Sedimentary Processes and Distribution of Particulate Gold in the Northern Bering Sea

GEOLOGICAL SURVEY PROFESSIONAL PAPER 689

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By C. HANS NELSON *and* D. M. HOPKINS

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By C. HANS NELSON and D. M. HOPKINS

ABSTRACT

Except for nearshore regions, most of the northern Bering Sea is remote from bedrock sources of gold onshore and insulated by Tertiary sediments from possible bedrock sources below the sea floor. However, land mapping, seismic profiles, cuttings from 51 holes drilled offshore by the U.S. Bureau of Mines, and 700 surface sediment samples show that during times of lowered sea level, glaciers pushed auriferous debris (1) as much as 5 kilometers beyond the present shoreline of Seward Peninsula and (2) nearly to the center of Chirikov Basin from Siberia's Chukotka Peninsula. Sediment textures, gold content, and presence of washed gravels far from the present shoreline indicate that subsequent transgression and regression of th sea have reworked the exposed glacial drift and left relict gravel as a thin lag layer overlying the glacial deposits; this veneer is richly auriferous along parts of the southern Seward Peninsula coast. During transgression and regressions of the shoreline, stillsands developed beaches at depths of about —36, —70 and —80 feet in the Nome region. Small amounts of gold are found in surface samples of the ancient submerged gravel, and larger concentrations may be present at depth. Streams have dissected the offshore moraines during periods of lowered sea levels, and gold is locally concentrated in the resulting alluvium but is generally buried and has not been well sampled by the few scattered drill holes. Since the last rise in sea level, nearshore bottom currents have deposited sand, silt, and clay, generally lacking gold, in the former stream valleys and in other topographic depressions; bottom currents also have prevented the burial of auriferous relict gravel in nearshore regions of elevated topography and in offshore eastern Chirikov Basin, where water masses are funneled toward the Bering Strait.

Flakes 1 mm in diameter or larger constitute the bulk of the gold in the auriferous relict gravel; the distributions of this coarse gold, as well as the lateral variations in median gold content of pannable particulate gold in different areas, provides evidence of the location of offshore gold sources. Most gold flakes 1 mm or more in diameter are found (1) in the vicinity of bedrock exposures on the sea floor, (2) near outcrops of mineralized material on land, and (3) in offshore deposits of glacial drift. Small gold particles (about 0.25 mm or less) have been widely dispersed from these source areas by waves and bottom currents, but gold particles larger than 1 mm have not been transported from the offshore sources by marine processes.

The fine-grained bottom sediments of the northern Bering Sea contain small quantities of fine-sized gold. Regional median values of pannable particulate gold amount to a few tenths of a part per billion in most areas in the Chirikov Basin and are higher near source areas, but gold too fine to be recovered in a gold pan also occurs in small quantities throughout the basin.

Statistical tests on the gold content of samples from the richest part of surface relict gravels overlying drift near Nome suggest that coarse gold flakes (1 mm or larger) are randomly distributed, that average tenor is 920 ppb, and that a potentially minable deposit exists. Geologic setting, distribution of coarse gold particles, and median gold content of the different areas in the northern Bering Sea indicate that other placer deposits are most likely to occur (1) offshore from Nome, in any relict-gravel veneer of older buried auriferous glacial drift or in basal gravel of ancient stream valleys and beaches cutting auriferous drift, (2) on the sea floor in gravels overlying bedrock near Sledge Island and to the northwest, and (3) in sea-floor exposures of possibly auriferous moraines in the northeastern part of the Chirikov Basin. In general, significant concentrations of gold should occur in offshore relict gravels deposited by shoreline or stream processes that rework glacial drift or bedrock that contains coarse gold.

INTRODUCTION

This paper describes an investigation of gold in bottom sediments of the Chirikov Basin, which is the part of the Bering Sea bounded by the Seward Peninsula, the Yukon River Delta, St. Lawrence Island, and the coast of the Chukotka Peninsula (fig. 1).

Our results indicate that gold is widely dispersed on the floor of the basin and that several nearshore areas and a few offshore areas merit further scrutiny in the search for gold placers of economic grade.

Several of Alaska's major placer tin and gold-producing areas and many minor ones are found near the shores of the northern Bering Sea (fig. 1) and, therefore, the 25,000-square-mile (65,000 sq km) submerged area encompassed within the Chirikov Basin east of the Russian-American Treaty Line seems a likely place in which to look for new tin and gold deposits. Studies of marine geology of the region were conducted during the summers of 1967 and 1968 by the U.S. Geological Survey in coopera-

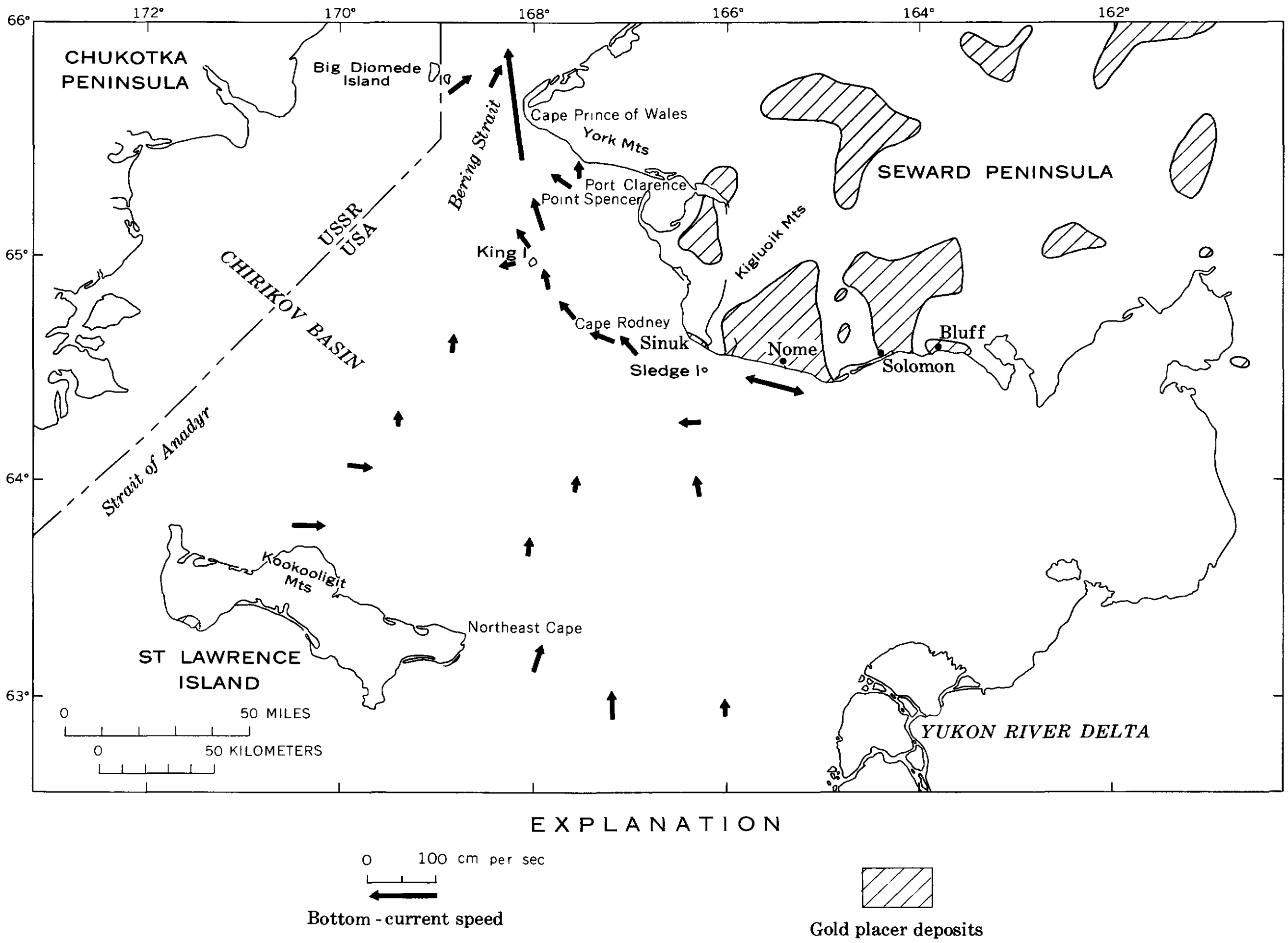

FIGURE 1.—Bottom currents and onshore placer gold deposits of the northern Bering Sea area. Bottom-current data are modified from Fleming and Heggarty (1966); placer locations are from Cobb (1967a, b, c; 1968a, b) and Cobb and Sainsbury (1968).

tion with the National Oceanographic and Atmospheric Administration (Marine Minerals Technology Center and National Oceanographic Survey) and the University of Washington. The survey program included the following: Recovery and study of about 700 bottom samples, detailed sampling of segments of the beach at Nome and Bluff, reconnaissance sampling of beaches at Tin City, Wales, and Northeast Cape, seismic profiling, ship-borne magnetic studies, and examination of borehole cuttings from 51 sites drilled by the U.S. Bureau of Mines near Nome (pl. 1). Many of the data are still being studied, but some of the results have already been reported (Hopkins, 1968; Hopkins and others, 1968; Nelson and Hopkins, 1968; Grim and McManus, 1970; McManus and Smyth, 1970; Nelson and others, 1969; Scholl and Hopkins, 1969; Silberman and Hopkins, 1969; Venkatarathnam, 1969; Greene, 1970; Tagg and Greene, 1970); a previous version of this report was released in the open files in 1969. Most of the useful gold data are already available to guide continuing exploration for mineral resources in the northern Bering Sea.

ACKNOWLEDGMENTS

A great many individuals have assisted us in gathering the data for this report. We must make special mention of the hospitality and cooperation of scientists Dean McManus, Lee Bennett, and Richard Perry and of the technical and sailing crews of the RV *Thomas G. Thompson* (Univ. Washington), the RV *Virginia City* (U.S. Bur. Mines), the OSS–1 *Oceanographer* and OSS–32 *Surveyor* (U.S. Coast and Geodetic Survey) and the charter vessel MV *Tomcod*. Assistance with the surface sampling by Leal Kimrey and processing of drill samples were provided by the U.S. Bureau of Mines under the direction of Howard Heginbotham and Gary Smyres. The Bureau of Mines drilling program was carried out under the supervision of Robert Robey, Alvin

Lense, Oleg Terichow, Richard Jenkins, and Bert Barnes. Jenkins and Barnes (Marine Minerals Technology Center) and Gary Greene of the Geological Survey collected samples using SCUBA equipment. The samples collected in 1967 were expertly panned by Les Darrington of Placerville, Calif., and Andy Peterson of Nome, Alaska. All the samples collected in 1968 were panned by Mr. Peterson. Procedures and techniques for studying the subvisible gold content of the bottom samples were developed by our colleagues Ray Martin and Kam Leong of the U.S. Geological Survey; other colleagues, Dick Tagg and John Schlee, assisted in size analysis and computer processing of data. We have benefited greatly from extensive conversations and cordial cooperation with W. W. Woodward and A. H. Daily, formerly of Shell Oil Co.; John Lord of American Smelting and Refining Co.; and John Metcalfe, James Crawford, and Carl Glavinovitz of the United States Smelting, Refining, and Mining Co. Frank Wang collected samples in the closely sampled areas near Sledge Island and between Cape Nome and Bluff and provided advice on interpretation of the results. C. L. Sainsbury generously offered use of a geological map that he compiled from field surveys in western Seward Peninsula from 1960 to 1968. Discussions with Ralph Hunter provided the necessary information for statistical analysis of the data, and he and Sainsbury critically reviewed the manuscript, making substantial improvements.

METHODS OF STUDY

Different types of samples were collected on the various cruises, and a variety of analytical techniques were used (table 1). Nearly all samples were concentrated prior to analysis to avoid particle-sparsity effects (Clifton and others, 1967). In addition, after 1967 very large raw samples were taken to remain within the limits of statistical reliability imposed by the relatively low concentrations and average particle sizes of the gold in most samples (Moore and Silver, 1968; Clifton and others, 1969). Moving averages were calculated to help alleviate particle-sparsity effects that were particularly apparent in the small-sized samples of gravel (>2 mm) with very coarse gold (>1 mm) collected off Nome in 1967.

TABLE 1.—*Methods of study*

Sample source (cruise)	Location method	Sampling method	Typical sample size (kg)	Method of preconcentrating gold	Method of gold analysis	Additional analyses at selected locations
Nome Beach (1967).	U.S. Geol. Survey topographic maps and aerial photographs.	Channel samples	5	Panning	Color count, AA.[1]	Texture, heavy minerals, lithology, roundness.[2]
Bluff Beach (1968).	do	do	5	do	do	Texture, heavy minerals.
Tin City and Wales Beaches (1968).	do	do	5	do	Color count, AA, emission spectrometer.	Tin content by emission spectrometer, wet chemical, and X-ray fluorescence.
Northeast Cape Beach, St. Lawrence Island (1968).	do	do	5	do	Color count, AA.	
RV *Virginia City* (U.S. Bur. Mines) (1967).	Raydist, PRS (Precision Ranging System), sextant.	Shipek grab sampler, SCUBA diver, Becker drill, Sonico drill. Drill cuttings flushed every 6–12 ft of drilling. Maximum sediment penetration of 244 ft.	2–5; 5–10; 9–12	> 5 mm screened out, remainder panned; whole phi size fractions <0.5 mm analyzed by AA.	Color count, AA, amalgamation and weighing.	Pebble lithology and roundness, texture. Stratigraphic and lithologic correlation of drill holes. Clay, heavy mineral, pollen, Foraminifera, Ostracoda, Mollusca, and radiocarbon dating studies in progress on selected drill samples.
RV *Thomas G. Thompson* (Univ. Wash.) (1967).	Loran A, radar.	10 gal Van Veen, Shipek, chain dredge.	0.5–10	Elutriation	AA	Texture, mineralogy, Foraminifera.
OSS–1 *Oceanographer* (1968).	Loran C, radar, satellite.	Campbell grab, 10 gal Van Veen, box corer.	10–30	> 2 mm removed by screening.	Color count, AA.	Studies of texture, heavy minerals, Foraminifera, Mollusca in progress, as well as studies of pebble roundness and lithology.
OSS–32 *Surveyor* (1968).	Radar, Raydist.	10 gal Van Veen	10–12	Clay and silt size removed by settling and siphoning techniques.	do	Do.
MV *Tomcod* (1968).	PRS	10 gal Van Veen	10–30	Panning	do	Do.
Eskimo skin boat (1968).	Compass triangulation fixes.	5 gal Van Veen	5–10	do	do	Do.

[1] Atomic absorption analysis of gold in elutriation and pan concentrates as described by VanSickle and Larkin (1968) and modified by Kam Leong at the Office of Marine Geology, Menlo Park, Calif.

[2] Seismic-refraction study of Nome Beach also completed (Greene, 1970).

Most samples were preconcentrated by screening out the gravel and then siphoning off the suspended silt- and clay-sized material. The material that remained, mainly sand with all gold more than 10 microns in diameter, was panned, the gold particles were counted, and their sizes estimated (table 2) so

TABLE 2.—*Size and weight classification of visible gold particles*

[Compiled from data of J. C. Antweiler (oral commun., 1969); A. Dailey (written commun., 1969); H. Heginbotham (written commun., 1967); Clifton and others (1969); Hite (1933)]

Visual gold particle size	Estimated modal weight[1] (mg)	Estimated modal diameter[1] (mm) Spheres	Flakes[2]	Comparable grain size
Visible gold[3]				
1 color	15	1.20	2.40	Very coarse sand.
2 color	4	.70	1.40	Coarse to very coarse sand.
3 color	1	.50	1.00	Coarse sand.
4 color or very good trace.	.3	.30	.50	Medium sand.
Good trace	.03	.16	.30	Fine sand.
Very fine trace	.003	.07	.125	Very fine sand.
Subvisible gold				
Ultra fine trace	0.0001	0.060	0.100	Very fine sand.
Smallest size particulate gold observed.	.000003	about 0.005–0.010		Very fine silt.
"Carlin type" gold.	....	about 0.001		Coarse clay.

[1] Range of panner's qualitative visual estimates probably is about ±50 percent in the No. 2 to 4 color size classes; larger sizes are classified as 1¼, 1½, and so forth. Estimates for trace-sized gold are highly variable and probably exceed ±100 percent.

[2] Diameter approximately 10 times the thickness.

[3] Expert panning normally will recover all visible gold; however, panning efficiency is highly variable and poor for subvisible gold.

that relative gold content could be evaluated immediately. The pan concentrates were analyzed by amalgamation or by atomic absorption techniques (VanSickle and Larkin, 1968) to determine actual gold content. A few samples were preconcentrated by elutriation to wash out silt- and clay-sized particles of low density so that only the gold and the coarser sediment would remain (R. Martin, unpub. data); this concentrate was then analyzed by atomic absorption techniques. Gold particle size was estiated for a few other samples by sieving the samples and then analyzing the total individual size fractions by atomic absorption techniques.

The continuing investigations of texture, mineralogy, and fossil content of northern Bering Sea sediments will eventually permit detailed analysis of sedimentary environments, processes of deposition, and geologic history.

OCEANOGRAPHIC SETTING

The Chirikov Basin is a shallow marine basin protected by land masses throughout most of its perimeter (figs. 1, 3). The eastern half is mostly less than 100 feet (30 meters) deep. Depths are greater than 150 feet (45 meters) only in a deep channel off Northeast Cape, St. Lawrence Island, in a small enclosed basin off the Kookooligit Mountains of St. Lawrence Island, and in parts of a broad troughlike feature that extends from the Anadyr Strait to the Bering Strait. Because the Chirikov Basin (fig. 1) is rather protected, wave energy is lower than in the North Pacific. Moving ice covers the sea for about 7 months of each year. Pressure ridges of ice occasionally become grounded in depths as great as 50 to 100 feet (15 to 30 meters) below sea level (Art H. Daily, oral commun., 1967; Gene L. Bloom, oral commun., 1968). Divers report that grounded ice "bulldozes" bottom sediment for short distances on the sea floor (H. G. Greene, oral commun., 1967). Distribution of gravel-sized material (discussed later in the paper) suggests that pressure-ridge ice in contact with the sea floor may pick up bottom sediment and release it short distances away.

Strong currents (1 knot or more) move along much of the coastline, and bottom currents intermittently approach 3 knots (150 cm per sec) in the eastern part of the Bering Strait (fig. 1). In the Nome region, bottom currents flow intermittently and suddenly at speeds of up to nearly 2 knots (100 cm per sec), moving either eastward or westward parallel to the coast. Sparse observations in the central regions of the Chirikov Basin indicate that currents are relatively slow, and none faster than half a knot (25 cm per sec) have been reported.

GEOLOGIC SETTING

The Chirikov Basin spans several geologic provinces of pre-Tertiary rocks (fig. 2). Most of Seward Peninsula is underlain by metamorphic rocks of Precambrian and early Paleozoic age, but unmetamorphosed limestone of Ordovician and Silurian age is thrust over the metamorphic rocks in the York Mountains of the western Seward Peninsula (Sainsbury, 1965, 1969; Sainsbury and others, 1969). Northern Chukotka is underlain by a similar sequence of Preccambrian and lower Paleozoic metamorphic rocks, and these are overlain by younger Paleozoic sedimentary rocks. Eastern St. Lawrence Island is composed of a sequence of gently folded and unmetamorphosed Paleozoic and lower Mesozoic rocks (Patton and Dutro, 1969). Western St. Lawrence Island and southern Chukotka are underlain by upper Mesozoic volcanic rocks, but Paleozoic metamorphic and sedimentary rocks are exposed in local structural highs in southern Chukotka. Sharply folded Cretaceaus sedimentary rocks, locally underlain by and interfingering with upper Mesozoic volcanic rocks, dominate the eastern shore of the Chirikov Basin north of the mouth of the Yukon River. The basin itself is underlain by a prism of

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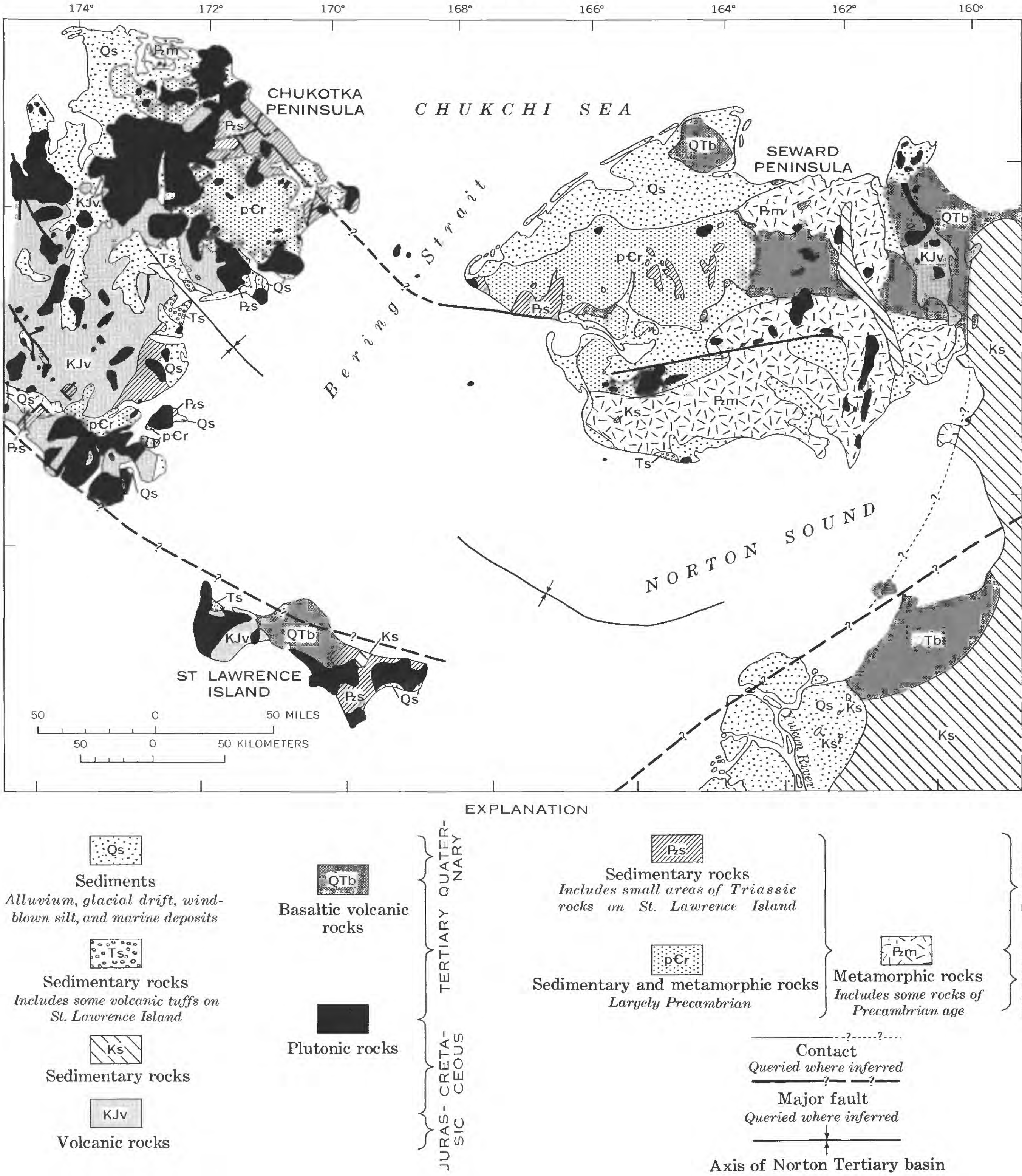


FIGURE 2.—Generalized geologic map of the northern Bering Sea region. Land geology in Alaska from Dutro and Payne (1957), Patton and Dutro (1969), Sainsbury, Kachadoorian, Hudson, Smith, Richards, and Todd (1969), and an unpublished map by Sainsbury (1969); land geology in Siberia from Krasny (1964). Structural features of marine areas from Scholl and Hopkins (1969) and Grim and McManus (1970).

Tertiary sediments locally more than 6,000 feet (1,800 meters) thick (Scholl and Hopkins, 1969). The Tertiary sediments extend onto present-day land areas in part of St. Lawrence Island and Chukotka.

Profitable gold placers are rarely found more than 6 to 12 miles (10 to 20 km) from bedrock sources, as Emery and Noakes (1968) have emphasized. Thus, the most promising areas for submerged placers in the Chirikov Basin are those close to known land placers (fig. 1), such as those at Nome, on other coastal areas on the Seward Peninsula, on the southwest shore of St. Lawrence Island, and possibly near the eastern coast of Chukotka. Small amounts of fine gold, however, appear to be dispersed for far greater distances than the larger sized gold generally recovered in commercial placer deposits in the land source areas. Detrital gold in the central part of the Chirikov Basin must have been derived mainly from the surrounding land areas, because potential bedrock sources beneath the basin itself are mostly buried deeply beneath the nearly undeformed Tertiary sediments.

Glaciers have played an important role in dispersing and redistributing placer gold on the Seward Peninsula, and so we have devoted much research to delineating the extent (fig. 3) and chronology of

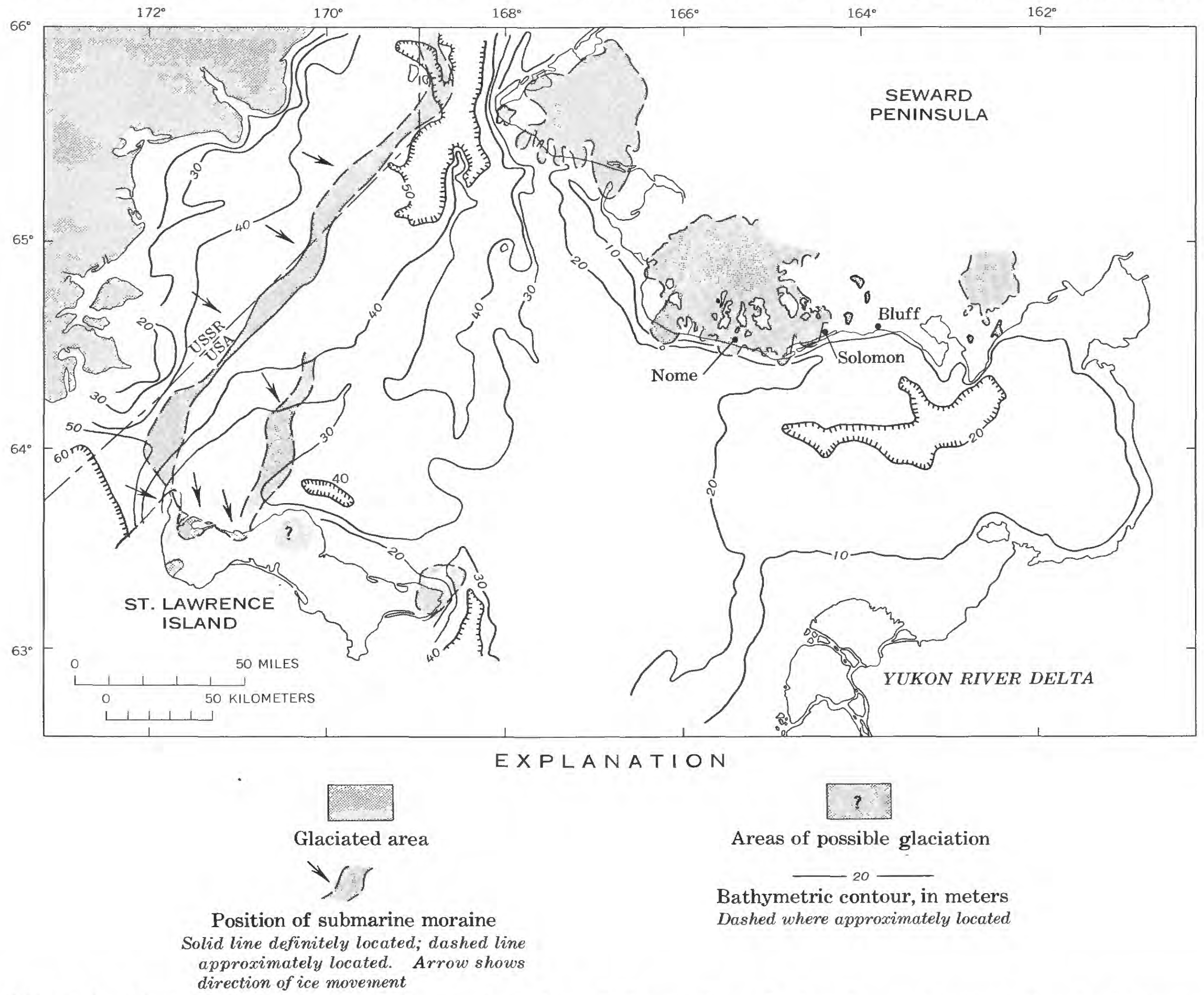


FIGURE 3.—Maximum extent of Pleistocene glaciation of the northern Bering Sea and surrounding land masses. Bathymetry from Grim and McManus (1970) and U.S. Coast and Geodetic Survey Preliminary Chart PBM–1, St. Lawrence Island to Port Clarence.

glaciation in the northern Bering Sea region. Glaciers, by mass transport, apparently can carry coarse gold particles long distances from bedrock sources, though with increasing dilution as the distance from the source increases. Evidence from seismic profiling (Tagg and Greene, 1970), from drill holes, and from surface sediment distribution shows that glaciers originating in the hills and mountains north of Nome have extended short distances beyond the present shoreline. The lower hills and small mountain ranges of western Seward Peninsula also have supported glaciers that evidently extended short distances beyond the present shore. The Chukotka Peninsula has been inundated by glacial ice that extended well beyond the present shoreline (Petrov, 1967).

We initially assumed, as did Creager and McManus (1967), that the floor of the Chirikov Basin had never been heavily glaciated; however, Sainsbury (1967) suggested the possibility that glacial ice moved eastward from Chukotka into the Bering Strait area, and much new evidence indicates that the basin has been extensively glaciated. Dredge hauls in 1967 and surface sediment sampling in 1968 resulted in the recovery of apparent glacial drift in areas well away from the present shore of Chukotka, and high-resolution seismic profiling revealed a series of linear belts of disturbed sediments interpreted as submerged and partly buried glacial moraines (Grim and McManus, 1970). Exposures of glacial drift overlying Pleistocene marine sand and gravel were discovered on a barrier bar of Nyrakpak Lagoon on the western shore of St. Lawrence Island in 1966 (D. S. McCulloch, unpub. data). In 1968, Hopkins recognized thrust structures in the marine sediments and erratic boulders in the till, features that suggest the drift was deposited by glacial ice that encroached from offshore. It now appears that glacial ice originating in Siberia once covered a large area in the western part of the Chirikov Basin and that these glaciers spread onto present-day land areas of northwestern St. Lawrence Island.

STUDIES NEAR NOME

GENERAL GEOLOGY

Knowledge of gold and sediment distribution in the Nome area will be considered first because it is most complete and can serve as a model for later discussion of the rest of the Chirikov Basin. Onshore geologic mapping and our offshore studies (figs. 4, 5) have shown that bedrock lies just below the sea bottom off the Cripple River in the western part of the area but that it is deeply buried beneath fine-grained marine sediments of late Tertiary and Quaternary age farther east. A series of upper Tertiary and Quaternary continental and shoreline deposits rest on bedrock near the modern shoreline and beneath the coastal plain. The emergent ancient beach deposits have yielded much of the gold produced in the Nome area.

The coastal plain at Nome was overridden by glacial ice at least twice, and glaciers extended several miles seaward of the present coastline in the area between the mouths of the Nome River and Rodney Creek (fig. 4). The first glaciation apparently took place during early Pleistocene time, and the last during the Illinoian Glaciation; the much smaller glaciers of Wisconsin age did not reach the coastal plain at Nome (Hopkins and others, 1960). The glaciers eroded mineralized bedrock and older alluvial placers in the hills north of Nome and

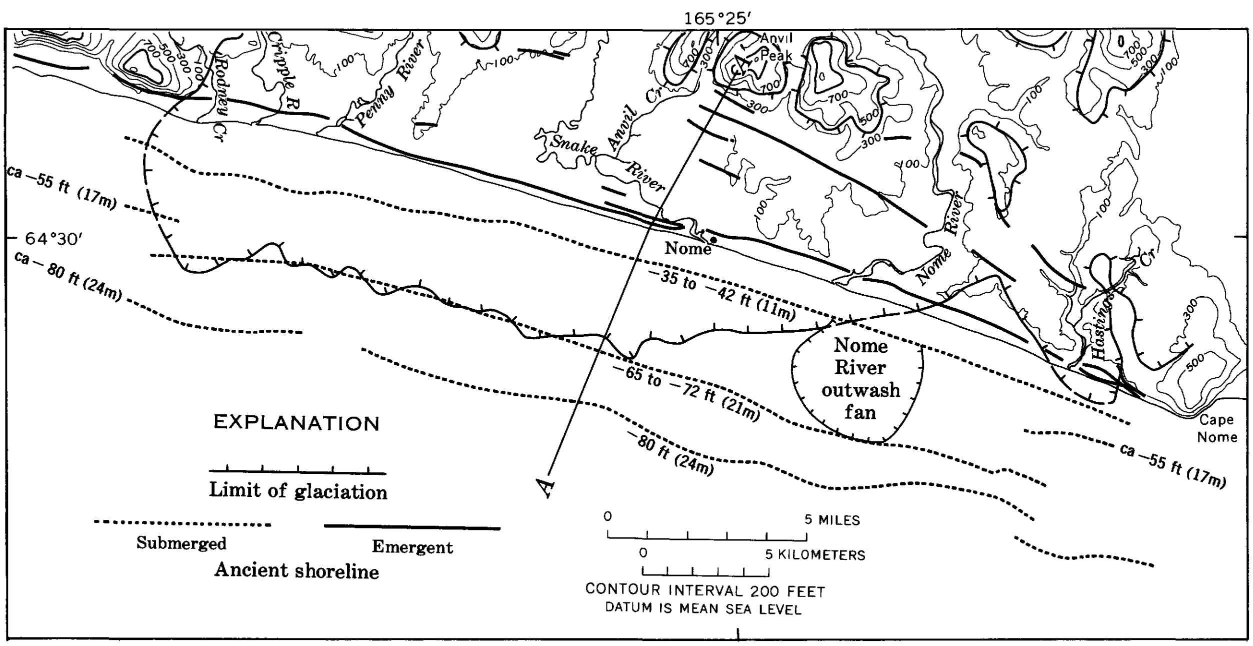


FIGURE 4.—Major features of Pleistocene geology of the coastal plain and offshore area at Nome. See figure 5 for section *A–A'*.

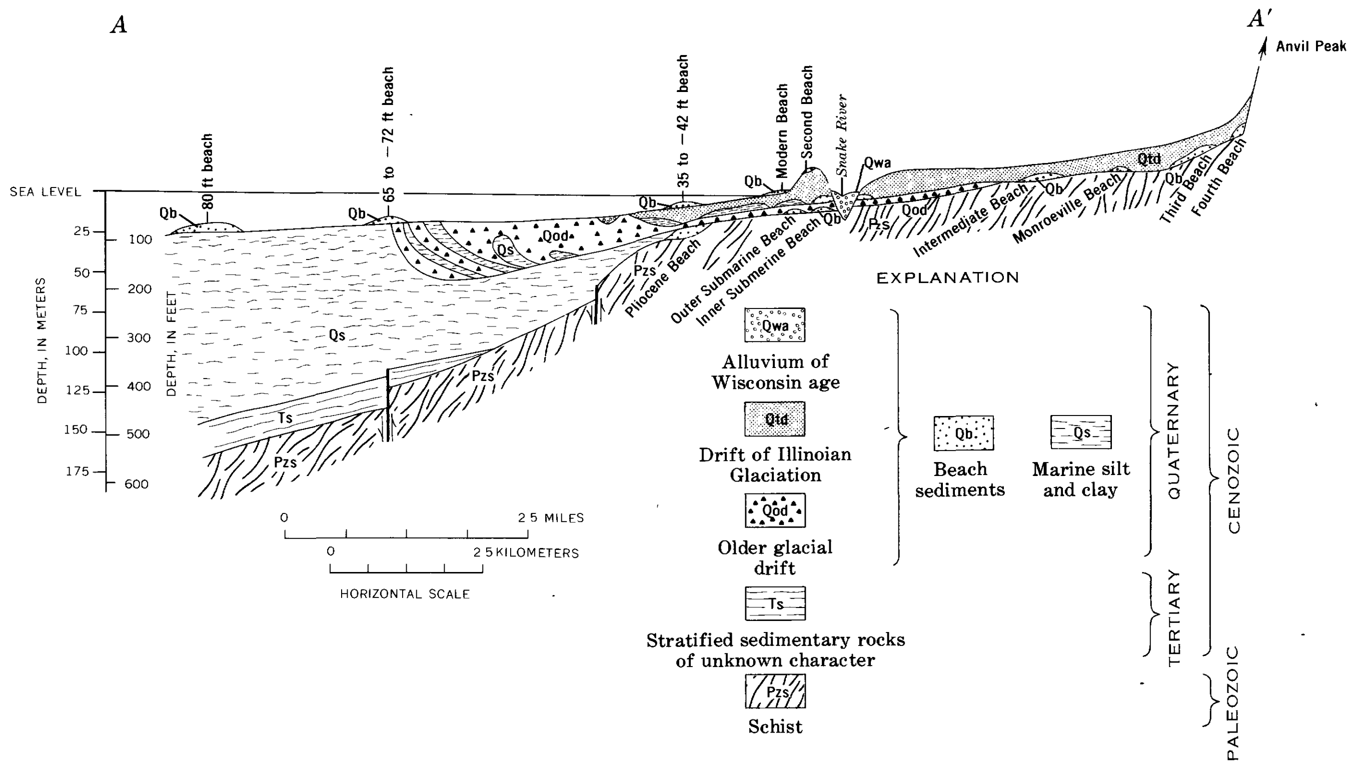


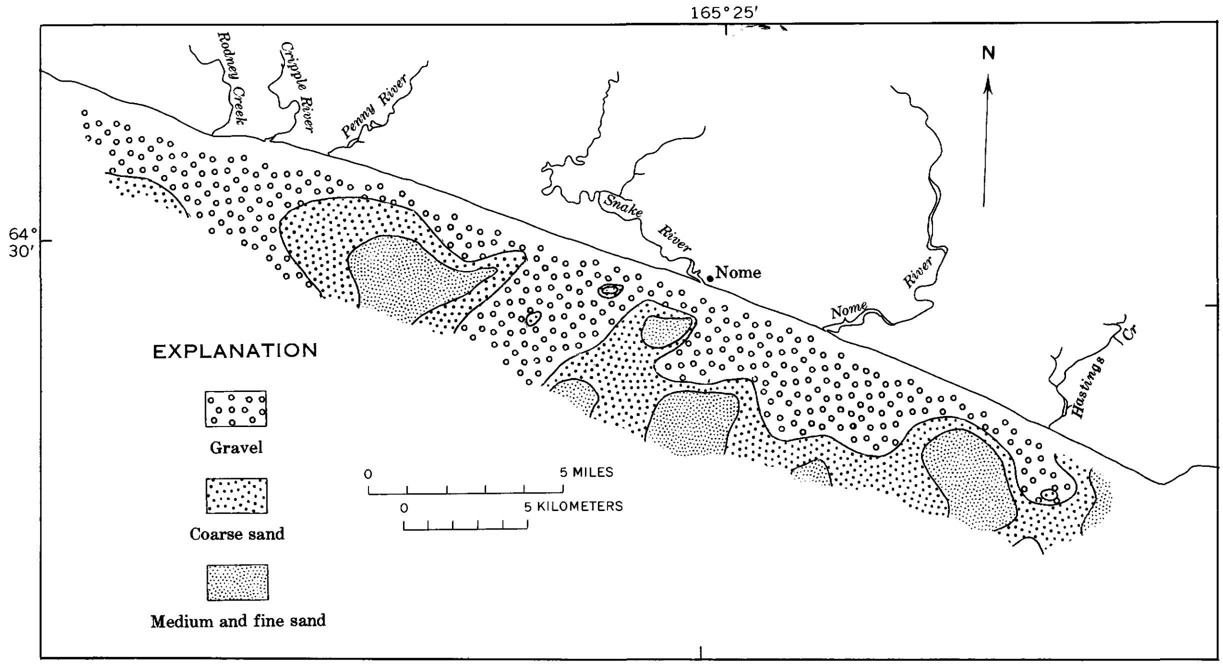
FIGURE 5.—Geologic section across the coastal plain area at Nome. Onshore geology from Hopkins (1967) and based in part on unpublished results of exploratory drilling by United States Smelting, Refining, and Mining Co. Offshore geology based on seismic-reflection profiles by A. R. Tagg and H. G. Greene, 1970, and results of exploratory drilling by Shell Oil Co. and U.S. Bureau of Mines.

excavated segments of the older beach placers on the coastal plain; consequently small quantities of gold are uniformly dispersed within the glacial drift. Offshore seismic-reflection profiles (Tagg and Greene, 1970) and drilling revealed a series of layers of glacial till intercalated with marine clayey silt at the margin of the offshore glaciated area (fig. 5); these deposits provide evidence that the glaciers sheared into the underlying marine sediments. During Pleistocene episodes of lowered sea level, a large fan of outwash gravel was built off the present mouth of the Nome River. Also, stream valleys eroded during low sea level episodes can be traced in the offshore area as discontinuous channels and chains of irregular depressions, now partly filled with muds.

Sediments of the present sea floor have been subjected to wave action during periods when sea level has risen to or above its present position. Beach deposits younger than the drift occur at about 30 feet (9 meters) above sea level and, offshore, at depths of —35 to —42 feet (about —11 meters), —65 to —72 feet (about —21 meters), and about —80 feet (about —24 meters). Beach gravel is also present off Cape Nome and off the western end of the Nome coastal plain at a depth of about —55 feet (—17 meters), but the —55-foot shorelines cannot be traced continuously across the Nome area. The onshore beach deposit at 30 feet (9 meters), locally called Second Beach, was formed during the Sangamon Interglaciation (Hopkins, 1967); the ages of the submerged beach deposits are uncertain, but the one at —70 feet (—21 meters) may have formed during an episode when sea level rose well above its minimum late Pleistocene position, about 30,000 to one at —70 feet (—21 meters) may have formed during the Holocene rise in sea level between 15,000 and 5,000 years ago. Second Beach and the modern beach at Nome have both been extensively mined for gold. The submerged beaches are therefore attractive exploration targets. Net longshore drift is eastward along the present beach in the Nome area, and the distribution of gold in the older beach deposits on the coastal plain suggests that longshore drift was also predominantly eastward when they were formed. Trends in pebble size, pebble roundness, and quartz content indicate that the eastward drift predominated during the formation of the submerged beach deposits as well (D. M. Hopkins, unpub. data). Pebbles derived from morainal and outwash areas have been carried eastward along the submerged beaches and deposited in linear belts extending across areas generally underlain by marine silt and clay.

BOTTOM SEDIMENTS

Distribution of bottom sediment near Nome (fig. 6) is determined by interaction of the present strong longshore and offshore currents with deposits of subaerial sediment left from earlier glaciers and streams; and by the effects of past wave action upon these subaerial sediments when the shoreline transgressed and regressed over the region. A narrow belt of well-sorted medium sand, evidently actively moving along the coast, extends from the modern strand



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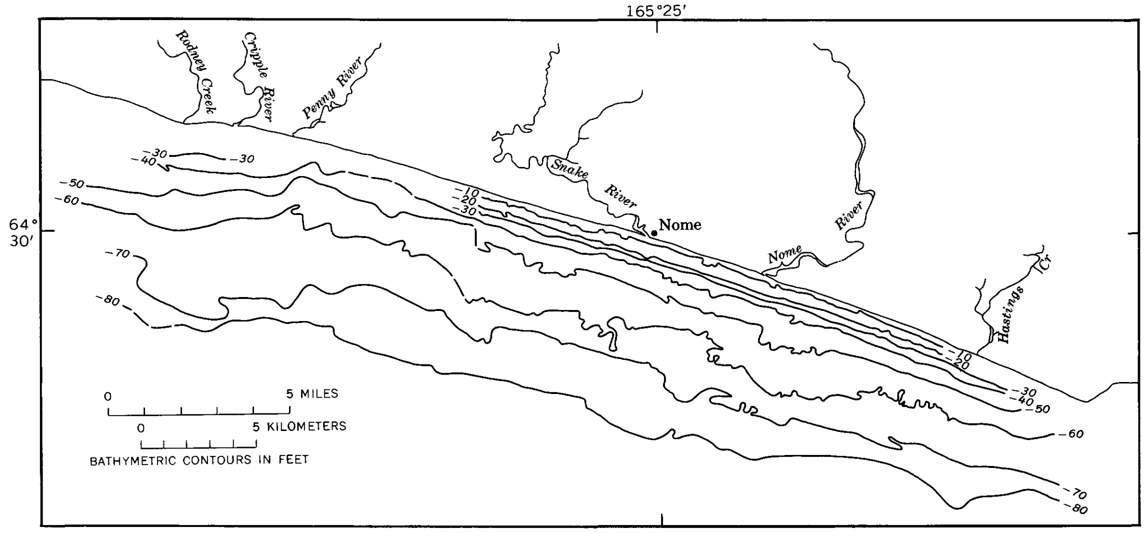

B

FIGURE 6.—Mean size distribution of surface sediments (*A*) and bathymetry (*B*) in the shore area near Nome. (Bathymetry from Tagg and Greene, 1970.)

to depths of —20 to —30 feet (—6 to —9 meters). Offshore from the trangressive sand, gravel is found in an irregular belt parallel to the shore and in seaward lobes where areas of moraine, outwash, alluvium, and bedrock extend farthest from shore. The gravel pattern is interrupted by tongues of finer sediment extending landward in the topographic lows and by small patches of well-sorted medium sand (fig. 6). Divers find that in the relict-sediment area, gravel is uncovered on topographic rises and is covered by sand in minor depressions; this explains the patchy distribution of sand in the relict-gravel region and suggests that the strong bottom currents (fig. 1) prevent deposition of sand on rises but deposit it in depressions. The gravel and sand patches form a thin mantle resting on less uniform till, outwash, and aluvium. The sorted surface gravel apparently was reworked by past wave action, which winnowed out fine sediment during shoreline migrations resulting from rises and drops in sea level. Seaward from the relict-gravel areas and regions of strong currents, the bottom sediments grade from muddy sand to clayey silt and contain variable amounts of pebbles.

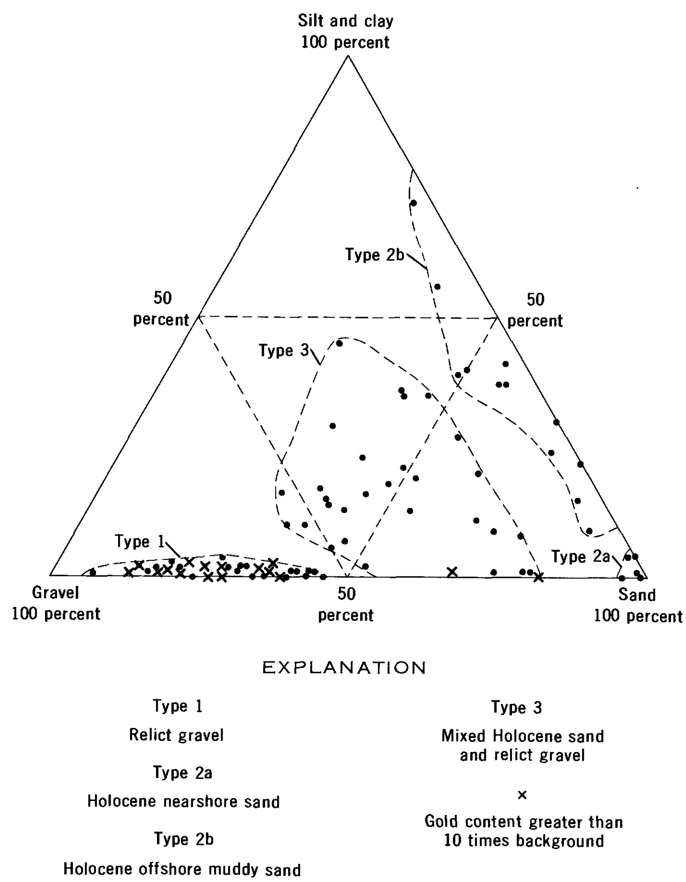

FIGURE 7.—Classification and gold content of sediment types in the Nome nearshore area.

Thus, four general types of surface sediment (fig. 7) characterize the surficial geology (fig. 8). Relict sediment containing more than 50 percent gravel occurs where transgressions and regressions of the shoreline have winnowed fine particles from till, outwash, alluvium, or weathered bedrock and where strong currents have prevented Holocene deposition (see type 1, fig. 7). Shoreward of the relict gravels, well-sorted and medium-sized transgressive sand, of Holocene age, containing 5 percent or less silt and clay, lies in the present-day zone of longshore current movement (see type 2a, fig. 7). Seaward of the relict-gravel zones, Holocene muddy sand grades offshore to clayey silt (see type 2b, fig. 7). A mixed-sediment type of Holocene mud and relict gravel 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 recent mud (see type 3, fig. 7). Submerged beach remnants have no distinct sediment type because they were cut indiscriminately across varied older marine and continental deposits at depths of —35 to —42 feet (—11 to —13 meters) and —65 to —72 feet (—20 to —22 meters). They can be distinguished by topographic and seismic expression, by the relatively high degree of rounding and abundance of quartz pebbles in the gravel fraction, and by size class modes (Nelson and others, 1969).

DISTRIBUTION OF GOLD

This report is concerned primarily with gold in the surficial sediments; however, a summary of the vertical distribution of gold in the Bureau of Mines drill holes provides some insight into the origin and significance of gold concentrations in subsurface sediments of the sea floor. Gold is commonly scarce or even absent in sediments on bedrock. The fine-grained marine deposits in the drill holes rarely contain visible gold. The glacial till, however, consistently contains small amounts, as it does onshore. The average value of gold in the till is about \$0.11 per cubic yard, which is 70 ppb (parts per billion).[1] Outwash interstratified within the till and alluvial gravel at the base of stream channels incised into the glacial drift commonly contain more gold than the till. Some buried beach gravel also contains appreciable amounts of gold. But the highest concentrations of gold in the drill holes generally were in gravels in the first 6-foot increment of drill cuttings. Surface grab samples, many obtained while the RV

[1] At \$35 per ounce, 10 ppb gold is equivalent to \$0.01 per ton, or \$0.016 per cubic yard.

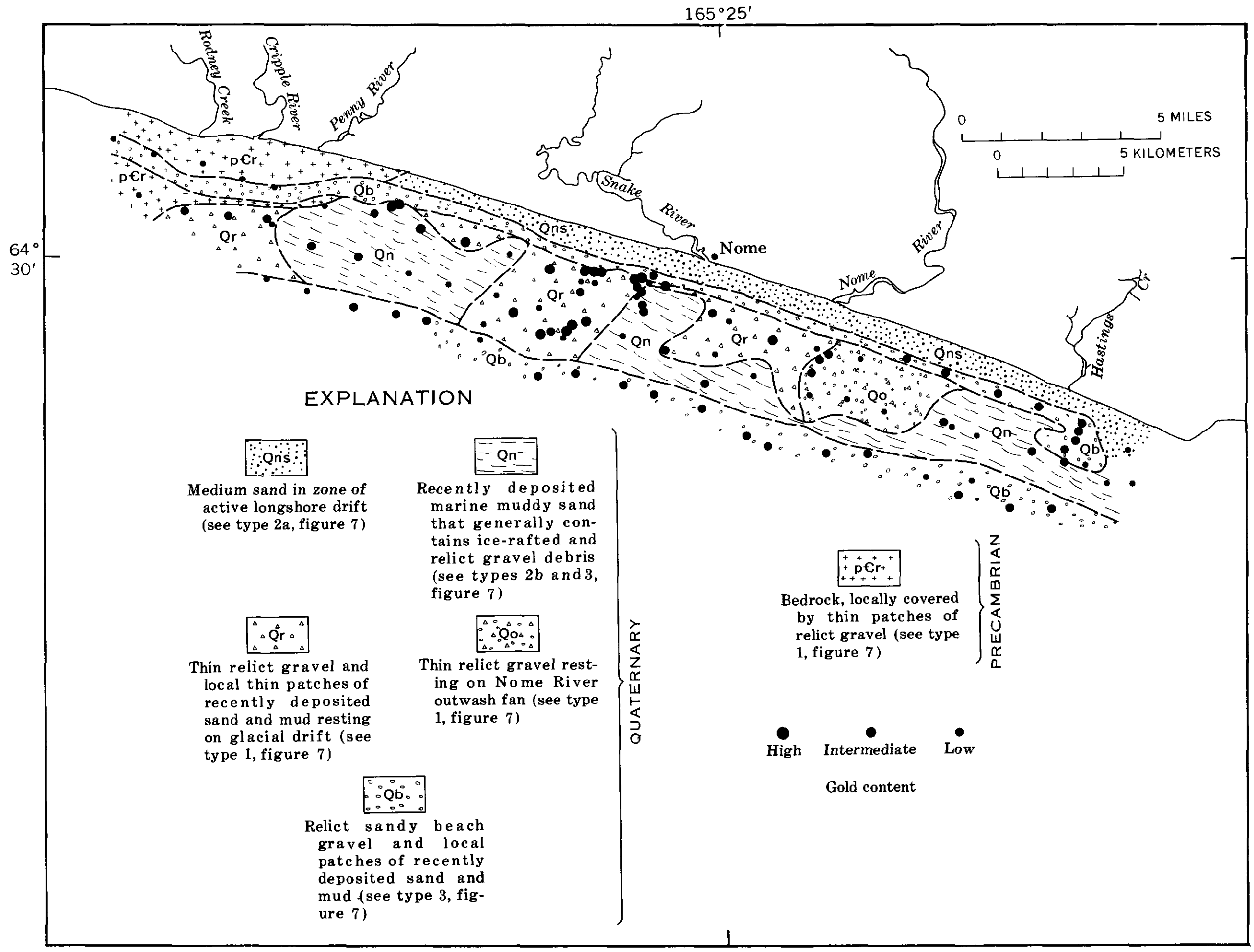

FIGURE 8.—General geologic map showing gold content of the surface sediments in the Nome nearshore area.

Virginia City was anchored at a drilling station, contain the greatest amounts of gold per unit volume of any samples.

The surface sediment with the highest gold content and the coarsest gold particles is the relict lag gravel that veneers glacial drift (fig. 8; table 3). Gold content is low but consistently above background in surface samples from submerged beach ridges. Most bottom samples recovered from the surface of the Nome River outwash fan and from the Holocene sand and mixed sediments, which generally cover sea floor depressions, contain only a few fine gold particles; their gold content is only slightly higher than the regional background values found throughout the northern Bering Sea.

The largest particles of gold occur in relict gravel over the drift and are as much as several millimeters in diameter; however, high contents are mainly caused by particles which average 1 mm in diameter and 1 mg in weight (No. 3 size, table 2). In general, sediments with more than 100 times the regional background value contain gold particles mostly of medium- to coarse-sand size; the gold in other samples, including those whose contents represent the background, consists of fine-sand size or smaller particles.

Samples from much of the relict gravel resting on glacial drift in the Nome area contain anomalous amounts of gold, and large parts of the drift area are mantled by a veneer of gravel containing gold in quantities that might be profitably extracted. Some samples contain as much as $4.00 in gold per cubic yard (2,500 ppb), and about one-third of the samples contain more than $1.00 in gold per cubic yard (600 ppb).

The layer of relict gravel that overlies glacial drift is relatively thin. Divers reported a thickness of only a few inches in some places, and our box cores and grab samplers recovered some stratified samples in which poorly sorted silty glacial till was covered by less than 6 inches (15 cm) of well-sorted relict gravel. In other places, comparisons between

TABLE 3.—*Comparative parameters of gold content in surface sediments of the northern Bering Sea*

Region and general sediment type	Approximate size of visible gold: Maximum[1] color size (mm)	Approximate size of visible gold: Mode[2] (mm)	50th percentile of pannable particulate gold values within region[3] (ppb)	Maximum gold content (ppb)	Average gold content for total sediment area[4] (ppb)	Number of samples
Nome nearshore:						
Relict gravel —						
over till	2 (1.4)	1.0	114.0	2,500.0	556.0	34
over outwash	GT (0.3)	0.062–0.25	3.0	12.0	4.0	7
over bedrock	....	....	.0	.0	.0	4
Holocene sands and muds	VGT (0.6)	0.062–0.6	3.0	24.0	8.0	19
Submerged sandy beach gravels	3 (1.0)	0.062–0.3	3.0	58.0	16.0	45
Modern Nome Beach:						
Beach gravels	2 (1.4)	0.125–0.250	5.0	1,910.0	155.0	....
Selected ruby sands	4 (0.6)	0.062–0.250	117.0	13,000.0	2,118.0	20
Bering Sea nearshore (excluding Nome):						
Solomon to Bluff —						
Holocene sediment	4 (0.6)	0.3–0.6	.2	[5]38.0 (104.0)	2.0	92
Cape Nome to Solomon —						
Relict sediment	GT (0.3)	0.3	.3	26.0	1.0	87
Sledge Island —						
Relict gravels	3 (1.0)	0.6–1.0	.9	36.0 (318.0)	4.0	30
Cape Rodney to Port Clarence—						
Relict gravels	3 (1.0)	0.6–1.0	.2	31.0 (87.0)	2.0	30
Port Clarence to Cape Prince of Wales —						
Relict gravels	4 (0.6)	0.3–0.6	.1	3.0 (13.0)	[5](4.2)	52
North shore St. Lawrence Island —						
Relict gravels	VFT (0.13)	0.13	0	2.0 (3.0)	.1	28
Open Bering Sea:						
Relict morainal gravels	3 (1.0)	0.13–1.0	.1	38.0 (259.0)	2.0	22
Sands and muds	VFT (0.13)	0.13	.1	182.0	3.0	186

1 Based on gold color counts (see table 2) of pan concentrates (VGT = very good trace, GT = good trace, VFT = very fine trace).

2 Size mode of visible gold responsible for greatest value in samples.

3 50th percentile value of gold content cumulative frequency distribution (see pl. 1) for each given region and sediment type. Therefore 50 percent of the samples in each local region are between 0 and the 50th percentile value, and this range represents the local background value for particulate pannable gold.

4 Based on only AA data.

5 Value in parentheses is based on color count estimate that was not confirmed by AA analysis. Lack of AA confirmation may be due to erroneous color count originally, loss of gold particles during sample transfer between containers or during transport from the field to analytical labs in Menlo Park, Calif., or to incomplete solution of gold while processing for AA test (K. Leong oral commun., 1969).

the lithology and gold content in the first 6-foot (2 meters) increment of drill cuttings and the lithology and gold content of grab samples obtained at the same anchorage indicate that relict gravel may be as much as 2 feet (60 cm) thick. The average thickness probably is about 1 foot (30 cm).

The gold in the relict gravel was apparently derived from the underlying drift. The gravel and sand particles within it show evidence of wave handling (Silberman and Hopkins, 1969), and we believe that the relict gravel was sorted from the drift when fine and light particles were winnowed out as the shoreline migrated across the till during periods of rising or falling sea level. Because gold is about eight times as abundant in the relict gravel (556 ppb, table 3) as in the drift (70 ppb), the gold concentration factor of the surficial gravel suggests that about 8 feet (2.4 meters) of glacial drift was reworked to form the 1-foot-thick relict-gravel layer. On the other hand, an average gravel content of about 25 percent in the underlying till indicates that less than 5 feet (1.5 meters) of till has been eroded off during migrations of the shoreline.

The shoreline features detected at depths of —35 to —42 feet (about —12 meters), locally at —55 feet (—17 meters), at —65 to —72 feet (about —21 meters), and at about 80 feet (about —24 meters) evidently represent positions where sea level changed less rapidly and where the shoreline was stabilized long enough for well-defined beach ridges and shore cliffs to form. The beaches at —65 to —72 feet (about —21 meters) and at —55 feet (—17 meters) were sampled most thoroughly, the —35 to —42 foot (about —12 meters) beach was sampled in only a few places, and the —80 foot (about —24 meters) beach was sampled in only one place. Surface samples from the submerged beaches contain much less gold than the relict-gravel layer overlying drift (table 3); the richest sample contains only $0.10 in gold per cubic yard (58 ppb). Though visible gold, including particles as large as 1 mm, occurs in most samples, trace-sized gold comparable to that characterizing the modern beach is far more common. The gold content is generally highest in places where the submerged beaches cross the glacial drift, and generally diminishes eastward from points where the beaches intersect the drift. Trends in pebble size, roundness, and lithology indicate that the submerged beaches had an eastward longshore drift (D. M. Hopkins, unpub. data). This drift transported sand and gravel along with small amounts of trace-sized but not coarse gold particles eastward from the lobes of glacial drift and from the areas of shallow bedrock west of Rodney Creek. Coarse sediments were also contributed to the ancient beaches by the Nome River outwash fan.

Though surface grab samples from the submerged beaches contain relatively little gold, higher concentrations may be present at depths of a few feet. Seismic-reflection profiles across the submerged beaches show that the internal structure is comparable to that of the modern beach (Tagg and Greene, 1970). Sediments are as much as 10 feet (3 meters) thick along the axial part of the submerged beaches, but the beach gravel is much thinner at the seaward edges, and perhaps at the landward edges as well. The mean thickness of beach sediments in the submerged shoreline areas shown in figures 4 and 8 is probably about 5 feet (1.5 meters).

The same processes that concentrated gold in the thin layer of relict wave-worked gravel on the drift should also have operated in the well-defined submerged beaches in places where they consist mostly of material reworked from auriferous glacial drift. In recent years, small-scale gold-mining operations on the beach at Nome have recovered fine gold from laminae of black or garnet-rich sand that lie a foot or more below the beach surface. The highest concentrations found during the extensive mining early in this century commonly lay at the base of the prism of beach sediments, several feet below the surface. Our bottom samplers could not penetrate depths comparable to those at which the highest concentrations are commonly found in the modern beach.

Relict gravel on the Nome River outwash fan contains relatively little gold in the areas that were sampled. The richest sample contains about $0.02 in gold per cubic yard (10 ppb), and the average gold content is even lower (table 3). Several samples contain trace-sized gold, but none contain coarse gold. Concentrations may be higher in the basal part of some of the glaciofluvial and alluvial gravel. Holes bored by the RV *Virginia City* in the Nome River outwash fan did not reveal significant gold concentrations at depth, but some bodies of submerged and buried alluvium do have significant gold concentrations. Generally, the highest gold concentrations in deposits of alluvium and outwash gravel on land are at the base of the deposit, and the upper part is relatively barren. In contrast, gold is generally evenly dispersed in glacial till. Thus, it is not surprising that the thin veneer of wave-worked gravel mantling the Nome River outwash fan contains much less gold than the wave-worked relict gravel overlying till.

Sandy and muddy bottom sediments commonly contain small quantities of gold in particles ranging from trace size to subvisible (table 2); the amounts and particle sizes are comparable to those in most other bottom sediments throughout the Nome region (table 3). Virtually all gold particles 1 mm in diameter or larger occur only in relict gravel overlying glacial drift, and the richer samples are confined to the drift area; thus, glacial till is probably the principal source of gold in the offshore area. The general absence of visible gold in mud immediately seaward of Nome (see table 4,

TABLE 4.—*Gold in samples obtained in the northern Bering Sea more than 3 nautical miles from shore*

Sample	Lat (N.)	Long (W.)	Total sample weight (kg)	Estimated color counts of gold: Visual	Estimated color counts of gold: µg[1]	Estimated color counts of gold: ppb	Atomic absorption (AA) analyses of gold: µg	Atomic absorption (AA) analyses of gold: ppb	Percent gravel	Remarks (All samples from pan concentrates unless otherwise noted)
Thompson cruise 1967										
TT18–11	63°56.8′	162°20.4′	0.6	....	....	....	6.5	12.0	0	AA total sample.
13	64°08.5′	163°05.6′	.1	....	....	....	3.0	23.0	0	AA with elutriation.
17	62°46.5′	165°25.0′	.6	....	....	....	17.4	31.0	......	Do.
21	63°02.0′	166°48.0′	.2	....	....	....	6.0	25.0	0	Do.
23	63°08.0′	167°20.0′	.9	....	....	....	9.6	11.0	0	AA with sample.
24	63°10.0′	167°32.0′	.6	....	....	....	16.4	27.0	0	AA total elutriation.
25	63°16.0′	168°00′	.3	....	....	....	20.0	66.0	0	Do.
29a	65°21.0′	167°09.0′	1.3	....	....	....	40.6	23.0	22	Do.
29b	65°21.0′	167°09.0′	.2	....	....	....	.0	.0	20	Do.
31	65°13.1′	167°27.0′	.4	....	....	....	8.6	20.0	0	Do.
44a	64°38.0′	170°36.2′	.6	....	....	....	10.2	16.0	0	Do.
44b	64°38.0′	170°36.2′	.8	....	....	....	5.4	7.0	0	AA total sample.
45	64°01.2′	169°02.0′	.2	....	....	....	9.6	45.0	0	AA with elutriation.
47	65°51.0′	169°33.0′	1.4	....	....	....	13.5	9.0	0	AA total sample.
Surveyor cruise 1968										
SU–139	63°24.7′	168°27.8′	5.3	1 fine tr	16.5	3.1	12.0	2.3	17	
141	64°12.5′	168°05.7′	6.3	....	....	....	27.6	4.4	0	
142	64°37.5′	167°55.4′	2.6	1 fine tr	16.5	6.4	30.0	11.5	0	
143	65°10.8′	167°44.0′	4.9	4 fine tr	66	13.4	6.5	2.9	0	[2]13.8.
147	64°04.5′	164°00.0′	4.6	2 fine tr	33.0	7.2	14.4	3.2	0	
Oceanographer cruise 1968										
ANC–73	65°37.7′	168°20.9′	36.8	....	....	....	3.9	0.1	57	
74	65°37.0′	168°28.7′	31.2	....	....	....	.8	.03	53	
75	65°32.0′	168°46.0′	19.9	....	....	....	2.6	.1	10	
76	65°27.0′	168°56.0′	9.1	....	....	....	4.0	.4	......	
77	65°19.5′	169°32.0′	28.0	....	....	....	....	....	68	
78	65°04.3′	169°34.39′	22.7	....	....	....	3.5	.2	0	

TABLE 4.—*Gold in samples obtained in the northern Bering Sea more than 3 nautical miles from shore*—Continued

Sample	Lat (N.)	Long (W.)	Total sample weight (kg)	Estimated color counts of gold: Visual	Estimated color counts of gold: µg 1	Estimated color counts of gold: ppb	Atomic absorption (AA) analyses of gold: µg	Atomic absorption (AA) analyses of gold: ppb	Percent gravel	Remarks (All samples from pan concentrates unless otherwise noted)
Oceanographer cruise 1968—Continued										
ANC–79	64°51.0′	169°50.0′	31.5	......	......	......	......	......	0	
80	64°47.2′	169°42.5′	23.0	......	......	......	7.0	.3	0	
81	64°40.0′	169°33.4′	25.2	3 fine tr ...	49.5	1.97	2.4	.1	<1	[2]2.0.
82	64°32.9′	170°06.4′	20.4	......	......	......	2.0	.1	<1	
83	64°27.0′	170°21.0′	10.7	......	......	......	.8	.1	35	
84	64°23.5′	170°12.0′	21.3	......	......	......	2.9	.1	54	
85	64°20.14′	170°01.78′	16.6	......	......	......	1.0	.1	2	
87	64°01.4′	170°27.0′	13.3	......	......	......	9.1	.7	59	
88	64°03.9′	170°30.8′	24.9	......	......	......	2.6	.1	50	
89	64°08.0′	170°36.0′	13.2	......	......	......	2.5	.2	48	
90	64°02.8′	171°02.8′	12.1	......	......	......	2.1	.2	......	
91	64°03.0′	171°24.8′	—	......	......	......	2.7	......	......	
94	63°54.0′	171°42.0′	14.4	......	......	......	2.1	.1	77	
120	63°39.8′	170°01.5′	15.1	......	......	......	1.0	.1	0	
122	63°37.2′	169°57.5′	25.1	......	......	......	.7	.2	0	
124	63°33.9′	169°53.6′	18.1	......	......	......	.4	<.05	0	
125	63°33.6′	169°49.0′	12.4	......	......	......	.5	<.05	0	
126	63°32.0′	169°44.6′	16.0	......	......	......	1.0	.1	0	
127	63°31.8′	169°40.0′	—	......	......	......	3.7	.2	57	
128	63°30.8′	169°37.0′	16.0	......	......	......	1.2	.1	44	
129	63°28.5′	169°35.0′	11.9	......	......	......	......	......	86	
145	63°20.5′	168°40.0′	27.1	3 fine tr ...	......	......	0	0	17	
146	63°24.0′	168°37.0′	10.6	......	......	......	3.0	.3	7	
147	63°28.0′	168°32.0′	29.3	......	......	......	1.5	.6	0	
148	63°35.8′	168°26.5′	11.6	......	......	......	1.5	.1	0	
149	63°30.5′	168°58.5′	12.7	......	......	......	3.0	.2	0	
150	63°37.0′	169°10.0′	23.0	......	......	......	1.8	.1	0	
151	63°41.0′	169°28.0′	6.2	......	......	......	1.1	.8	.0	
153	63°49.0′	169°40.0′	8.5	1 fine tr ...	16.5	19.4	5.2	.6	0	
154	63°50.0′	169°47.0′	12.3	......	......	......	1.0	.8	0	
155	63°52.8′	169°54.4′	16.2	1 fine tr ...	16.5	1.0	25.0	1.5	0	
156	64°02.02′	169°02.70′	19.9	......	......	......	1.2	.1	0	
157	64°08.05′	169°30.84′	16.2	......	......	......	6.5	.4	0	
158	64°12.48′	169°47.33′	32.2	......	......	......	2.0	.1	0	
159	64°17.47′	169°20.21′	23.6	Few fine tr.	49.5	2.1	3.8	.1	0	
160	64°22.53′	168°51.67′	29.4	......	......	......	1.5	.1	0	
161	64°33.85′	169°02.86′	31.5	Few fine tr.	49.5	1.6	7.7	.2	0	
162	64°41.5′	169°12.2′	16.0	......	......	......	2.6	.2	0	
163	64°43.8′	169°59.5′	11.8	......	......	......	2.0	.2	0	
164	64°49.0′	169°28.5′	35.3	......	......	......	2.9	.1	11	
165	64°54.6′	168°03.5′	12.3	Many fine tr	66	5.4	119	9.7	0	
166	64°57.0′	167°49.0′	21.3	1 No. 4 and fine tr.	330	15.4	2.6	.1	0	
167	65°04.0′	168°00.0′	32.5	Many fine tr	66	2.0	7.8	.2	12	
168	65°10.0′	168°13.0′	29.2	......	......	......	1.3	<0.05	0	
169	65°15.0′	168°25.0′	22.6	......	......	......	.5	<0.05	0	
170	65°23.0′	168°39.0′	14.2	......	......	......	2.5	.2	0	
172	65°24.0′	168°19.1′	15.8	......	......	......	2.1	.1	19	
173	65°17.0′	168°07.5′	19.3	......	......	......	2.4	.1	0	
174	65°17.5′	167°43.2′	27.1	......	......	......	3.8	.1	......	
175	65°16.0′	167°23.7′	29.0	......	......	......	4.5	.2	<1	
176	65°15.9′	167°18.0′	11.0	......	......	......	1.4	.1	21	
177	65°16.6′	167°12.3′	11.0	......	......	......	2.4	.2	<5	
178	65°16.4′	167°02.3′	12.5	......	......	......	2.0	.2	<5	
180	65°13.4′	167°26.8′	11.8	......	......	......	7.8	.7	15	
181	65°13.0′	167°26.8′	12.5	......	......	......	1.6	.1	50	
182	65°10.6′	167°23.4′	11.1	......	......	......	1.4	.1	62	
183	65°09.5′	167°20.0′	14.6	......	......	......	7.0	.5	22	
184	65°08.2′	167°20.0′	19.9	......	......	......	12.0	.6	37	
185	65°05.4′	167°23.0′	25.3	Few fine tr	49.5	2.0	6.4	.3	19	
186	65°04.0′	167°22.0′	27.3	Few fine tr	49.5	1.8	1.8	.1	0	
187	65°02.1′	167°21.5′	30.6	Very good tr	300	9.8	9.3	.3	12	
188	65°00.8′	167°19.5′	22.5	Many fine tr	66	2.9	3.4	.2	49	
189	64°59.0′	167°13.0′	36.8	1 fine tr ...	16.5	.5	25.6	.7	14	
190	64°58.0′	167°10.5′	17.3	......	......	......	1.5	.1	78	
191	64°54.0′	167°09.0′	7.9	......	......	......	1.5	.2	91	
193	64°50.5′	167°03.0′	20.1	Few fine tr	49.5	2.5	6.7	.3	21	
194	64°48.5′	166°58.5′	21.8	......	......	......	3.9	.2	27	
195	64°44.8′	166°53.7′	6.0	Few fine tr	49.5	8.3	0	0	15	
196	64°45.0′	166°50.5′	11.4	......	......	......	2.0	.2	16	
197	64°43.7′	166°47.2′	16.5	......	......	......	4.7	.3	15	
199	64°41.5′	166°39.2′	21.6	......	......	......	13.5	.6	57	
200	64°39.7′	166°36.5′	14.6	......	......	......	0	0	40	
201	64°38.5′	166°34.0′	11.7	3 very good tr.	1000	85.5	162.7	13.9	71	
202	64°36.2′	166°31.2′	3.7	Very good tr	300	81.0	114.1	30.9	33	
203	64°35.7′	166°29.0′	23.8	......	......	......	65.0	2.7	33	
204	64°34.0′	166°26.0′	14.8	......	......	......	3.4	.2	8	
205	64°32.6′	166°23.2′	15.5	Very good tr	300	19.4	61.4	4.0	15	
206	64°31.2′	166°21.0′	20.4	Many fine tr	66	3.2	25.8	1.3	14	
210	64°33.6′	166°44.0′	19.2	Many very good tr.	1300	67.7	307.6	32.8	56	
211	64°36.0′	167°0.7′	9.4	Few fine tr	49.5	5.3	6.9	.7	0	
213	64°40.3′	167°31.2′	10.4	......	......	......	1885.8	181.8	......	
214	64°34.6′	167°44.0′	13.0	......	......	......	1.8	.1	7	
216	64°18.5′	168°20.8′	13.0	......	......	......	4.0	.3	......	
217	64°10.0′	168°40.4′	15.7	......	......	......	7.4	.5	......	
218	63°58.4′	168°30.4′	14.3	......	......	......	0	0	......	
219	63°47.95′	168°21.8′	15.2	......	......	......	10.1	.7	......	
220	63°56.13′	168°10.8′	29.4	......	......	......	2.2	.1	......	
221	64°03.8′	167°59.6′	28.1	......	......	......	3.2	.1	......	
222	64°09.5′	167°51.1′	16.9	......	......	......	1.9	.1	......	
223	64°17.31′	167°39.5′	12.1	......	......	......	2.8	.2	......	
224	64°18.29′	167°22.0′	8.3	......	......	......	2.0	.2	......	
225	64°19.83′	167°06.3′	17.4	......	......	......	3.9	.2	45	
226	64°20.4′	166°53.7′	16.9	......	......	......	1.9	.1	27	
227	64°22.7′	166°37.4′	10.7	......	......	......	2.1	.2	34	
228	64°23.76′	166°25.8′	15.1	......	......	......	.9	.1	3	
229	64°18.4′	166°21.6′	21.7	......	......	......	1.8	.1	......	

TABLE 4.—*Gold in samples obtained in the northern Bering Sea more than 3 nautical miles from shore*—Continued

Sample	Lat (N.)	Long (W.)	Total sample weight (kg)	Estimated color counts of gold: Visual	Estimated color counts of gold: µg[1]	Estimated color counts of gold: ppb	Atomic absorption (AA) analyses of gold: µg	Atomic absorption (AA) analyses of gold: ppb	Percent gravel	Remarks (All samples from pan concentrates unless otherwise noted)
				Oceanographer cruise 1968—Continued						
ANC-230	64°13.9′	166°14.9′	21.0	...	...	...	2.0	.1	...	
231	64°20.8′	166°08.4′	25.5	...	...	...	3.4	.1	...	
232	64°25.4′	166°13.7′	14.3	...	...	...	29.5	2.1	6.2	
233	64°26.5′	166°04.5′	22.7	...	...	...	3.4	.2	22	
234	64°29.9′	166°02.3′	19.7	2 good, 3 fine tr.	109	5.5	164.9	8.4	39	
236	64°26.5′	165°48.0′	33.6	Many fine tr	66	1.7	61.2	1.8	15	
237	64°22.2′	165°51.0′	19.3	...	...	...	32.4	1.7	9.1	
238	64°15.4′	165°54.6′	9.0	...	...	...	1.5	.2	12	
239	64°11.0′	165°45.0′	24.4	...	...	...	.4	<.05	4	
240	64°18.2′	165°40.2′	18.0	...	...	...	2.9	.2	2	
242	64°27.0′	165°35.9′	11.8	2 fine tr ...	33	.1	33.4	3.3	15	
245	64°24.0′	165°26.2′	40.8	9 good tr ...	264	6.5	174	4.3	12	
246	64°19.6′	165°29.3′	21.7	...	...	...	29.8	1.4	...	
247	64°13.6′	165°31.2′	9.5	...	...	...	10.2	1.1	...	
248	64°10.2′	165°24.0′	2.6	...	...	...	3.2	1.2	...	
249	64°15.6′	165°16.0′	15.1	...	...	...	0	0	...	
250	64°20.8′	165°14.0′	36.0	...	...	...	6.0	.2	15	
251	64°25.0′	165°14.4′	20.2	...	...	...	16.2	.8	48	
220–229	...	...	9.8	...	...	...	99.5	10.0	...	Overpan sample.[3]
231–245	...	...	5.7	...	...	...	71.6	13	...	Do.[3]
				Tomcod cruise 1968						
AWF-378	64°29.3′	164°22.6′	18.1	2 fine tr ...	33.0	1.8	23.6	1.3	25	
379	64°29.8′	164°20.5′	17.1	3 fine tr ...	49.5	...	76.0	4.4	15	
380	64°30.3′	164°18.5′	8.8	...	...	...	0	0	0	
381	64°30.3′	164°16.2′	9.9	...	...	...	.4	<.05	0	
382	64°30.2′	164°14.1′	3.9	...	...	...	9.9	1.7	0	
389	64°29.6′	163°57.0′	9.5	...	...	...	0	0	0	
390	64°29.7′	163°54.7′	10.4	...	...	...	0	0	0	
391	64°29.7′	163°52.5′	6.9	...	...	...	0	0	0	
392	64°29.7′	163°50.3′	7.4	...	...	...	0	0	0	
393	64°29.6′	163°48.0′	7.2	...	...	...	0	0	0	
394	64°29.7′	163°16.0′	7.7	...	...	...	0	0	0	
395	64°29.6′	163°43.5′	4.9	...	...	...	0	0	0	
396	64°29.5′	163°41.0′	8.1	...	...	...	0	0	0	
397	64°28.6′	163°41.0′	10.7	...	...	...	0	0	0	
398	64°28.6′	163°43.4′	7.2	...	...	...	0	0	0	
399	64°28.7′	163°16.0′	8.6	...	...	...	0	0	0	
400	64°28.6′	163°48.0′	9.0	...	...	...	2.6	.3	0	
401	64°28.7′	163°50.3′	10.9	...	...	...	0	0	0	
402	64°28.6′	163°52.5′	6.7	...	...	...	0	0	0	
403	64°28.6′	163°54.7′	11.1	...	...	...	0	0	0	
404	64°28.7′	163°57.0′	10.4	...	...	...	0	0	0	
405	64°29.8′	164°59.9′	10.9	...	...	...	6.0	.6	...	
406	64°29.2′	164°02.4′	9.1	...	...	...	11.8	1.3	44	
407	64°29.9′	164°04.8′	10.6	...	...	...	0	0	0	
408	64°30.0′	164°07.3′	10.4	...	...	...	3.6	.3	0	
409	64°30.1′	164°09.5′	9.3	...	...	...	0	0	0	
410	64°30.2′	164°11.8′	10.4	1 fine tr ...	16.5	1.6	2.9	.3	0	
411	64°19.3′	164°14.3′	5.6	...	...	...	0	0	0	
412	64°19.3′	164°16.4′	8.8	...	...	...	0	0	0	
413	64°29.4′	164°17.7′	21.1	...	...	...	0	0	10	
414	64°28.8′	164°19.5′	14.4	1 fine tr ...	16.5	1.2	1.2	.1	0	
416	64°28.1′	164°23.5′	17.3	2 fine tr ...	33	...	11.0	.1	12	
417	64°28.8′	164°24.5′	13.0	1 fine tr ...	16.5	...	9.6	.1	32	
430	64°28.4′	164°26.5′	17.4	...	...	...	1.8	.1	20	
431	64°28.0′	164°28.5′	16.9	2 fine tr ...	33.0	2.0	3.2	.2	24	
432	64°27.5′	164°25.3′	6.9	...	...	...	1.6	.2	15	
433	64°27.2′	164°27.5′	15.5	...	...	...	1.6	1.2	16	
434	64°26.6′	164°29.6′	16.3	...	...	...	0	0	12	
435	64°26.1′	164°36.6′	16.0	...	...	...	0	0	4	
436	64°25.6′	164°38.6′	16.0	2 fine tr ...	33	2.1	4.8	.3	30	
437	64°25.2′	164°40.5′	16.6	...	...	...	0	0	24	
438	64°24.6′	164°42.6′	15.8	1 fine tr ...	16.5	1.0	2.8	.2	17	[2]1.2.
439	64°24.2′	164°44.5′	10.7	...	...	...	1.6	.1	48	
440	64°23.3′	164°46.5′	12.3	...	...	...	15.6	1.3	44	
442	64°23.3′	164°49.5′	11.4	...	...	...	15.2	1.3	55	
451	64°27.6′	164°25.5′	12.5	...	...	...	...	.1	17	
452	64°27.2′	164°27.3′	11.6	...	...	...	...	.1	26	
453	64°26.7′	164°29.2′	16.7	1 fine tr ...	16.5	1.0	4.9	.3	13	[2]1.3.
454	64°26.3′	164°26.3′	16.0	2 fine tr ...	33	2.1	12.8	.1	7	
456	64°25.3′	164°35.5′	34.7	1 fine tr ...	16.5	.5	7.3	.2	12	
457	64°24.8′	164°37.4′	16.9	...	...	...	0	0	14	
458	64°24.3′	164°39.3′	20.2	...	...	...	4.4	.2	16	
459	64°23.8′	164°41.5′	9.5	...	...	...	5.8	.6	22	
460	64°23.3′	164°43.5′	13.9	...	...	...	0	0	39	
461	64°22.8′	164°45.4′	19.6	2 fine tr ...	33.0	1.7	4.2	.2	22	
462	64°22.4′	164°47.2′	19.5	1 fine tr ...	16.5	...	8.4	.4	11	
463	64°22.3′	164°49.3′	19.7	2 fine tr ...	33.0	1.7	7.4	.4	18	
464	64°22.2′	164°51.5′	19.7	...	...	...	3.8	.2	23	
465	64°22.1′	164°53.8′	20.6	2 fine tr ...	33.0	1.6	4.6	.2	9	
466	64°21.9′	164°56.1′	21.8	...	...	...	0	0	13	
467	64°21.8′	164°58.3′	20.4	...	...	...	6.6	.3	22	
468	64°22.8′	164°58.5′	19.7	...	...	...	...	<.05	5	
469	64°22.8′	164°56.2′	18.3	...	...	...	12.8	.7	29	
470	64°23.0′	164°54.0′	17.2	...	...	...	6.8	.4	30	
471	64°23.2′	164°51.8′	17.4	2 fine tr ...	33	1.9	7.5	.4	31	

[1] AA analysis shows that size of gold traces in pan concentrates was difficult to distinguish and that the average content of gold trace was 16.5 µg or the midpoint between average content from a good and a very fine trace (see table 2). Consequently, the average value of 16.5 µg was used in evaluating gold content from color counts.

[2] Values are based on the estimated weight of the visible gold in pan concentrates (see table 2) and the weight of the background gold found by AA analysis. These samples had anomalously low AA values compared with their visible gold content. This discrepancy was due either to loss of gold particles before AA analysis and (or) to incomplete solution of larger particles during AA analysis. These best estimate values have been utilized in figure 9.

[3] Material remaining after the pan concentrate has been removed. Overpan material from many samples of the same sediment type was combined, and these composite sample groups were analyzed for gold content not removed by panning.

Oceanographer, samples ANC–238–240; 248–250) and the fact that gold is common in mud east and west of glacial drift suggests that trace-sized gold particles were carried laterally from the drift along with other fine sediment. This wide dispersal of small gold particles in sandy and muddy bottom sediments probably was accomplished by longshore currents and longshore drift when sea level was lower than at present.

Thus, the distribution and particle size of gold in the samples of bottom sediment near Nome indicate derivation from the unsorted deposits of glaciers that eroded the many areas of gold-bearing bedrock and the abundant older placers landward of the present shoreline (Hummel, 1962a, b; Moffit, 1913). A thin deposit of relict gravel greatly enriched in gold was created in areas where the shoreline migrated relatively rapidly across the drift; thicker beach deposits were formed where the shoreline was temporarily stable, but the gold concentrations in these thicker deposits, if present, are too deep for our samplers to penetrate. Gold concentrations in the bodies of alluvial and outwash gravel, if present, lie below the depths reached by our samplers and also below the depths reached by eroding waves during transgressions of the sea; consequently the wave-worked gravel layer mantling the areas of alluvium and outwash gravel contains much smaller concentrations of gold than the veneer of wave-worked gravel on the glacial till. However, small amounts of gold, apparently carried by longshore drift laterally from the till areas, have been deposited in Holocene beach gravel, sands, and muds resting on older till, outwash, alluvium, or marine sediments.

Pressure ridges of sea ice that have grounded in gold-bearing gravel and then raised during high tides and storm surges may also have moved small amounts of gold and a few large gold particles into areas that would otherwise be nearly barren.

ECONOMIC POSSIBILITIES

Nearly all the Nome samples were obtained within the 3-mile limit, in areas leased by individuals under prospecting and mining permits; thus, we cannot discuss the economic possibilities of specific areas. However, we can state that in some areas where thin relict gravel overlies glacial drift, the gravel may contain enough gold to merit consideration as a minable ore body. Furthermore, although samples from the sea floor surface do not define any minable deposits in the areas of submerged beach ridges, such deposits could exist at depths of less than 10 feet (3 meters) below the sea bottom. Ore deposits in other areas, if present, probably lie at greater depths. Future prospecting for shallow offshore placer deposits in the Nome area should focus primarily upon the "skin deposit" on the drift and upon thicker basal gravel of the now-submerged beaches in areas where the beaches are composed mostly of material reworked from the glacial drift.

Gold is erratically distributed in the main drift area, but nearly all samples contain clearly anomalous amounts of gold, and some are very rich. The variability of gold content per unit volume is partly due to the local thin patches of relatively barren current-deposited sand or mud that cover the richer gravel and partly due to the particle-sparsity effect of samples too small to be representative. Samples from one 6-square-mile area have an average value of $1.48 per cubic yard (920 ppb), and the gold consists mostly of No. 3 size flakes (1 mm diameter). Clifton, Hunter, Swanson, and Phillips (1969) showed that more than 55 lb (25 kg) of sediment are required to obtain a representative sample in material containing gold of this particle size and in this abundance. The samples from the Nome area ranged in weight from less than 2 lb (1 kg) to nearly 45 lb (20 kg), but most weighed less than 11 lb (5 kg). To compensate for inadequate sample weights, moving averages of gold tenor were calculated for groups of samples from similar sedimentary environments. (See table 3.)

First, a mean value was calculated from samples from each square-mile area in an arbitrary grid. Then, these values were averaged with those in square-mile areas to the east and west, and this average value was plotted in the central grid square. Because the original sample pattern consisted of samples collected on a 1-mile grid plus added samples at borehole drilling sites, each mean value was based on at least three samples, and most were based on five or more samples. The average total sample weight upon which moving-average calculations were based was 65 lb (30 kg). A comparison of cumulative frequency distribution on curves for individual and for moving-average gold values within a 6-square-mile area of relict gravel indicates that particle-sparsity effects are greatly reduced by using moving-average data (fig. 9).

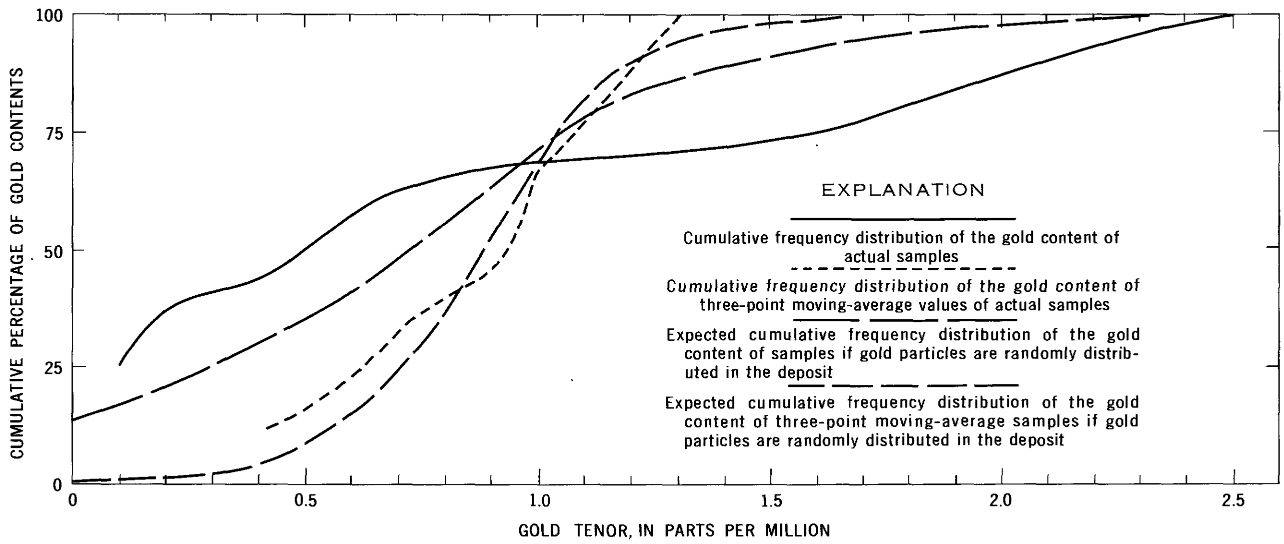

FIGURE 9.—Actual and expected cumulative frequency distribution of gold values in the area of maximum gold tenor.

Detailed statistical analysis of the data suggests that the average gold tenor of the bottom sediment in the richest 6-square-mile area studied has been reliably estimated. Clifton, Hunter, Swanson, and Phillips (1969) reported that sample gold tenors should follow a binomial distribution, which is approximated by the Poisson distribution, if the particles are randomly distributed through the deposit. Consequently, the actual or observed cumulative frequency distribution curves of individual or moving-average gold values from samples of inadequate and varying weight can be contrasted with theoretical curves calculated from the Poisson distribution (in a manner similar to that described by Griffiths, 1960) to evaluate the actual randomness of gold particle distribution and reliability of sampling (fig. 9). To construct the Poisson curves of expected random distribution, the following methods were used:

1. Expected number of gold particles, which is the parameter θ in the table B (p. 455–459) of the Poisson distribution given by Johnson and Leone (1964) or the parameter λ of table A–15 given by Dixon and Massey (1957), was calculated by using a modification of Moore and Silver's equation (1968, p. 2); this equation was

$$\lambda = \frac{40n\delta}{\Pi D^3 \rho}$$

where

λ = expected number of particles.
ρ = density of placer gold, 17 grams per cubic centimeter.
n = sample weight in grams.
δ = tenor of deposit, in this case assumed to be 920 ppb, the average of all samples obtained.
D = effective diameter, in centimeters, of gold flakes having a 10:1 diameter to thickness ratio. In this case, the effective diameter of gold particles was calculated to be 1 mm by using Clifton, Hunter, Swanson, and Phillips' equation (1969, p. C15).
Π = 3.14.

2. Expected curves were constructed from the values of λ obtained for each of six sample weight groups the smallest, intermediate, and largest thirds of the individual samples, and the smallest, intermediate, and largest thirds of the moving-average samples. The final expected curves for each three sample weight groups of the actual samples and of the moving-average samples were averaged to approximate the expected curve for a group of samples of varying weight.

The closeness of fit between expected cumulative frequency distributions of gold tenor and actual cumulative frequency distributions indicates that the actual distribution is consistent with the assumption that (1) the average gold tenor of the bottom sediment in the 6-square-mile area is 920 ppb and (2) the gold particles are randomly distributed through the area. Although the closeness of fit was not tested statistically, it appears, qualitatively, to be very good for the moving-average gold values. This suggests that the reliability of the estimated gold tenor of the area is very high. If, as this qualitative test suggests, gold is randomly distributed, then moving averages calculated for aggregated 30-kg samples of combined areas should virtually eliminate particle-sparsity effect and should have 95 percent of the values between 570 and 1,840 ppb. The entire distribution of the moving-average values falls between 400 and 1,300 ppb; this again suggests that gold distribution of the deposit approaches randomness and that the average ore tenor is close to 920 ppb.

All these data suggest that in large areas the relict gravel mantling glacial drift contains enough coarse gold to be minable at a profit, and they emphasize the value of large, closely spaced bottom samples in the delineation of "skin deposits" of gold-bearing gravel. The total minable volume cannot be reliably estimated because average thickness and exact lateral extent of the rich "skin deposits" have not been adequately established by the few drill holes and because offshore mining costs are unknown. The total volume available would be reduced or enlarged if the highly auriferous relict gravel is, on the average, significantly thinner or thicker than estimated or if much of the partly buried and unsampled relict gravel surrounding the richest 6-square mile area also is highly auriferous. A major problem in mining rich "skin deposits" would be the requirement that only the thin surface residuum be excavated. If much of the underlying drift were also excavated, the average tenor would diminish owing to dilution by low-grade material.

Samples of the surface gravel on the submerged beaches contain an average of only $0.03 in gold per cubic yard (16 ppb), but as we have noted, the highest concentrations in the deposits along the well-defined submerged shorelines are probably deeper than the sampling equipment could reach. The submerged beaches definitely merit continued exploration using boring equipment that can penetrate gravel and sand to depths of 10 or 15 feet below the sea bottom. Because the pay streaks are likely to be relatively narrow (not wider than 500 ft and possibly as narrow as 100 ft), boreholes should be closely spaced. Attention should be focused primarily upon areas where the submerged beaches are in contact with the glacial drift. Gold-bearing material in the drift probably becomes increasingly diluted by incorporation of older marine mud with increasing distance from the shore. (See discussion in "Studies Near Nome—General Geology" and fig. 5.) Therefore, the beaches that rest on drift close to shore probably are more promising than those at greater distances from the shore.

STUDIES ELSEWHERE IN THE CHIRIKOV BASIN

BOTTOM SEDIMENTS

Bottom sediments in the easternmost part of the Chirikov Basin consist of sandy clayey silt or silty clayey very fine sand apparently derived from the modern Yukon River, whereas most of the basin is floored by compact silty fine sand of unknown origin (McManus and others, 1969) (fig. 10). Yukon River sediments apparently are encroaching upon the silty sand, and this encroachment, along with relative coarseness of the silty sand, suggests that the sand as well as the nearshore gravels are relict deposits formed under environmental conditions that differ from those that now prevail in the Chirikov Basin (McManus and others, 1969).

Coarse sediments are found in nearshore areas along the Seward Peninsula and St. Lawrence Island, in the Bering Strait, and in several areas well away from shore in the west-central part of the basin (fig. 10). These sediments have not been studied in as great detail as the Nome sediments; thus, conclusions as to their origin are considered tentative.

The small patches of coarse angular gravel near Topkok Head and Bluff probably reflect the presence of submarine outcrops of bedrock. Coarse relict sediments in the nearshore area between Solomon and Cape Nome probably are derived from morainal deposits and a fringing outwash apron deposited by glaciers that extended to or slightly beyond the shoreline in this area. Seismic profiling and bottom sampling suggest that bedrock is either exposed or buried beneath a very thin cover of coarse sediment, largely of local origin, in the area extending from Rodney Creek past Sledge Island to the vicinity of the mouth of the Sinuk River. Samples could be taken only at the outer fringe of the wide shoal between Sledge Island and the entrance to Port Clarence, but widespread occurrence of gravel there indicates that coarse sediments cover much of this region. Recent seismic profiling at the edge of this area and the observation of wave-planed bedrock along this coastline suggest (C. L. Sainsbury, 1968, oral commun.) that bedrock close to or at the sea floor is the cause of the coarse sediment mantle.

The gravel offshore along the south coast of the Seward Peninsula between Port Clarence and Cape Prince of Wales probably includes reworked glacial detritus (fig. 10) as well as material eroded from shoreline cliffs, terraces, and shallow submerged outcrops. A large sea valley extending westward along the coast from Port Clarence to Bering Strait is probably cut into similar deposits, but is floored with alluvium overlain by transgressive sands and

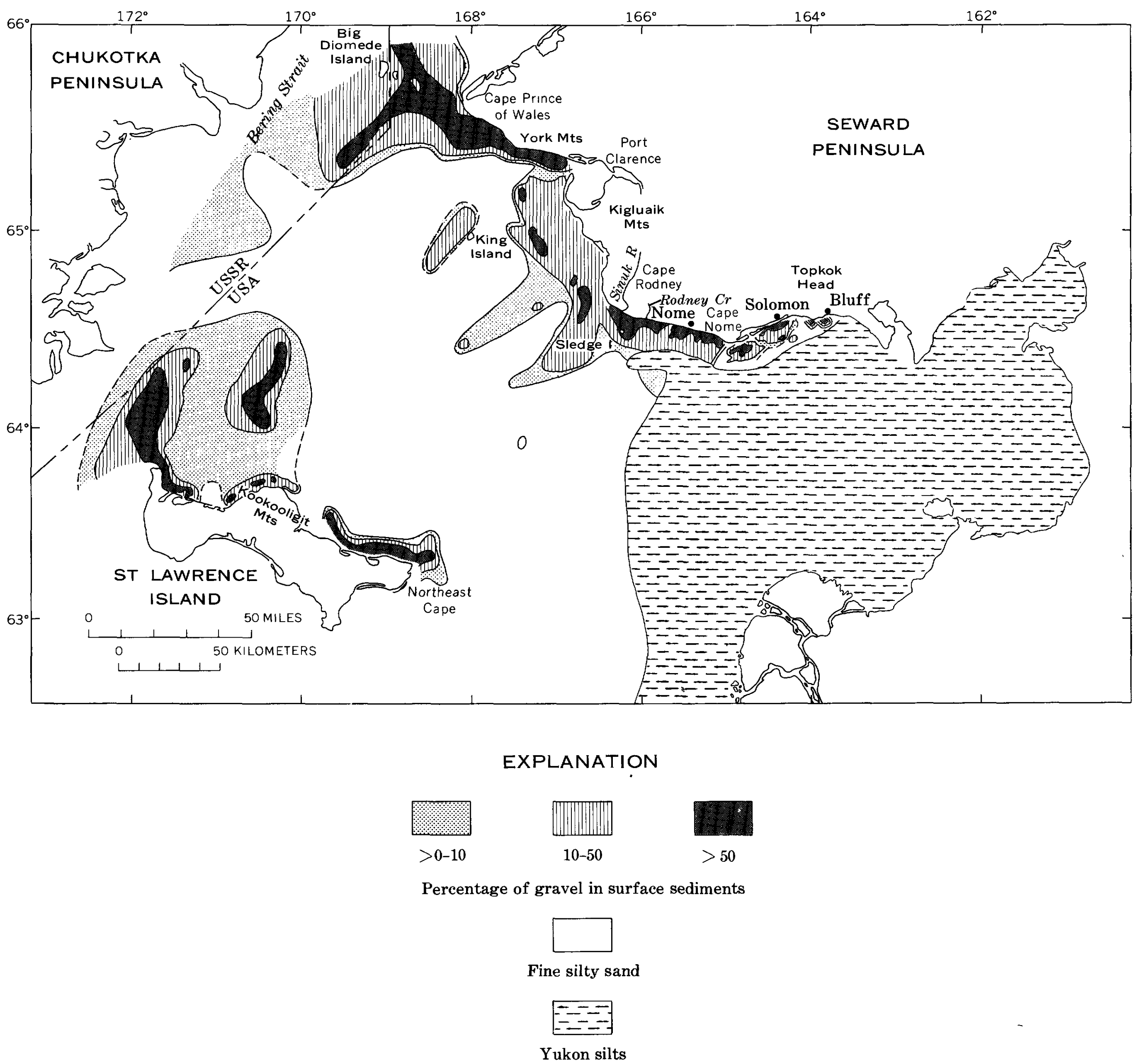

FIGURE 10.—Distribution of sediments in the northern Bering Sea (distribution of Yukon silts and clay modified from McManus and others, 1969).

ponded recent muds. Both glacial drift and sediment tentatively identified as alluvium have been recovered from the floor of the Bering Strait.

The belts of gravel extending southwestward from the Bering Strait toward St. Lawrence Island and southwestward from a point west of King Island seem to mark the crests of morainal ridges built by glaciers that originated in Siberia. Parts of these ridges are buried beneath younger deposits (Grim and McManus, 1970), but they reappear as linear gravel patches near the coast of St. Lawrence Island (fig. 10).From the Kookooligit Mountains eastward to Northeast Cape the coarse sediments close to the north coast of St. Lawrence Island appear to be derived from submerged bedrock outcrops. Probable coarse alluvium was recovered in a dredge haul from the bottom of the deep channel east of Northeast Cape, and possible glacial drift in a dredge haul from a higher area east of the deep channel.

GOLD DISTRIBUTION IN COARSE-GRAINED SEDIMENTS

The association of high gold values with coarse relict sediments noted offshore at Nome holds true in other parts of the Chirikov Basin, as well. No other area in the Chirikov Basin, however, has yielded samples as rich as the richest samples at

Nome, and samples from some relict gravel areas are essentially barren. Fine sands throughout the Chirikov Basin locally contain visible gold and in places may define a relatively high regional background, although they do not constitute a recoverable resource.

More than a third of the samples recovered in the area of coarse sediments between Cape Nome and Solomon contain fine trace-sized gold, and one sample from off the mouth of the Solomon River contains a No. 4 sized particle. Gold content per cubic yard, however, is generally low, and the richest sample contains only a few cents per cubic yard. The general lack of land placers between Solomon and Cape Nome may explain the low gold values offshore, even though much of this area has been glaciated (fig. 3). Although the Solomon River and its tributaries have produced considerable placer gold, the area offshore from the river is on the east margin of the glaciated area, and glaciers have carried debris only a short distance offshore (fig. 3). The largest particles of gold in the offshore area probably were moved there by glaciers that scraped through the few preexisting placers and the associated mineralized bedrock on land. Some fine trace-sized gold particles may have a similar source, but much trace-sized gold probably was transported from the offshore Nome sources by longshore drift when sea level was lower.

Sediments in the Sledge Island area were difficult to sample because of the coarseness of the bottom gravel and the presence, in some places, of outcrops at the sea floor. No samples were obtained at many stations within 3 to 5 km (2 to 3 nautical miles) of the Seward Peninsula coast. Nearly half the samples from the remaining stations contain fine trace-sized gold, and several samples have No. 3 sized particles. The richest sample contains about \$0.50 in gold per cubic yard (318 ppb) by color count (table 3). The relatively high values in the Sledge Island area are surprising, because gold placer deposits are only sparsely distributed on the mainland nearby. The occurrence of highest values in the outer sampling lines suggests that the gold is derived from previously unrecognized areas of mineralized bedrock in the offshore area.

About a third of the bottom samples from the area between Cape Rodney and Point Spencer contain visible gold, and several of these have No. 3 or 4 sized particles. The richest sample contains about \$0.14 in gold per cubic yard (87 ppb). These samples, like those from the Sledge Island area, were collected offshore from a land area in which productive placers are small and sparsely distributed. The presence of coarse gold in fair abundance well offshore suggests that mineralized bedrock may be present at the sea bottom nearby.

No. 4 sized particles, possibly of gold, were recovered in samples from the south coast of western Seward Peninsula between Point Spencer and Cape Prince of Wales. The values from pan color counts were higher than those from atomic absorption analysis, but the lower analysis values may be the result of the unusual way that this particular series of samples was prepared. They were ground to a fine powder ($<$400 mesh) so that a small split could be taken for emission spectrographic analysis for tin; possibly, the atomic absorption techniques did not adequately analyze such a fine powder (Kam Leong, oral commun., 1969). For this region, color counts probably are the best data available; they give a maximum value of 93 ppb and an average value of \$0.007 per cubic yard (4.2 ppb) (table 3). Small maximum size of gold particles, low gold tenor of sediments, and lack of gold placers in the adjacent land area (C. L. Sainsbury, written commun., 1969) all suggest that there are no offshore gold sources in the Port Clarence to Cape Prince of Wales region.

Fine gold was recovered in samples from the beach at Northeast Cape, and some samples of bottom sediment offshore from the Cape contain trace-sized particles of gold, but the gold content of these samples is less than \$0.005 per cubic yard (3 ppb).

A few samples recovered near the western coast of St. Lawrence Island and from the morainal gravel areas to the north contained bright metallic particles up to 1 mm in diameter that were identified as gold during panning. The richest of these samples, by color count, contained \$0.40 in gold per cubic yard (259 ppb) (table 4, sample ANC–86); unfortunately, the pan concentrate was lost before an atomic absorption analysis could be run to confirm this value. Atomic absorption analysis of other samples revealed no significant amounts of gold. A microprobe analysis of metallic particles from a heavy mineral separate of the westernmost sample from the morainal area (table 4, ANC–93) indicates that native copper is present (K. Venkatarathnum, mineralogist, Univ. Washington, written commun., 1968). Since atomic absorption analysis for gold destroys the sample, the nature of the metallic particles in the pan concentrates from the St. Lawrence Island area cannot be confirmed; however, recent discovery of native copper on St. Lawrence Island and reported occurrences from Chukotkan moraine source rock (W. Patton, U.S. Geological Survey, oral commun., 1971) indicates particles probably were native copper. To alleviate any problems from possible misidentification in these or any other samples, only atomic absorption analyses and amalgamated gold weights have been used to calculate average and median values, except for samples from the Port Clarence to Cape Prince of Wales area (table 3).

GOLD DISTRIBUTION IN FINE-GRAINED SEDIMENTS

The fine-grained sediments of the open Bering Sea contain very fine visible and subvisible free gold particles and probably some intragranular gold; however, total gold contents of most samples have not been ascertained because only a small part of the subvisible and intragranular gold within a sample is obtained by panning, the main method of sample concentration. Nevertheless, the values from concentration by panning and subsequent atomic absorption analysis should be statistically representative of content of particulate pannable gold and can be compared from area to area.

Most fine-grained sediments seaward from the 3-mile limit in Chirikov Basin contain less than 1 ppb of particulate pannable gold (table 4). Atomic absorption analysis of pan concentrates does confirm observation of fine trace-sized gold ($<$0.250 mm) in sediments as much as 20 miles (36 km) from the nearest shoreline (table 4, *Oceanographer,* samples ANC–81, 159, 161). One sample (table 4, *Oceanographer,* sample ANC–213) contains 182 ppb ($0.29 per cubic yard) according to atomic absorption analysis, but this is suspect because no gold was visible in the pan concentrates. The most reliable maximum values of particulate pannable gold near the center of Chirikov Basin seem to be those of about 10 ppb (table 4, *Oceanographer,* sample ANC–165); near the 3-mile limit of the open Bering Sea the most reliable maximum values appear to be those close to 30 ppb (table 4, *Oceanographer,* samples ANC–202 and 210).

One group of open Bering Sea samples (table 4, *Thompson,* samples TT18–13, 17, 21, 24, 25, 29a, 31, 44a, 45) was elutriated to remove silt- and clay-sized particles of normal density. The residues — sand-sized particles and, perhaps, some silt-sized heavy-mineral particles — were then subjected to atomic absorption analysis. All the residues, except one duplicate grab sample (table 4, *Thompson,* sample TT18–29b), contain measurable amounts of fine visible and subvisible gold in about equal amounts; gold contents range from 16 to 66 ppb, or considerably more than those in most of the 172 pan concentrate samples from the open Bering Sea. The high values of the elutriated samples were obtained less than 20 nautical miles from the shore, where values generally are higher; in addition, more very fine and subvisible gold may be retained by elutriation than by panning. Values still appear to be anomalously high, however, compared with those obtained from all other methods. This is especially true since analyses of whole sediment samples, which would detect subvisible as well as some of the intragranular gold of a sample, showed much lower values (table 4, *Thompson,* samples TT18–11, 23, 44b, 47).

Atomic absorption analysis of size fractions of total sample material yields values significantly higher than those obtained from pan concentrates, but less than those found in the elutriated concentrates, even in duplicate samples (table 4, *Thompson,* samples TT18–44a, 44b). The open Bering Sea samples (table 4, *Thompson,* samples TT18–11, 23, 44b, 47) analyzed by size fractions are from widely scattered locations more than 20 miles (36 km) offshore, yet each sample value is very close to the overall group average of 10 ppb. An interesting corollary is found in about 20 Nome nearshore samples analyzed in the same manner. Their average gold content is 10 ppb, and individual sample deviation is very low. Similar values and relationships were found for composited overpan[2] samples from the open Bering Sea (table 4, *Oceanographer,* samples ANC–220–229 and 231–245).

GOLD BACKGROUND TENOR AND PARTICLE SIZE AS GUIDES TO SOURCE REGIONS

Absolute background values for gold content (assumed to include intragranular gold, as well as fine-grained visible and subvisible gold particles smaller than 0.250 mm) cannot be utilized for regional and local comparisons because of analytical problems imposed by the particle-sparsity effect. Analyses of sands of the open Bering Sea indicate that gold particles of relatively large size (0.100 to 0.250 mm) are widely distributed and account for a significant part of the low gold content of the sediment. Clifton, Hunter, Swanson, and Phillips show (1969, fig. 3) that a statistically significant analysis of the gold

[2] Overpan sample is the material remaining after the pan concentrate has been removed. To obtain composited samples, parts of the overpan material from many samples of the same sediment type were combined, and these whole composite sample groups were then analyzed.

content of silty sand containing gold particles of this size and in this abundance must be based upon samples weighing about 25 kg. Because it is impractical to routinely analyze samples of this size by the atomic absorption technique (Van Sickle and Larkin, 1968), most samples were analyzed only for particulate pannable gold and comparisons are based on these kinds of data.

The rather consistent results of the few gold analyses of whole sample material from the open Bering Sea (table 4, *Thompson*, TT18 samples; also composited samples ANC–220–229 and 231–245) and the Nome nearshore region (data from leased areas, not shown in tables) suggest that the total background of sediments beneath the Bering Sea, away from areas of gold concentrations, is closer to 10 ppb of gold than to values a tenth as large which are indicated by pan concentrate samples (table 4). A suggested average background content of 10 ppb gold for the generally sandy sediments of the northern Bering Sea, which is in an area of known gold sources, agrees quite well with the most recent and reliable neutron activation determinations of the average gold content of sandstone (7.5 ppb; Jones, 1969).

Several reasons are apparent for the discrepancy between the gold values generally obtained from analysis of whole sediment and analysis of pan concentrates. Analysis of whole sample material by size fractions reveals that more than half of the gold in sediment with no apparent gold concentration is in the subvisible range. Gold this small generally is lost during panning. Also, most of the intragranular gold of a sample would be lost during panning, whereas it might be included in a total sample analysis. The fact that the visible gold content determined by analysis of whole samples and of elutriated samples is higher than that of pan concentrates seems to suggest that some particulate pannable gold may be lost in the panning overwash. In addition, color count data seem to show that somewhere during the entire processing and transfer of pan concentrates from the gold pan in the field to analyst in the laboratory, trace-sized gold may be lost.

Average background values of gold content in whole samples, although about 10 times greater than most particulate pannable gold values, have not been well defined locally or regionally and may never be thoroughly determined because of laborious analytical techniques required for whole samples of adequate size. Nevertheless, well-established local and regional values of particulate pannable gold do provide a partial measure of background contents of gold that can be used on a common and regional basis for comparison.

The data were synthesized by plotting the cumulative frequency percentage of all particulate pannable gold values for different areas of the northern Bering Sea (pl. 1; fig. 11)). In all areas except for the Sledge Island and Nome nearshore regions, about 75 percent of the values are less than 1 ppb; thus, the general background of particulate pannable gold in the bottom sediments of the Chirikov Basin is 1 ppb or less. This background value is independently confirmed by the fact that gold is visible in most pan concentrates of samples containing more than 1 ppb gold (table 4). Since fine trace-sized gold apparently has been dispersed over most of the area, sparsely distributed particulate pannable gold values slightly above 1 ppb are not anomalous nor indicative of gold source regions. However, the occurrence at the 75th-percentile level of values of 20 and 3.5 ppb in the Nome and Sledge Island areas, respectively (fig. 11), represents a significant deviation from the regional background of pannable particulate gold observed elsewhere in the Bering Sea and thus suggests that gold sources are present nearby.

The regional median values (50th percentile) of pannable particulate gold content vary from one part of the Chirikov Basin to another in a way that suggests a relationship of gold sources (fig. 11; table 3, col. 4). Regional median gold values are consistently higher in nearshore areas along the coast of the Seward Peninsula than in the open Bering Sea or along the shore of St. Lawrence Island. This suggests that, except for the possible occurrences of coarse gold in the morainal areas north of the western shore of St. Lawrence Island, the major sources of gold in bottom sediments are the present-day onshore or nearshore Seward Peninsula areas. The very low regional median gold values of samples from the open Bering Sea and from the north coast of St. Lawrence Island imply that these areas are farthest from significant gold sources. The fact that regional median gold values become higher toward the Sledge Island and Nome nearshore areas and are significantly higher within these areas suggests that these are specific source areas. Although the median gold values for most of the different environments within the Nome area are much greater than those elsewhere in the Chirikov Basin, the marked differences in median values (table 4) from one to another of the Nome nearshore sedimentary en-

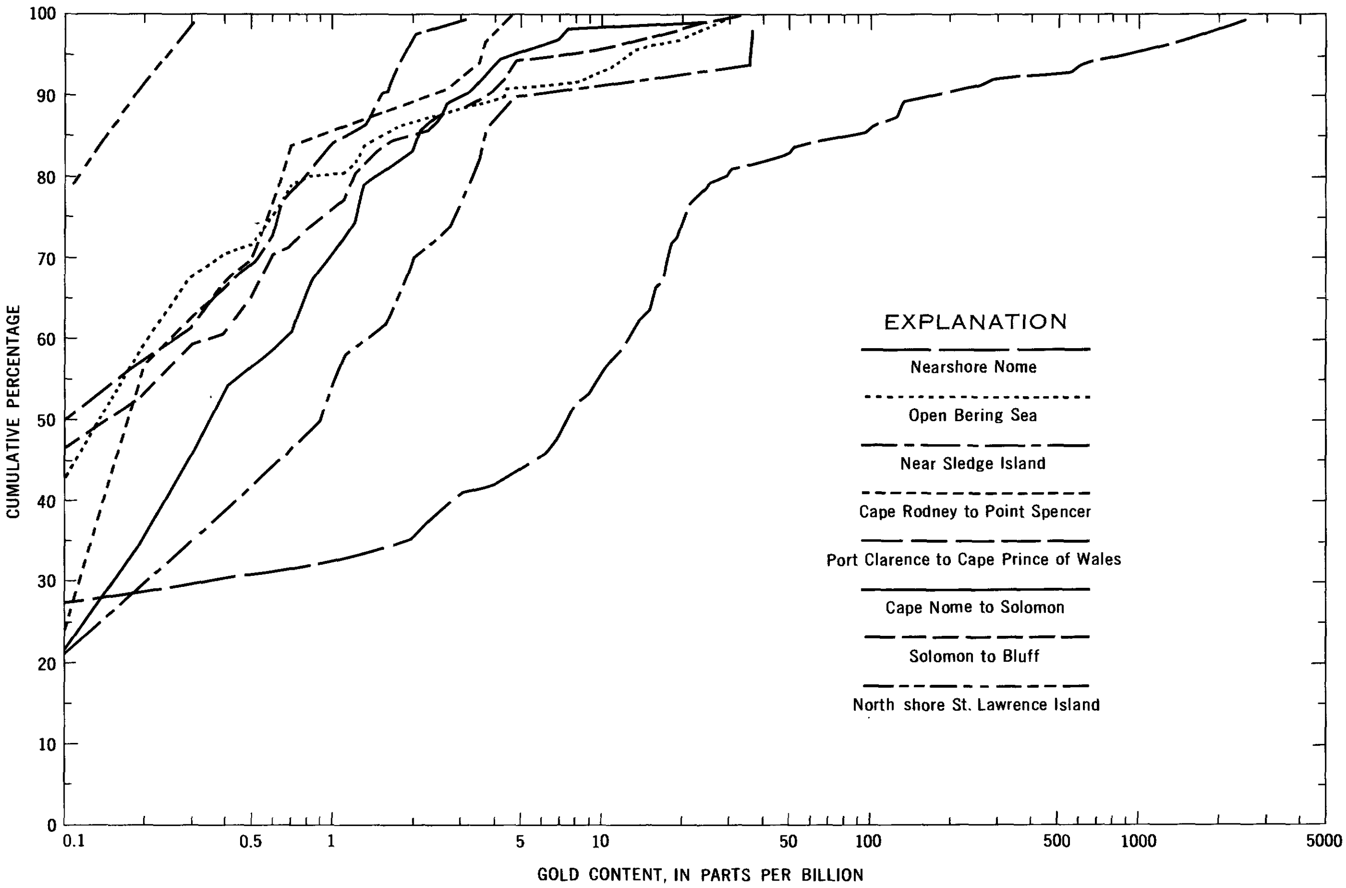

FIGURE 11.—Cumulative frequency distribution of gold content in different regions of the northern Bering Sea.

vironments (fig. 8) indicate that till is a major offshore source of gold; median gold values of the Nome nearshore areas also suggest that the local background of pannable particulate gold, excluding this source area, is about 3 ppb.

Regional variations in the maximum size of gold particles seem to confirm the conclusions concerning source relationships based upon regional median values of pannable particulate gold (table 3). Gold in areas far from the sources is no larger than fine-trace size; gold in the apparent source areas includes coarse particles (>1 mm), whereas gold in nearshore areas on the fringe of a source is generally not larger than medium-sand size and much is fine-trace size. Even in the local area of Nome, the gold-size relationships are similar. The specific drift source areas contain No. 2 and 3 size particles (>1 mm in diameter), whereas recent sediment surrounding drift areas has trace-sized gold (medium-sand size or smaller).

The presence of coarse gold clearly identifies a source area; however, an area, particularly a beach, that lacks coarse gold may have possible sources of fine gold and significant gold accumulations. Data on gold size from ancient beaches at Nome (A. E. Daily, written commun., 1968) and from the present beach there (table 3) show that trace-sized gold can be transported along and greatly concentrated on beaches. Consequently, on beaches, trends in median gold values are more significant than gold-size characteristics for the recognition of gold sources and areas of exceptional concentration. Since trace-sized gold is readily moved by longshore drift, beach areas where such drift has been obstructed may be sites of significant gold accumulation. The concentration of fine gold offshore from southern Oregon (Clifton, 1968a) and northern California (Moore and Silver, 1968) may be an example of such a process.

PROCESSES OF GOLD TRANSPORT AND DISPERSAL

The distribution of gold particles of various sizes reveals something about the sedimentary processes that disperse particulate gold offshore. The association of coarse gold (>1 mm in diameter) with areas of glacial drift and bedrock and the lack of it away from these areas suggest that in the marine environment only mass transport mechanisms can move coarse gold for any distance. The offshore drilling at Nome seems to show that small bodies of stream valley alluvium in the high-value area of the drift do contain coarse gold; however, the ancient streams that crossed the drift when sea level was low apparently did not carry gold any great distance beyond the drift, just as coarse placer gold in present-day Arctic streams is not transported more than a few miles from its source.

Our data from drilling and surface-sediment sampling point to the conclusion that most gold in offshore sediments isolated from bedrock was deposited there by glaciers, which scraped the gold from onshore bedrock and placer sources. Furthermore, the association of coarse gold with glacial drift and the lack of coarse gold in outwash fan deposits of the sea floor suggest that mass transport by glacial ice movement has been the chief process by which coarse gold was transported. Possibly, because of deposition of outwash fan material over till sources, outwash streams did not rework and carry significant amounts of coarse gold in the waning phases of glaciation, during which the offshore outwash material was deposited. During the early phases of outwash transport as streams cut through and reworked auriferous drift coarse gold may have been concentrated offshore; limited evidence from drill holes off Nome appears to support this idea.

Ice rafting may redistribute some gold offshore. When pressure ridges of sea ice or shore-fast ice become grounded on auriferous sediments, coarse gold can be plucked up and then carried farther offshore until the ice melts and drops the gold back to the sea floor. Since our data on gravel distribution suggest that ice rafting is only effective in redistributing coarse terrigenous debris to a limited areal extent, a similar case might be inferred for coarse gold transport. Areas of relict gravel are commonly surrounded by an aureole of pebbly mud, approximately represented by regions where the bottom sediments contain 1 to 10 percent gravel (fig. 10). Coarse gold is not likely to be rafted significantly beyond this aureole, and indeed almost no coarse or medium gold was found beyond it.

Shoreline processes have actively concentrated coarse gold in source areas and also transported trace-sized gold away from its source. Surf-zone erosion and selective transport, which removes the finer sediment, have concentrated gold in relict gravels overlying drift and bedrock. In the several shoreline migrations of Quaternary eustatic changes in sea level, gold-bearing drift and auriferous bedrock were extremely reworked, and significant concentrations of gold in the relict gravels were formed at the sea bottom. Since all the Chirikov Basin is shallow (fig. 1), the entire sea floor has been subjected to longshore drift processes at one time or another during the Holocene transgression. We believe that the trace-sized gold particles found in the fine-grained bottom sediments were dispersed by longshore drift during the progression and regression of the shoreline across the basin. Modern currents of about 15 to 25 cm per sec (fig. 1) prevent deposition in most offshore parts of the basin (Hjulstrom, 1938; Sundborg, 1956), but cannot move trace-sized gold particles which have an effective diameter of about 0.4 mm (R. Martin, unpub. data); consequently, trace-sized gold particles, which are found throughout much of the basin (pl. 1), seem to have required longshore transport to disperse them far offshore from their apparent nearshore sources.

The nearshore distribution of trace-sized gold and of median gold values (table 3) also suggests that fine gold has been transported laterally along ancient and modern shorelines by longshore drift and that fine gold has not been moved perpendicularly away from the shore by modern bottom currents. The modern current-deposited mud south of Nome and east of Solomon lacks trace-sized gold, whereas the relict sediments immediately east and west of Nome commonly contain trace-sized gold and have higher median values. The great abundance of fine gold in the modern beach, in submerged beaches, and in ancient beaches on land again suggests that longshore drift is the chief mode of transport of fine gold.

Bottom currents have played their principal role in preventing deposition in the areas of gold concentration, but the strong bottom currents in the Nome nearshore area may have dispersed small amounts of trace-sized gold. R. Martins' effective density curves (unpub. data) and Sundborg's size-velocity curves (1956) suggest that fine trace-sized gold (about <0.5 mm) can be moved by the strongest nearshore currents (75 to 100 cm per sec) known in the Nome region (fig. 1); indeed, the recently deposited sediments off Nome which surround drift source areas do contain fine trace-size gold. The distribution pattern of gold and the data on bottom currents, however, indicate that modern bottom currents cannot transport trace-sized gold far beyond the Nome nearshore region, nor can they move medium and coarse gold from the source regions, even in nearshore areas.

CONCLUSIONS

1. Because the highly auriferous sediments contain coarse gold (>1 mm), the particle-sparsity effect must be considered in gold-rich as well as gold-poor areas. Consequently, about 25 kg (55 lb) of sample is required to obtain a reliable estimate of the content of particulate pannable gold of any type of sediment from the northern Bering Sea.

2. To analyze large sample quantities, we suggest screening out the gravel fraction, elutriating to remove silt and clay, and then panning.

3. Inadequate sample size can be compensated for in homogeneous sedimentary environments by calculating moving averages, and comparisons can be made with statistical probability curves generated for samples with low and variable weights; this comparison suggests that such average values are representative and that coarse gold can be randomly distributed within restricted areas of certain sedimentary environments.

4. The richest concentrations and coarsest particles (1 mm or larger) of gold occur in sea-floor relict gravels that mantle glacial drift lobes in the Nome nearshore region and in gravel patches over bedrock in the Sledge Island area; these bodies of relict gravel formed during transgression and regression of the shoreline when eustatic changes of sea level occurred in Pleistocene time.

5. Relict gravels that overlie outwash fans appear to have no concentrations of gold in their upper surface; however, drilling suggests that buried outwash and alluvial channels that cut into auriferous glacial drift can contain significant concentrations of gold.

6. The submerged beach gravels of the sea floor, which are identified by their bathymetric locations and by pebble roundness and lithology, contain only low concentrations of gold; however, the gold content may be greater in the buried back-beach deposits.

7. Except along the present shoreline, Holocene sands and muds throughout most of the southern Bering Sea generally contain only sparse fine gold flakes (0.25 mm in diameter or smaller).

8. The total background gold content of Chirikov Basin sediments is not well defined. Analysis of several whole samples suggests an average of about 10 ppb. However, a partial background of pannable particulate gold can be used for comparison throughout the basin.

9. Trends toward higher median content of pannable particulate gold (>1 ppb) and slightly coarser gold in the bottom sediments near the Seward Peninsula coast point to the Nome-Sledge Island area as a major source for the gold dispersed in the finer sediments of the northern Bering Sea. Local source areas have median gold values about 10 or more times than those of areas without gold concentrations; they also contain gold particles of 1 mm or larger.

10. Lack of movement of gold particles 1 mm in diameter or larger from certain glacial deposits and bedrock areas indicates that coarse gold is not transported from these source regions by normal marine processes; however, modern-day ice rafting, in rare instances, seems to have dropped coarse gold into offshore fine-grained sediments that generally lack gold but contain ice-rafted pebbles.

11. Lack of fine gold in most sediments recently deposited from currents and presence of fine gold in widespread relict sediments apparently laid down by Holocene transgressions of the shoreline across the Bering Sea suggest that longshore drift is mainly responsible for dispersal of fine gold particles throughout bottom sediments of the northern Bering Sea.

12. Whereas shoreline processes have been largely responsible for offshore gold concentration and dispersal in the Chirikov Basin as well as in the land placers at Nome, the modern currents have prevented sediment deposition over much of the northern Bering Sea and consequently have preserved relict auriferous deposits on the present sea bottom.

13. Statistical analysis of values in the richest 6-square-mile area of the highly auriferous relict gravels near Nome indicates the following: Gold particles about 1 mm in diameter are common, these particles are randomly distributed, bottom samples are representative, the surface gravel averages 920 ppb in gold, and potentially minable deposits are present.

14. Although surface samples contain relatively little gold, presence of coarse gold, high background values, and geologic setting suggest that gold may be concentrated in submerged beach sediments. Very closely spaced drilling and vertical sampling increments would be necessary to detect any possible back-beach deposits, which are most likely to occur where inner beaches have been cut into auriferous till.

15. The coarse gold and high background values in gravel patches over sea-floor bedrock of the Sledge Island area indicate a possible offshore bedrock gold source; this area as well as the gravel shoal to the northwest are promising for gold exploration.

16. Confirmation of the presence and possible economic potential of apparent native copper in morainal gravel off St. Lawrence Island is recommended.

17. In regions of relict sediments, it appears that gold content of surface samples can identify and outline placer accumulations of gold in surface and underlying materials; however, where there is a cover of recently deposited fine-grained or muddy sediment which generally lacks gold, underlying deposits may be masked.

18. Most of the central part of Chirikov Basin is not an encouraging place for further prospecting, because the bottom sediments are fine grained and bedrock that might furnish local sources of gold lies buried beneath many hundreds of feet of Cenozoic sediments.

19. Although subvisible gold increases background values of normal sediments of the northern Bering Sea significantly and is considerably above background values in some samples, there is not enough to be worth mining.

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