediments is attributed to the following factors:

a. <u>The occurrence and mode of transportation of gold and other heavy minerals</u>: The lack of correlation between gold and other heavy minerals is understood when the source region of gold and its hydraulic properties are taken into consideration. According to Nelson and Hopkins (1969, p. 43), coarse gold particles (1 mm or larger) are concentrated in relict gravel that mantles glacial drift. Because of the high specific gravity, coarse gold particles are not usually moved from their source region by normal marine processes such as longshore currents and bottom currents. On the other hand, heavy minerals of medium to fine-size (1/2 - 1/16 mm) can be transported along with light mineral particles by longshore and bottom currents. This is also supported by a high concentration of heavy minerals (18% by weight) in Holocene sand winnowed by strong bottom currents (*Fig. 12b*)

b. <u>Heterogeneous nature of relict sediments</u>: Medium to finer fractions of the relict sediments probably have been partially derived from later deposition of Holocene sediment, and contamination of some samples of relict gravel from underlying glacial drift is suspected because relict gravel forms a very thin mantle (1' average thickness) on glacial drift.

MINERAL COMPOSITION VARIATIONS

The bar diagrams (Fig. 17) of heavy mineral composition indicate more or less similar mineral composition for the various sediments of Nome. Major heavy minerals such as garnet, epidote, chloritoid, sphene, staurolite, and micaceous minerals (chlorite, muscovite, and biotite) occur in all of the sediments in varying proportions. There are no typical minerals or mineral assemblages, or physical characteristics of minerals, which are diagnostic of particular sediments. The average mineral composition of heavy mineral assemblages from various sediments are reported in Table 3.

Mineral Composition of Onshore Holocene Sediments (Modern Beach and River Sediments) (Fig. 17a)

The "ruby sand" of the Nome beach is made up almost entirely of minerals of high specific gravities such as garnet, zircon, and ferromagnetic minerals.

In general, the modern beach sediments are characterized by higher frequencies of garnet (65-75%) and staurolite (5-6%) than are the nearshore sediments. It seems that garnet and staurolite, being minerals of comparatively high specific gravity (S.G. 3.8-4.3), they are concentrated in the onshore beach and river sediments by winnowing processes.

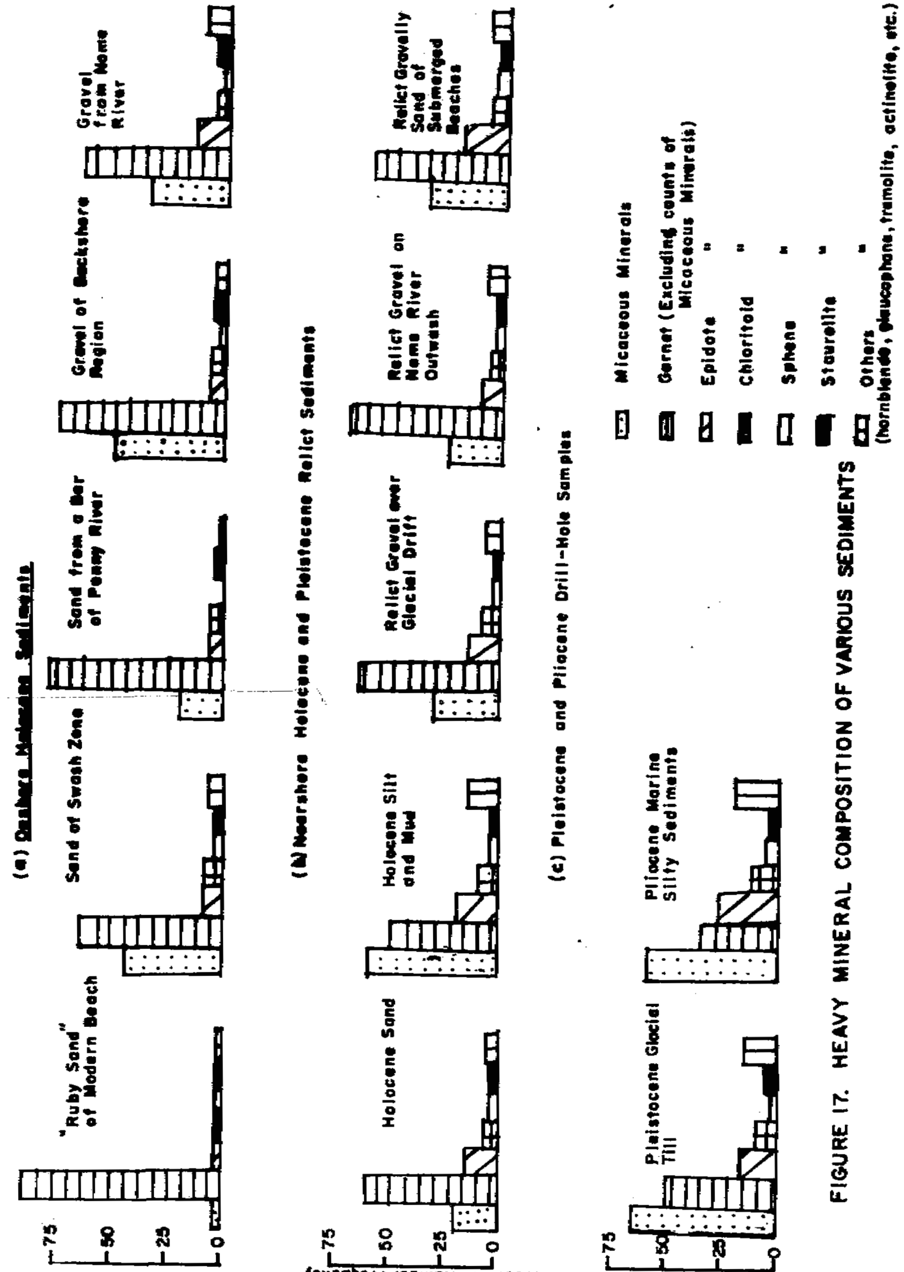


FIGURE 17. HEAVY MINERAL COMPOSITION OF VARIOUS SEDIMENTS

Table 3

Average Mineral Compositions for Various Sediments

Sediment types	Mean phi	Garnet	Epidote	Chloritoid	Sphene	Staurolite	Others	Micaceous minerals
ONSHORE HOLOCENE SEDIMENTS								
Modern beach sediments								
Ruby sand	0.45	90	1	1	1	3	4	0.5
Sand samples from swash zone	0.54	65	10	11	3	4	7	45
A sand sample from a bar at Penny River	0.45	77	8	7	-	6	2	21
Gravel samples from backshore region	-1.2	75	7	7	2	4	5	50
Gravel samples from Nome River	-	65	14	5	2	5	9	35
NEARSHORE HOLOCENE AND PLEISTOCENE RELICT SEDIMENTS								
Holocene sand	-1.2	68	14	7	3	3	5	20
Holocene silt and mud	4.0	50	19	11	4	3	13	60
Relict gravel on glacial drift	-1.5	64	15	7	3	3	8	25
Relict gravel on Nome River outwash	-22	70	10	8	3	2	7	33
Relict gravelly sand of submerged beaches	1.5	60	20	7	4	2	7	33

Table 3 (continued

Sediment types	Mean phi	Garnet	Epidote	Chloritoid	Sphene	Staurolite	Others	Micaceous minerals
PLEISTOCENE AND PLIOCENE SEDIMENTS FROM NEARSHORE DRILL-HOLES								
*Pleistocene glacial till (Illinoian and pre-Illinoian)	-	50	19	10	3	4	14	65
*Pliocene marine silty sand	-	35	27	14	7	1	16	60

*Grain size data is not available.

Number frequencies of garnet, epidote, chloritoid, sphene, staurolite, and others (tourmaline, hornblende, glaucophane, tremolite-actinolite, sillimanite, kyanite, and zircon) are expressed in terms of percents, excluding micaceous minerals and ferromagnetic minerals.

Number frequencies of micaceous minerals (chlorite, muscovite, and biotite counted together) expressed as percents of all nonopaque minerals in heavy concentrates.

The frequencies of other minerals such as epidote, chloritoid, sphene, tourmaline, hornblende, etc., are rather low in the modern beach and river sediments.

Mineral Composition of Nearshore Holocene and Pleistocene Relict Sediments (Fig. 17b)

High concentrations of garnet in nearshore sediments are associated with high weight percentages of heavy minerals. The percentage of garnet is maximum (68-70%) for Holocene sand and relict gravel on the Nome River outwash fan, which also carry a high weight percentage of heavy minerals. The percentage of garnet is slightly low (60-64%) for relict gravel on glacial drift and relict gravelly sand of submerged beaches. Garnet minima (35-55%) more or less coincides with patches of Holocene silty sediment (mean phi 4.0), which also shows a low weight percentage of heavy minerals (Fig. 18). The frequencies of epidote and chloritoid, which are the next most abundant minerals after garnet, increase with the decrease in frequency of garnet, and their maxima is in the Holocene silty sediment (Figure 19, 20). Sphene is relatively more abdundant in nearshore sediments than in onshore beach and river sediments. Its maxima is also associated with Holocene silty sediment (Fig. 21). Staurolite is more abundant in modern beach and river sediments than in nearshore sediments (Fig. 22); because of its high specific gravity (Sp. Gr. 3.8), it is concentrated in the onshore sediments.

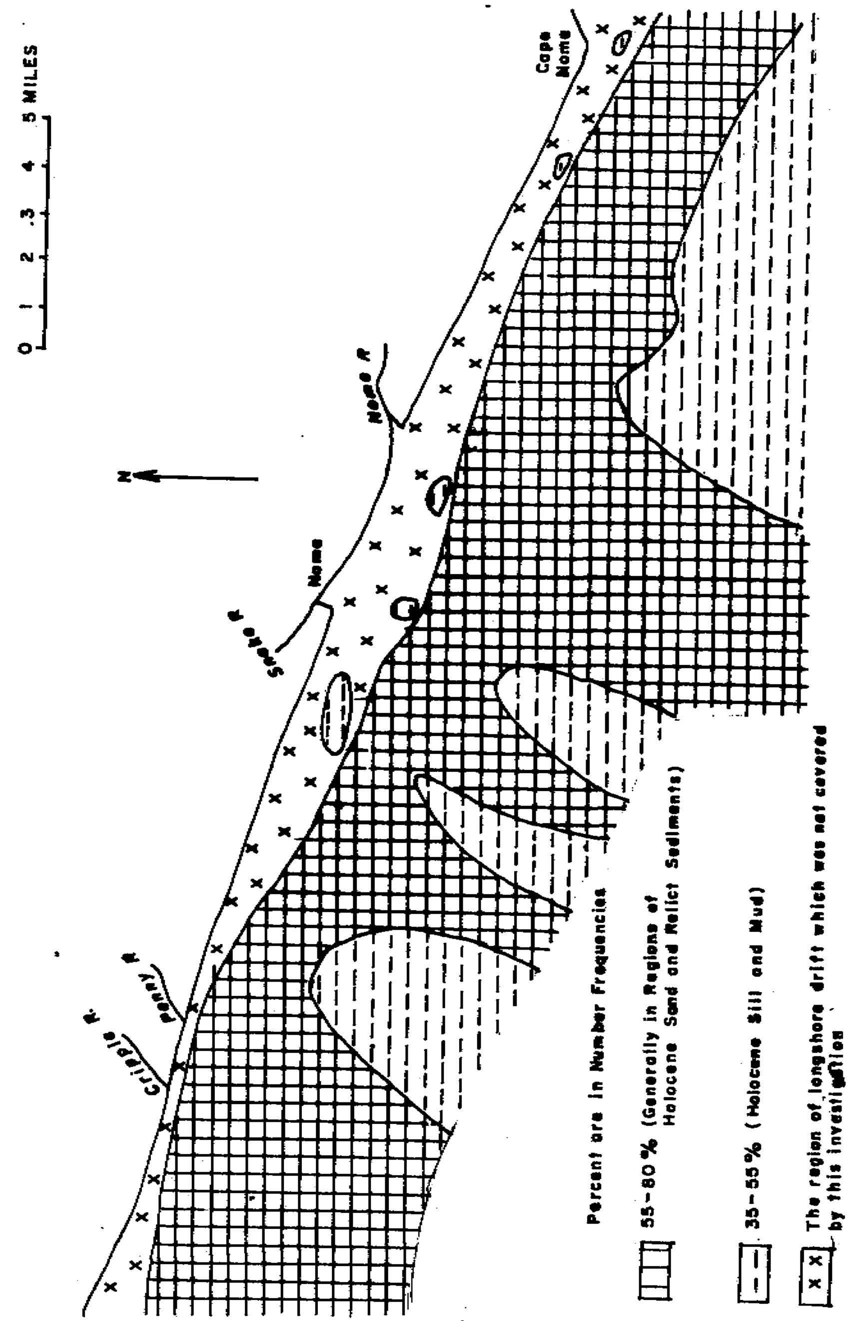


FIGURE 18. GARNET PERCENTAGE MAP

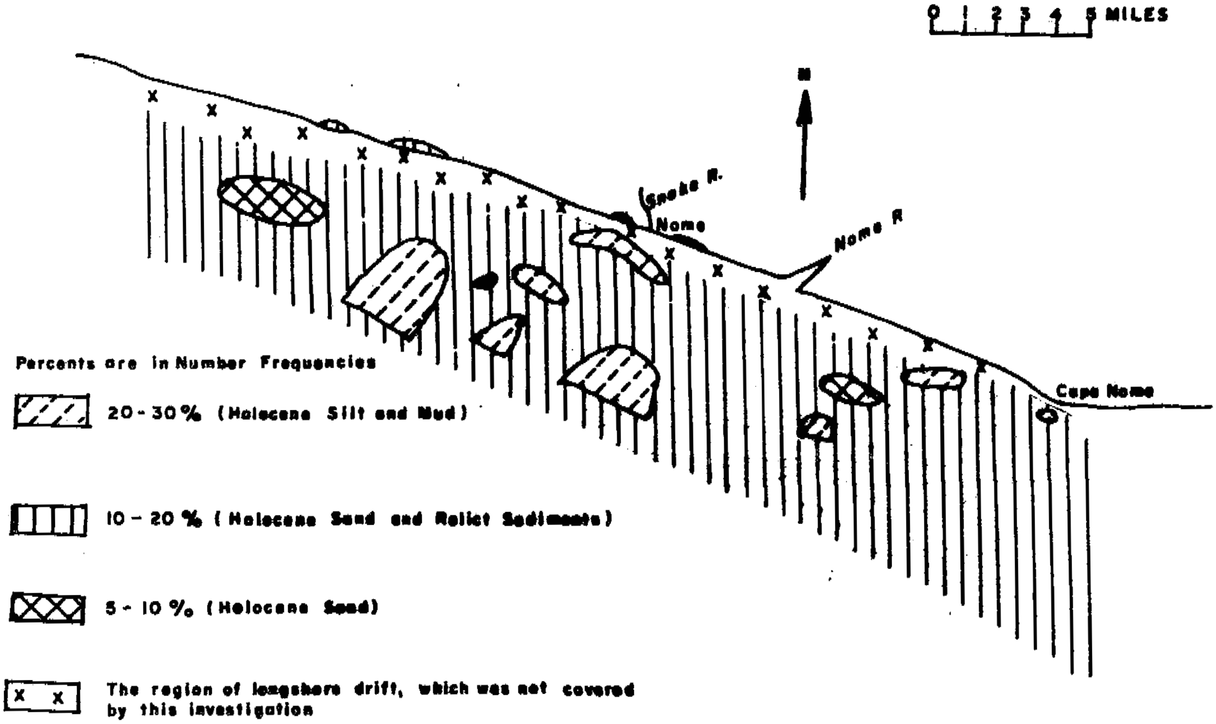


FIGURE 19. EPIDOTE PERCENTAGE MAP

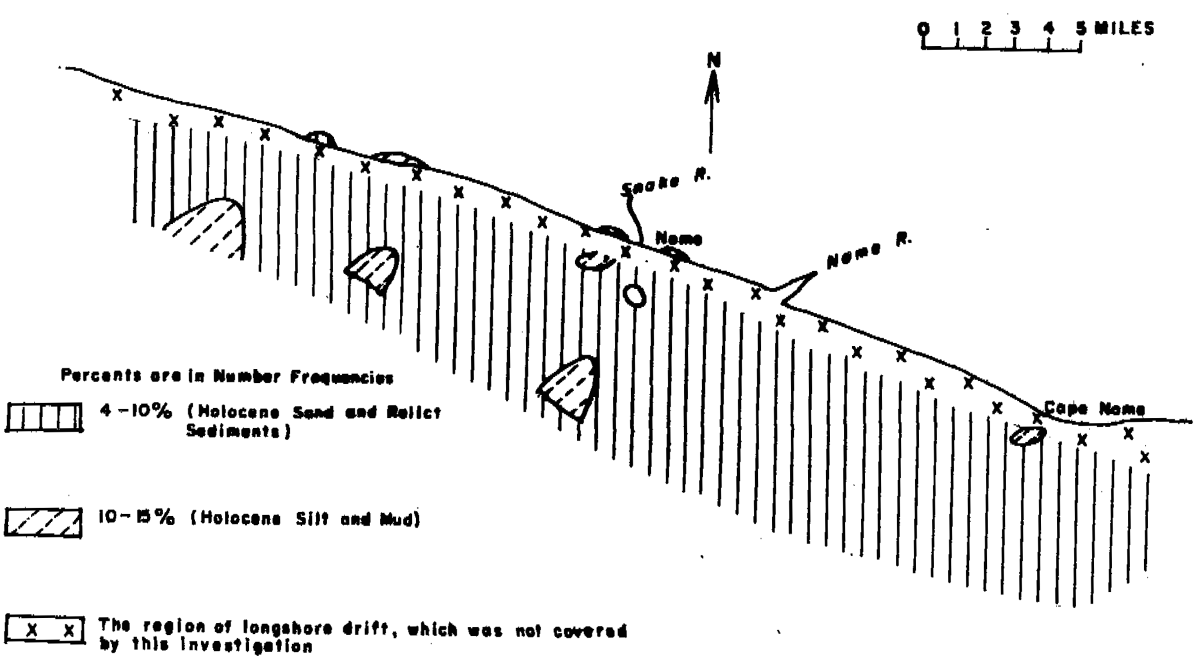


FIGURE 20. CHLORITOID PERCENTAGE MAP

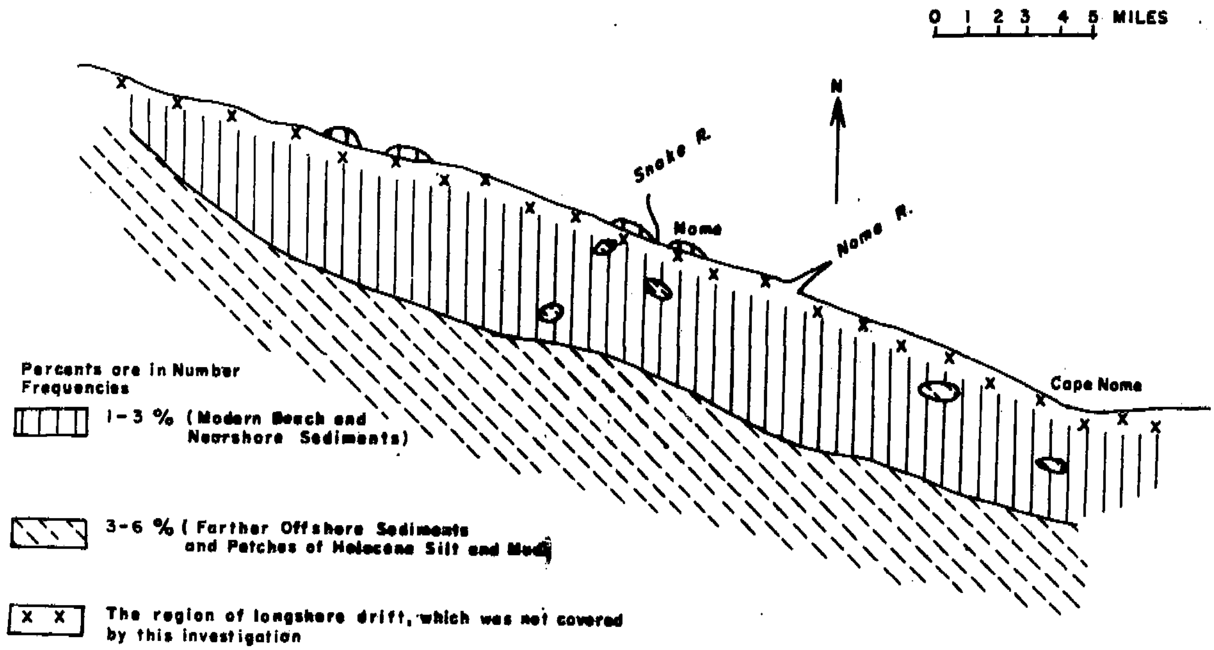


FIGURE 21. SPHENE PERCENTAGE MAP

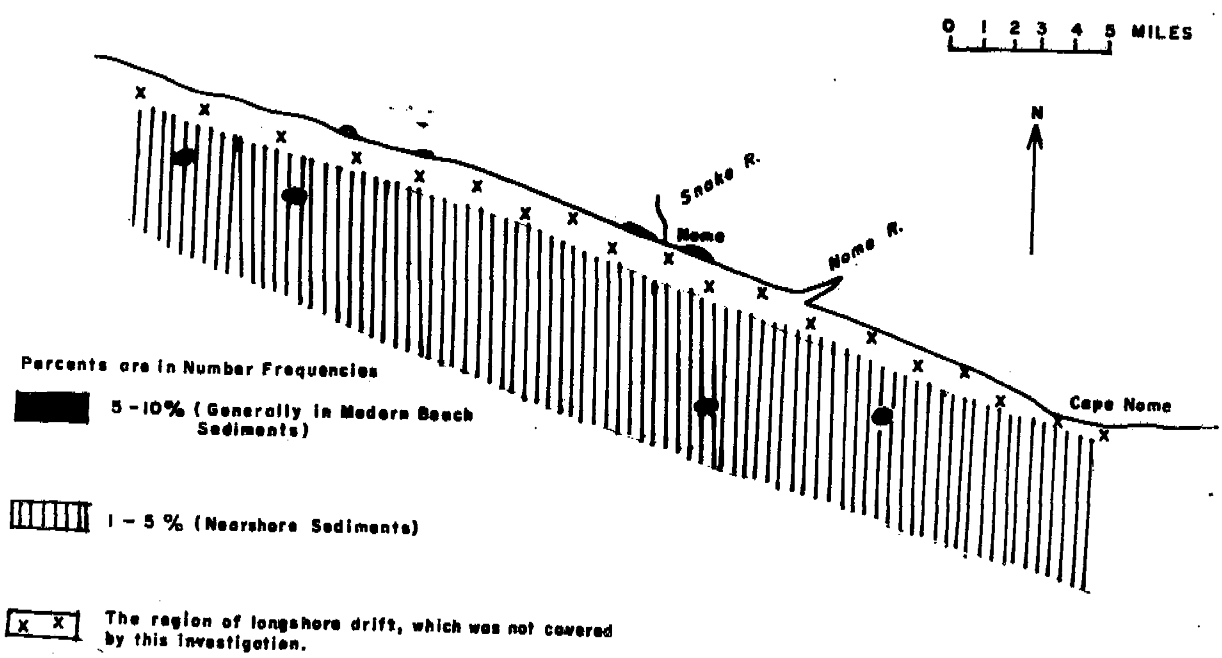


FIGURE 22. STAUROLITE PERCENTAGE MAP

The mineral frequency variations in the offshore direction (Fig. 23) show little change in the relative abundance of the heavy minerals. In general, the relative frequencies of epidote, chloritoid, sphene, and other minerals such as hornblende, glaucophane, tremolite-actinolite, and tourmaline increase with the decrease in garnet frequency of Holocene silty sediment.

The percentage of micaceous minerals (percentage computed from total counts of all nonopaque minerals in the heavy residue) bears an antipathetic relationship with heavy mineral weight percentages and garnet percentages. In the Holocene sand and relict gravel on the Nome River outwash fan, which have high weight percentages of heavy minerals (18%) and high garnet percentages (68-70%) the percentage of macaceous minerals is comparatively low (20-25%). Micaceous minerals percentage maxima (40-70%) is in the Holocene silty sediment (mean phi 4.0), which is also characterized by a low garnet percentage (35-55%) and a low weight percentage of heavy minerals (Fig. 24). Weak currents, which deposit fine silt and clay, usually carry micaceous minerals in great abundance, and garnet and other minerals of high specific gravity in small amounts.

Mineral Composition of Pleistocene and Pliocene Sediments (Fig. 17c)

The mineral composition of Pleistocene glacial till from one drill-hole reflects the poorly sorted nature of the

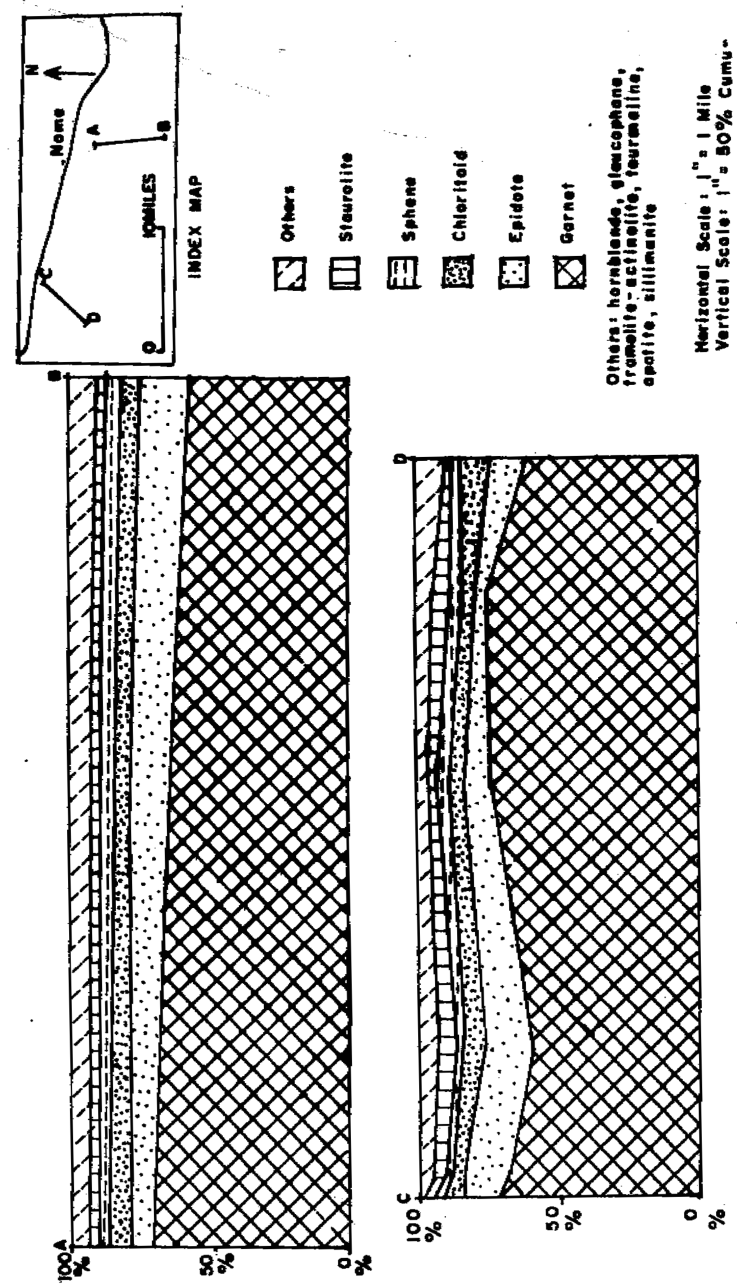


FIGURE 23. VARIATION OF HEAVY MINERALS IN OFFSHORE DIRECTION

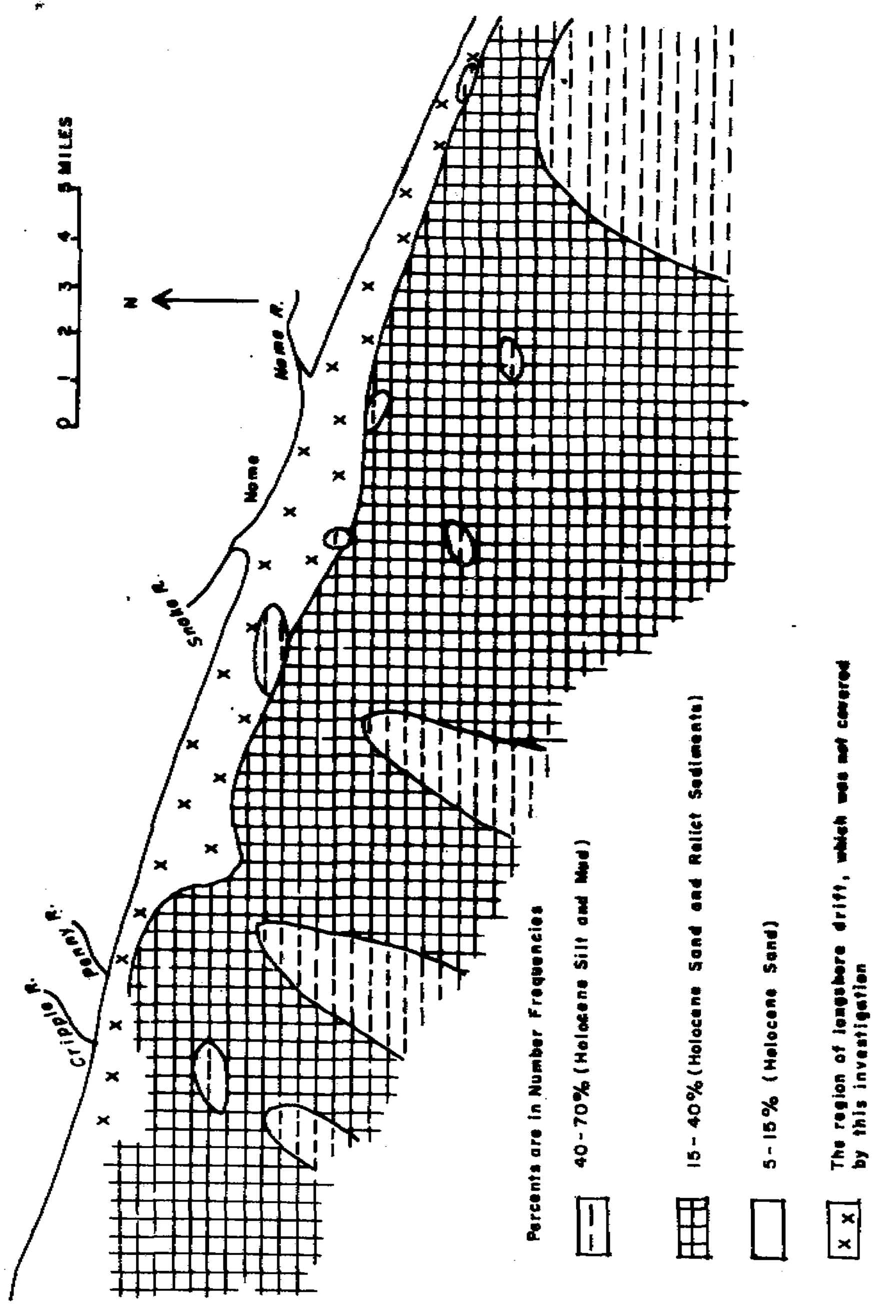


FIGURE 24. MICACEOUS MINERALS PERCENTAGE MAP

glacial deposits. It is characterized by a great abundance of micaceous minerals (65% of the nonopaque minerals in heavy concentrate) and a low content of garnet (50% of the nonopaque minerals excluding micas). The mineral composition of the Pliocene marine silty sediment from three nearshore drill-holes corresponds to the nearshore Holocene silty sediment. Similar to the Holocene silty sediment, it shows a high concentration of micaceous minerals (60%) and a low content of garnet (35%).

Discussion

Four principal factors that can modify the mineral composition and limit the interpretation of heavy mineral assemblages in terms of source region are: (1) weathering, both in the source area and in the depositional basin, (2) mechanical destruction during transportation, (3) selective sorting of minerals according to size and density, and (4) chemical destruction after deposition (Van Andel, 1959, p. 154).

According to Van Andel (1959, p. 155) the weathering is most active in regions of tropical climate, low relief, and in basins with a slow rate of deposition. In tropical regions the weathered crust is thick and, therefore, can supply an appreciable quantity of sedimentary detritus. The process of weathering seems to be of little importance in this region of arctic climate. No appreciable mechanical wear is reported in river sediments even after 600-1000 miles of transportation. Even for beach sand, where the movement of particles by wave action is considerable, no conclusive proof for the elimination or even reduction of sand-size particles has been presented (Van Andel, 1959, p. 155). The effect of chemical destruction after deposition (intrastratal solution) is probably of minor importance for the sediments under discussion, as they are mostly from sea bottom or from shallow depths. Significant alteration of heavy mineral assemblages and removal of unstable minerals by intrastratal solution generally occur under severe conditions (deep burial of sediments) and if enough time is available (Van Andel, 1959, p. 160). However, the effect of sorting is often important and can significantly change the mineral composition when the assemblages contain species of widely divergent size and density (Van Andel, 1959, p. 156). Sorting of mineral grains is related to the principle of hydraulic equivalance (Griffiths, 1967, p. 217). According to this principle, groups of detrital minerals in mechanical equilibrium in sediments are hydraulically equivalent. The factors which influence hydraulic equivalent are effective density, size, and shape. Minerals of the same density and habit react similarly under the same hydraulic conditions.

Nonopaque heavy minerals of the Nome region can be classified into three specific gravity groups: (1) garnet, S.G. 4.1-4.3; (2) epidote, chloritoid, sphene, and other

minerals such as hornblende, glaucophane, tremolite-actinolite, tourmaline, sillimanite, apatite, S.G. 3.3-3.8; and (3) micaceous minerals such as chlorite, muscovite, and biotite, S.G. 2.77-3.3. A triangular diagram (Fig. 25) of these three groups of minerals clearly demonstrates the effect of sorting of heavy mineral grains on the basis of size and specific gravity. The plot of the highly winnowed, well sorted (sorting coefficient: 1.2)"ruby sand" of Nome beach lies at the extreme garnet end. Holocene sand (mean phi 1.2), which has been worked by strong bottom currents, lies in the region of high garnet content and low micaceous minerals content. Nearshore Holocene silty sediment (mean phi 4.0), Pliocene marine silty sediment, and poorly sorted till of Pleistocene age lie in the region of the micaceous minerals. Micaceous minerals are associated with fine sized silty and muddy sediments because the micaceous grains are hydraulically equivalent to silt and mud (Doyle and others, 1968, pp. 381-389). The garnet content is low in the silty and muddy sediments because garnet has a high specific gravity (S.G. 4.1-4.3) and is therefore concentrated in medium and fine sand. Pleistocene relict sediments are somewhat scattered between the garnet and micaceous minerals areas of the diagram, probably because of their heterogenous nature. The mineral composition of the heavy mineral assemblages from various sediments is more or less similar. Minor variations in the relative abundance of heavy minerals

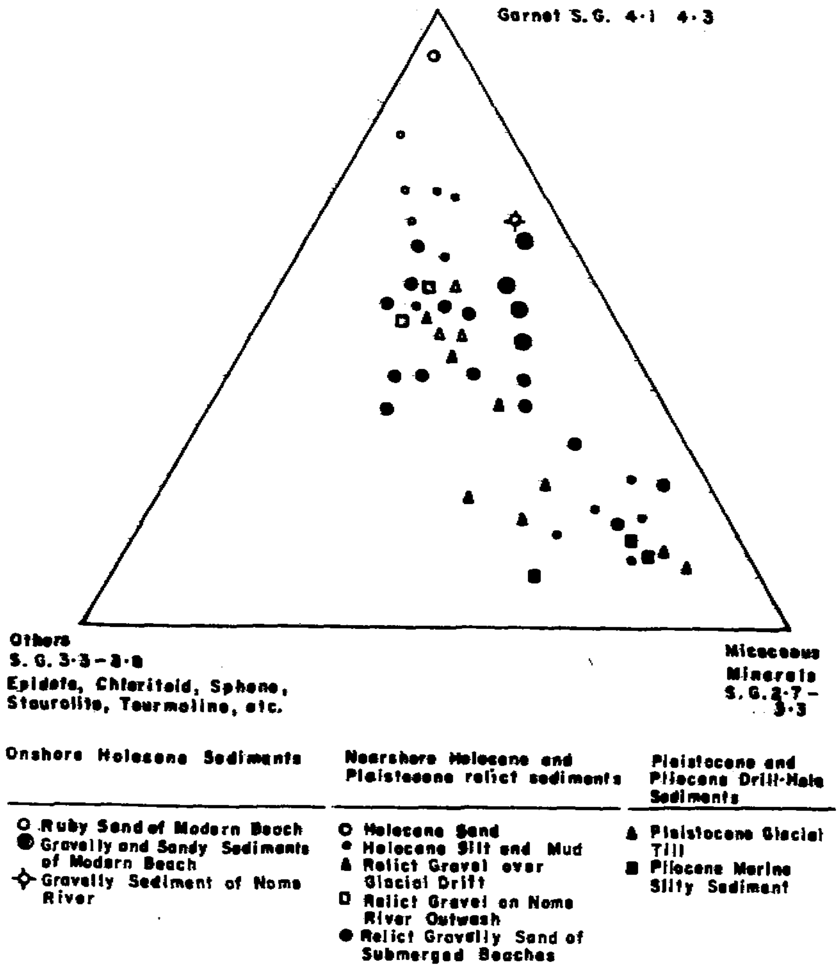


FIGURE 25. TRIANGULAR DIAGRAM OF HEAVY MINERAL ASSEMBLAGES

mainly reflect the effect of the sorting of mineral grains according to size and specific gravity.

Chapter 5

PROVENANCE

The specific source rocks for the heavy minerals of the Nome sediments are difficult to establish in the absence of detailed data regarding accessory minerals of the rocks from the inland region. However, an effort has been made to identify source rocks on the basis of petrographic description of rock types from published and unpublished reports of the U.S. Geological Survey (Collier and others, 1908; Moffit, 1913, Hummel, unpublish. rept.).

Much of the Nome area is underlain by calcareous muscovite-chlorite schist, graphitic mica-schist, and marble. Chlorite and muscovite are the major constituents of these schists. Also, epidote and amphiboles are reported to be major constituents in some of the schists (Moffit, 1913, p. 27). Hornblende, actinolite, and soda-amphibole (Crossite?) were found by Hummel (unpub. rept.) in amphibole schists of this region. Chloritoid, apatite, sphene, tourmaline, and zircon are common accessory minerals of these schists. In addition, green and brown biotite and garnet are present in the chlorite-mica schists. In the marbles, garnet, tremolite, and minerals of the epidote group are important minor constituents and apatite, sphene, and tourmaline are commonly present (Hummel, unpub. rept.).

According to Hummel (unpub. rept.), the biotite-garnet schists of the Kigluik Mountains (Fig. 3) are of medium to high grade as they are characterized by the presence of sillimanite and staurolite and the general absence of minerals of the epidote group. Hornblende and diopside are locally present as minor constituents of some of the schists and apatite, graphite, pyrite, pyrrhotite, and tourmaline are accessory constituents (Hummel, unpub. rept.).

Granite, granodiorite, and greenstone are important intrusive rocks of the Nome region. They mainly occur as small dikes and sills, although a granitic body of considerable size crops out near Cape Nome. Biotite is a minor constituent of this granite and apatite, magnetite tourmaline, sphene, and zircon are present as accessories (Moffit, 1913, p. 33; Hummel, unpub. rept.). Granodiorite is characterized by the presence of biotite and epidote as important minor constituents. Accessory minerals include garnet, sparse amphibole, tourmaline, magnetite, ilmenite, leucoxene, and zircon (Hummel, unpub. rept.). Moffit (1913, p. 32) reported glaucophane in greenstone schists of this region.

Minerals such as chlorite, epidote, chloritoid, hornblende, and tremolite-actinolite, which constitute the bulk of the heavy mineral suite of this region, probably have been derived from schists and marbles of the Nome region, as these are the most abundant rocks of the area. Calcareous mica-chlorite schist and marble seem to be the major source rocks for sphene. Garnet, which is the predominant mineral in heavy mineral suite, probably has been derived mainly from mica-chlorite schists and biotite garnet schists. Staurolite and sillimanite are definitely derived from high grade schists of the Kigluik Mountains. Kyanite has not been identified in the metamorphic rocks (Hummel, *unpub. rept.*), although it has been identified in the heavy mineral assemblages of Nome sediments.

Apatite, sphene, tourmaline, and zircon are found as accessories in both metamorphic and igneous rocks of this region. Tourmaline that occurs as small euhedra and contains abundant opaque (carbonaceous) inclusions, probably has been derived from mica-chlorite schists (Pettijohn, 1949, p. 18). Multiple sources such as mica-chlorite schist, granite, and granodiorite are suggested for zircon, which occurs in three varieties (colorless, slightly yellowish, and a purple color variety known as hyacinth) and ranges in shape from perfect prismatic euhedral crystals to ellipsoidal shaped rounded grains.

Chapter 6

SUMMARY AND CONCLUSIONS

1. Heavy mineral assemblages found in the various sediments of the Nome region are dominated by garnet, epidote, chloritoid, sphene, and staurolite. Hornblende, glaucophane, tremolite-actinolite, and tourmaline are more or less persistent, but subordinate minerals. Heavy minerals are more abundant in the 3-4 phi size fraction than in any other fraction. Garnet is somewhat more abundant in the 1-2 phi size fraction, whereas epidote, chloritoid, and other minerals, such as sphene, staurolite, hornblende, and glaucophane, are more concentrated in the 2-4 phi size fraction.

2. In the modern beach sediments, a high concentration of heavy minerals (15-30%) is associated with well-sorted sand (sorting coefficient: 2.8) of the swash zone and sand from a bar at Penny River. The sand of the swash zone and river bar are mainly worked by waves and littoral currents, and as a result, are better sorted than sediments from other parts of the beach (Greene, 1970). The heavy mineral percentage is relatively low (8%) for the poorly sorted gravel (sorting coefficient: 3.8) of the backshore region, which is worked by waves and ice.

In general, the high concentration of heavy minerals is expected in relict sediments because they have been winnowed by several transgressions and regressions of the sea during Pleistocene time. In the nearshore relict sediments of Nome, such as the relict gravel that mantles glacial drift and relict gravelly sand of submerged beaches, however, the weight percentage of heavy minerals is lower (12%) than Holocene sand (18%). The high weight percentage of heavy minerals in Holocene sand (mean phi 1.2) suggests the winnowing of sand by strong bottom currents. The low weight percentage of heavy minerals for relict gravel on glacial drift and relict gravelly sand of submerged beaches is probably due to the heterogenous nature of the relict sediments. The medium and fine-sized sand fractions of relict sediments are thought to have been introduced during Holocene time. Pleistocene glacial till and Pliocene marine silty sediment from several nearshore drill-holes show a low weight percentage of heavy minerals (8%).

3. In nearshore sediments, the maximum concentration of coarse gold particles (1 mm or larger) occurs in relict gravel that mantles glacial drift, rather than in any other sediment type such as relict gravel on the Nome River outwash fan, relict gravelly sand of submerged beaches or Holocene sediment (Nelson and Hopkins, 1969). Relict gravel on glacial drift, which carries a high gold value, does not show a high concentration of heavy minerals. Also, a very low concentration of micaceous minerals is expected for

relict gravel on glacial drift. The micaceous minerals percentage therein is more (30%) than that in Holocene sand (20%) that carries a low gold value. The lack of correlation between gold values and heavy minerals (weight percentage of heavy minerals, garnet percentage, and micaceous minerals percentage) is attributed to two factors: (1) the difference between hydraulic properties of gold and other heavy minerals, and (2) the heterogenous nature of relict sediments. Coarse gold particles, once concentrated in relict gravel that mantles glacial drift, are not moved by longshore currents and strong bottom currents because of their extremely high specific gravity (Nelson and Hopkins, 1969, p. 43), and medium to fine-size fractions of the relict sediments could have been introduced during the Holocene age.

4. The results of this investigation are disappointing because there are no minerals or mineral assemblages or the physical characteristics of minerals which are diagnostic of a particular sediment type. Minor mineral compositional variations observed in the heavy mineral assemblages from the various sediments of this area mainly reflect the effect of sorting of mineral grains according to size and specific gravity. Garnet and staurolite are somewhat more concentrated in modern beach and river sediments because of their high specific gravity (S.G. 3.8-4.3).

In nearshore sediments, the high garnet concentration is more or less associated with the high weight percentage of heavy minerals. Garnet is slightly abundant in Holocene sand (mean phi 1.2) and in Pleistocene relict gravel on the Nome River outwash fan (mean phi 2.2), which carries a high weight percentage of heavy minerals. The garnet content is minimum for Holocene silty sediment (mean phi 4.0), which has a low content of heavy minerals. In general, the relative abundance of other minerals, such as epidote, chloritoid, and sphene, increases with a decrease in garnet in the Holocene silty sediment (Fig. 23). Micaceous minerals are most abundant (40-70%) in silty and muddy sediments because light micaceous minerals are hydraulically equivalent to fine-size sediment (Doyle and others, 1968, pp. 381-389).

The mineral composition of Pliocene marine silty sediment from nearshore drill-holes is similar to that of the nearshore Holocene silty sediment, and has a high content of micaceous minerals and a low garnet content. Also, Pleistocene glacial till samples from one nearshore drill-hole were found to contain a high concentration of micaceous minerals which reflects the poorly sorted nature of the glacial drift.

5. The Nome sediments of Holocene, Pleistocene, and Pliocene ages are derived mostly from the metamorphic rocks of Nome and adjacent regions. The majority of the minerals such as garnet, chlorite, epidote, chloritoid, sphene, staurolite, hornblende, and tremolite-actinolite are reported

to occur in the metamorphic rocks of inland regions (Hummel, in press). Glaucophane has been reported to occur in the greenstone sills of this region (Moffit, 1913, p. 32). Zircon is found in granite, granodiorite, and mica-chlorite schist as an accessory mineral. Kyanite is the only mineral identified in the heavy mineral suite that has not been identified in the metamorphic rocks of Nome and adjacent regions (Hummel, unpub. rept).

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APPENDIXES

Appendix A

Weight Percentages of Heavy Minerals
(in 1-4 phi size fractions)

Sample No.	Weight Percent	Sample No.	Weight Percent	Sample No.	Weight Percent
18	9.0	98	17.6	244	31.8
19	26.8	101A	28.4	245	13.5
21	7.0	104	14.8	250	10.2
22	10.0	105	17.4	251	9.0
27	15.0	107	18.0	D-6-1	13.0
28	23.8	108	22.6	D-17-1	8.3
45	25.0	110	8.2	D-17-2	5.5
48A	9.4	113	15.0	D-19-11b	8.8
51	10.2	114	7.7	D-44-7b	13.6
52	18.4	115	14.5	D-47-3	7.4
60	14.4	117	18.0	D-47-6	7.8
63	6.0	118	17.0	D-47-8	7.8
65	25.0	119	8.0	D-47-12	7.9
67	9.0	120	7.6	G-12-51	5.8
69	9.2	120A	8.0	G-14-2b	30.5
71	11.8	121A	18.0	G-17-3	11.8
77	13.2	122	4.4	G-21-1	6.0
79	8.1	123	13.0	G-29-4	5.3
80	19.6	124	8.7	G-34-8i	90.0
84	8.0	128	6.0	G-35-1b	82.0
86B	10.0	235	10.0	St.116	38.5
89	17.0	236	7.4	G-47-2a	8.8
90	9.3	237	8.1	Ahp-20b	18.3
95	17.4	241	5.7	Ahp-68	16.4
96	18.5	243	12.3		

Appendix B

Weight Percentages of Heavy Minerals and Ferro-magnetic Minerals in Three Size Fractions

Sample No.	Grain size in phi	Weight Percent of Heavy Minerals	*Weight Percent of Ferromagnetic Minerals
21	1-2	6.1	6
	2-3	6.7	8
	3-4	9.1	28
45	1-2	8.8	3
	2-3	15.9	3
	3-4	60	8
65	1-2	10	8
	2-3	29	12
	3-4	60	40
84	1-2	9.1	6.5
	2-3	6.6	14
	3-4	10	20
86B	1-2	6.1	2
	2-3	4.5	6.5
	3-4	24.4	8
107	1-2	5.8	9
	2-3	12.7	4
	3-4	28.8	18
113	1-2	18	4
	2-3	13.2	8
	3-4	22.2	12
117	1-2	14.1	4
	2-3	12.3	6
	3-4	37.2	12
121K	1-2	15	2
	2-3	13.5	4
	3-4	56	6
G-34-8i	1-2	97.6	10
	2-3	99.3	29
	3-4	56	60

*Weight percent of the heavy mineral fractions

Appendix C

Franz Separation Data

Slope: 15^{o}
Tilt: 10^{o}

Fraction 1. Current at 0.2 amp
(a) ilmenite

Fraction 2. Current at 0.35 amp
(a) spessartite-almandine (R.i 1.79-1.81)
(b) chlorite
(c) chloritoid
(d) the variety of chloritoid which shows marked crossed dispersion

Fraction 3. Current at 0.45 amp
(a) epidote
(b) staurolite
(c) green and brown hornblende
(d) garnet
(e) chlorite
(f) chloritoid

Fraction 4. Current at 0.75 amp
(a) epidote
(b) staurolite
(c) tourmaline
(d) actinolite-tremolite
(e) garnet
(f) chlorite
(g) chloritoid
(h) green and brown hornblende

Fraction 5. Current at 1.2 amp
(a) tremolite-actinolite
(b) sphene
(c) clinopryoxene
(d) epidote
(e) staurolite

Fraction 6. Fraction rejected at 1.2 amp
(a) sphene
(b) muscovite
(c) apatite
(d) sillimanite
(e) zircon
(f) kyanite