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MARINE GEOLOGY AND BATHYMETRY OF THE NEARSHORE SHELF OF THE CHUKCHI SEA, OGOTORUK CREEK AREA, NORTHWEST ALASKA *

By

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This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

*This report concerns work done on behalf of San Francisco Operations Office, U. S. Atomic Energy Commission.

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MARINE GEOLOGY AND BATHYMETRY OF THE CHUKCHI SHELF OFF THE OGOTORUK CREEK AREA, NORTHWEST ALASKA

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ABSTRACT

During July and August 1958 the U. S. Geological Survey conducted a study in behalf of the Atomic Energy Commission of the oceanography, bathymetry, and marine geology of the nearshore shelf of the Chukchi Sea off the Ogotoruk Creek area, northwest Alaska. Ogotoruk Creek enters the Chukchi Sea about 32 miles southeast of the large cuspate spit of Point Hope at long 165°44'46" W. and lat 68°05'51" N. The Ogotoruk Creek area extends approximately 10 miles west and 7 miles east of the creek mouth. Knowledge of the marine geology and oceanography is confined primarily to the nearshore shelf, which includes about 70 square miles of the shelf and is defined as the sea floor lying shoreward of the 50-foot submarine contour. The 50-foot contour generally lies from 2 to 4 miles from shore. Submarine topography was studied to a distance of 15 miles from shore over an area of approximately 340 square miles.

A northwest coastal current flows past the Ogotoruk Creek area and during July and August averaged 0.5 mile per hour. Persistent northerly winds cause general upwelling near shore and at times of pronounced upwelling the coastal current was reversed or appreciably reduced in speed. Longshore currents shoreward of the breaker zone averaged 0.3 mile per hour and moved to the east for the greater part of the time of the study.

The overall seaward slope of the inner 15 miles of the Chukchi shelf from a depth of 40 to 135 feet is approximately 0°04', or about 6 feet per mile. Slopes near shore to depths of 15-20 feet are steep and average 2°30'. Beyond these depths they decrease gradually out to a depth of 40-45 feet. Seaward of this point the shelf is flattest and slopes are as low as 0°01'. This terrace or flat part of the nearshore shelf is about 2 miles wide and descends to a depth of 50-55 feet beyond which the gradient increases to about 0°06'. At depths greater than 85 feet the submarine declivity gradually decreases to 0°03' at a distance of 15 miles from shore.

A flat-bottomed trough, Ogotoruk Seavalley, heads about a quarter of a mile from shore off the mouth of Ogotoruk Creek. The shallow seavalley averages only 6 feet in relief and extends 15 miles from shore to a depth of 135 feet. A number of smaller channels also indent the gentle sloping inner Chukchi shelf east of the seavalley and nearshore west of it.

Many outcrops of Paleozoic and Mesozoic formations on the nearshore shelf indicate that it is a wave-planed platform. Wave planation is thought to have taken place primarily in Sangamon and pre-Sangamon time (approximately 100,000 to 1,000,000 years ago). Ogotoruk Seavalley is believed to be a drowned subaerial valley which was excavated by Ogotoruk Creek during periods of glacially depressed sea level.

Unconsolidated sediments overlying the nearshore shelf are chiefly slightly rounded residual gravel which have been derived from submerged outcrops. Detrital sand and silt, contributed from the nearby coastal area during Recent time, overlie the shelf near shore and at depth as much as 50 feet seaward of segments of the coast underlain by fine-grained clastic rocks of Mesozoic age. Owing to a small volume of detrital clasts contributed by the coastal area detrital sedimentation is not prominent over the nearshore shelf.

Beaches fronting the Ogotoruk Creek area are 30-260 feet wide, range from less than 10 to about 25 feet thick, and are composed of sandy gravel having a median diameter of about 10 mm. Rounded clasts of graywacke, siltstone, limestone, and chert are the principal constituents of the gravel. Longshore currents accompanying moderate storms transport gravel and sand parallel to shore at rates of 5 cubic yards per hour. Sediment transported by longshore currents accumulates as spits at stream mouths and as areas of new beach below rocky headlands.

INTRODUCTION

In 1958 the U. S. Geological Survey was requested by the Albuquerque Operations Office, U. S Atomic Energy Commission to conduct geologic studies to develop data which will contribute to determining the feasibility and safety of detonating several nuclear explosives to create an excavation that could be used for a channel and harbor near the mouth of Ogotoruk Creek, northwest Alaska. The proposed test excavation is project Chariot of the Atomic Energy Commission's Plowshare program.

The U. S. Geological Survey carried out investigations in the vicinity of Ogotoruk Creek from July 7 to August 25, 1958. The work was divided into two phases, an onshore mapping and engineering geologic study, and an offshore geologic examination of the shallow shelf of the Chukchi Sea. This paper concerns only the latter phase, although some coastal geology and physiography is described. The onshore geology will be discussed in a separate publication when onshore mapping is completed.

Marine investigations included the collection of some biologic data, but the work primarily entailed a study of the physical oceanography, the bathymetry, and the marine geology of the near-shore shelf of the Chukchi Sea.

Location

Ogotoruk Creek is approximately 32 miles southeast of Point Hope, a prominent cuspate spit, and about 125 miles northwest of the town of Kotzebue, Alaska (fig. 1). Ogotoruk Creek enters the Chukchi Sea at long 165°44'46" W. and lat 68°05'51" N. The Chukchi Sea is the shallow arm of the Arctic Ocean that lies north of Bering Strait.

Climate

The average yearly air temperature at the test site is about -7°C; hence, the ground is permanently frozen probably to a depth of several hundred feet. Winter snowfall is light and summer precipitation is about 8 to 12 inches (U. S. Weather Bureau, 1958).

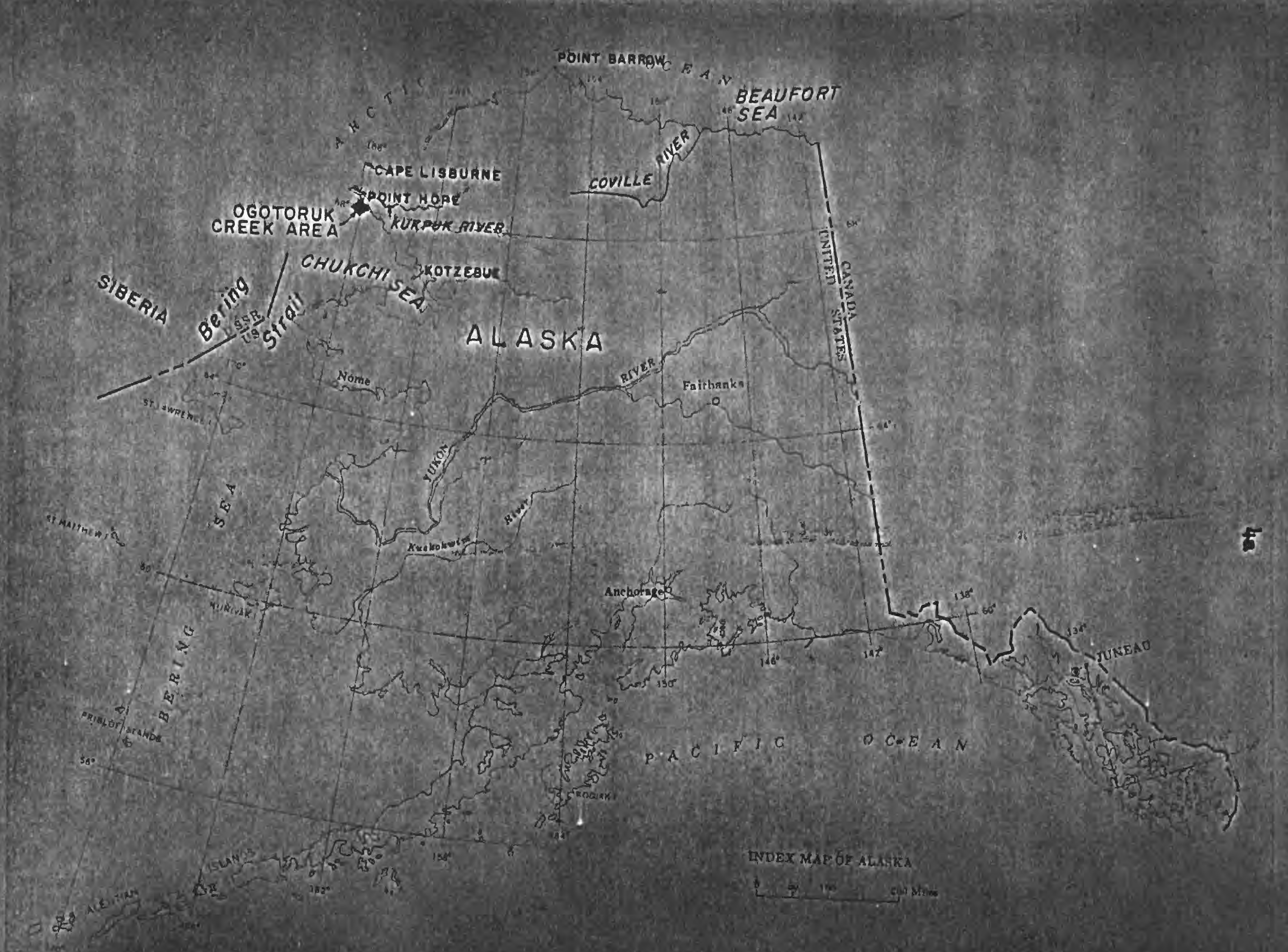

Figure 1. Index map showing location of Ogotoruk Creek area, Northwest Alaska

During the present study (July and August 1958) air temperatures ranged from 27° C to within a few degrees of freezing and approximately 5 inches of rain were recorded. Daily cloud cover was generally 60-65 percent; winds averaged about 15 miles per hour, and blew mainly from the north and northwest.

The sea off the Ogotoruk Creek area is frozen from about mid-November to mid-June, although in any particular year freeze-up and break-up may be more than a month earlier or later.

Previous investigations

A number of investigators have studied the geology and oceanography of the Chukchi Sea. Notable among these are: Buffington, Carsola and Dietz (1950); LaFond and Pritchard (1952); Carsola (1954a, 1954b, and 1954c); LaFond (1954); and U. S. Navy Electronics Laboratory (1954).

In the vicinity of Ogotoruk Creek virtually no published data on the marine geology and bathymetry exist. The geology of the coastal region has been briefly sketched by Collier (1906) and Kindle (1909a); Kindle (1909b) made a few commentaries on the nature of the beach gravels near Cape Thompson, a promontory 7 miles west of Ogotoruk Creek.

Acknowledgments

From August 9 to 11 the U. S. Navy generously allowed the Survey personnel to make use of the facilities of the icebreaker U.S.S. Burton Island. The authors are especially appreciative of the

cooperation shown them by the officers, civilian personnel, and crew of the Burton Island. Dr. K. O. Emery accompanied the authors aboard the Burton Island and was largely responsible for directing a bathymetric survey of the sea floor from 4 to 15 miles from shore. Dr. Emery also assisted and advised the writers in other phases of the investigation. Dr. George Shumway and Messrs. John Beagle, George Dowling, and Park Richardson, who were part of the civilian scientific staff aboard the Burton Island, made eight dives off the Ogotoruk Creek area and freely made their findings available to the authors.

Foraminifera in bottom sediments collected from the nearshore shelf were identified by Mrs. Patsy Smith of the U. S. Geological Survey.

Present study

Areas described

The nearshore Chukchi shelf of the Ogotoruk Creek area that was studied is delimited approximately by the 50-foot submarine contour, and includes the inner 2-4 miles of the shallow sea floor from the mouth of Eesook Creek eastward to the mouth of Kisimulowk Creek (fig. 2), a distance of 17 miles. Eesook Creek is approximately 10 miles west of Ogotoruk Creek, and Kisimulowk Creek enters the Chukchi Sea about 7 miles east of Ogotoruk Creek. Although discussion of the marine geology is limited to the area of the nearshore shelf, which includes approximately 70 square miles, description of the bathymetry extends seaward for 15 miles (fig. 2).

Collection of data

Most of the oceanographic and geologic data discussed in this paper were collected by members of the U. S. Geological Survey from a 14-foot open-cockpit boat powered with an outboard engine. In all, 302 data-collecting stations were occupied from July 9 to August 21, 1958; station positions were determined with horizontal sextant angles to onshore reference points which were easily identifiable on aerial photographs and published topographic maps. Depth sounds were made at 268 stations and samples of the unconsolidated bottom sediments were procured at 225 stations; these stations are shown on figure 2. Bottom samples were taken with a positive-acting grab attached to a hand-sounding line having 5-foot graduations. The maximum capacity of the grab was not more than about one kilogram of sample.

Surface water temperature and Secchi disk transparency readings (the Secchi disk is a white-painted disk 30 cm in diameter which is lowered until it just passes from view; this depth is then recorded as the Secchi disk transparency reading) were recorded at most of the stations shown on figure 2. Surface water samples were collected at 28 stations and later analyzed for salinity and other pertinent data. Velocity (speed and direction) of surface currents was measured at 33 stations by surface drogues. The drogues were simply constructed wooden current-crosses or vanes which were weighted to float about 6 inches below the surface with only a thin tracking periscope-like extension remaining above the surface. Drogues were also used to measure speed and direction of longshore currents; these measurements, together with recordings of wave and surf conditions, were made daily and sometimes hourly. A graduated staff driven into the sea bottom about 10 feet from shore served as a rough gauge for determining tidal fluctuations.

A portion of the data used in constructing the bathymetric chart shown on figure 2 was taken by the U. S. Geological Survey, but most of the information was supplied by Holmes and Narver, Inc., of Los Angeles, and by the U. S. Navy. Civilian geologists and biologists aboard the U.S S. Burton Island made eight dives off the Ogotoruk Creek area. These descents provided valuable information on the bottom sediments and permitted accurate location and description of the lithology and attitude of submarine outcrops. Photographs of the sea floor were also taken by the diving team. Eighteen bathythermograph lowerings were made from the Burton Island to determine subsurface water temperatures; the position of four of these lowerings are shown on figure 2.

The authors were jointly responsible for the collection of field data and samples. The laboratory work leading to the classification of the sediments, analyses of the oceanographic data, and preparation of the maps, are the work of the senior author. Most of the conclusions presented were reached after joint discussion, and separation of responsibility is not attempted.

COASTAL PHYSIOGRAPHY AND GEOLOGY

Meaningful interpretation of the nearshore bathymetry and marine geology of the Ogotoruk Creek area is dependent upon a general knowledge of the coastal physiography and geology. It is useful, therefore, to describe the physiography and geology between Eesook and Kisimulowk Creeks.

Physiography

For 1-1/2 miles east of Eesook Creek the shoreline is a narrow alluviated coastal plain which terminates in low coastal bluffs 10-15 feet high. Landward of the coastal plain are abandoned sea cliffs which rise to elevations of 300 to 400 feet (fig. 2). Several fresh-water lagoons are impounded by beach gravels at the outer edge of the coastal plain.

East of the low coastal plain and for approximately 7 miles eastward to Cape Crowbill (fig. 2), the shoreline is a precipitous sea cliff from 600 to 700 feet high. The cliffs rise to a roughly flat upland which can be traced into the interior of western Alaska (Hopkins, 1959). The continuity of the sheer seawall is broken only east of Emmikroak Creek where the coastline for approximately 1-1/2 miles is lower and cliffs are less precipitous (fig. 2).

Except at stream mouths, east of Cape Crowbill to Kisimulowk Creek the shoreline is fringed by a coastal terrace from 200 to 500 feet wide which terminates in coastal bluffs 20 to 70 feet high. The terrace fronts a line of abandoned sea cliffs which rise to elevations of 800 feet (fig. 3).

Figure 3. Mouth of Ogotoruk Creek, view is to the east. White spots by airstrip near center of photograph are tents of U.S. Geological Survey camp. Line of cliffs east of creek are abandoned sea walls; they are fronted by seaward-thinning wedge of colluvium which terminates in low coastal bluffs 20-70 feet high.

Major streams flow parallel to the regional structural grain, which strikes northeastward, and consequently valleys and interstream ridges trend southwestward and intersect the coastline nearly at right angles. Valleys are cut below flat-topped ridges of roughly concordant height (760-980 ft.) which are believed to be remnants of an erosional surface of Pliocene age (Hopkins, 1959). Downwarping of this surface farther to the west in late Pliocene or early Pleistocene time formed the shallow Chukchi Sea, and the present drainage pattern has largely formed since that time (ibid.). Ogotoruk and Kisimulowk Creeks, the largest streams draining the coastal area, meander gently in flood plains approximately a quarter of a mile wide in their lower reaches. The valley of Ogotoruk Creek is about 2 miles wide and is cut into bedrock; numerous outcrops are in the bed of the creek. Smaller streams entering the Chukchi Sea occupy narrow V-shaped valleys cut in bedrock and alluvium and extend inland for a distance of 1/4-mile to 4 miles (fig. 2).

Geology

In general, the rocks are progressively younger eastward from Eesook Creek toward Kisimulowk Creek (fig. 12), and include units ranging in age from Devonian(?) to Cretaceous-Jurassic(?). At the base of the low coastal bluffs near Eesook Creek fine-grained quartzite and micaceous silty shale of probable Mississippian age are exposed. Unexposed calcareous sandstone and shale beds of Devonian age (?) are thought to underlie the Mississippian clastic rocks (Collier, 1906, pl. 1), and to crop out on the sea floor approximately 1 mile from shore.

The sheer sea cliffs east of the coastal plain expose limestone which is provisionally correlated with the Lisburne group of Mississippian age (Bowsher and Dutro, 1957, p. 3). The limestone is commonly siliceous and some of the units consist chiefly of black chert. A synclinal belt, trending nearly at right angles to the shoreline, of clastic rocks of Mesozoic and Permian age is exposed along the lower and less precipitous sea cliffs near Emmikroak Creek. Fine-grained graywacke, siltstone, and shale believed to represent the lowermost Jurassic(?) rocks of the area occupy the central part of the syncline; green argillite, shale, and limestone tentatively correlated with the Shublik formation of Triassic age (Patton, 1957), and green argillite and chert beds provisionally correlated with the Siksikpuk formation of Permian age (ibid.), crop out along both flanks of the syncline and at Cape Crowbill.

East of the Triassic rocks near Cape Crowbill, and probably beneath most of Ogotoruk Valley, the rocks are predominantly siltstone. Farther east the rocks consist of interbedded graywacke and siltstone and are probably Cretaceous in age. The coastal terrace which fronts the ancient sea cliffs consists of a seaward-thinning wedge of colluvium; the colluvium is derived from outcrops of fine-grained rocks of Mesozoic age and consists of coarse angular rock fragments enclosed in a silty matrix.

Structurally, the geology of the Ogotoruk Creek area is very complex, but in general the structural grain strikes northeastward or nearly at right angles to the trend of the coastline. West of Cape Crowbill beds are overturned and thrust eastward. East of Cape Crowbill the Mesozoic rocks dip steeply and are intricately folded. The principal stratigraphic units and a few of the major structural elements of the Ogotoruk Creek area are shown on figure 12.

OCEANOGRAPHY

The Chukchi Sea is essentially a thin layer of water averaging about 150 feet in depth which overlies a drowned continental shelf connecting North America and Siberia (fig. 1). Water enters the Chukchi Sea primarily from the south through Bering Strait and in part from the northwest along the Siberian coast (LaFond, 1954). Major currents flow parallel to the Alaskan coast and eventually enter the Arctic Ocean near Point Barrow, Alaska. The characteristics of this coastal current as it passes the Ogotoruk Creek area, together with other oceanographic observations, are described and discussed below.

Water temperature and salinity

During most of July and August 1958 surface water temperatures over the nearshore shelf remained near 12°C. Surface salinities during these 2 months averaged near 28.9°/oo (parts per thousand by weight). In the Chukchi Sea, water having a temperature from 10°-12°C and a salinity less than 30.00°/oo has been defined as Alaskan Coastal water by LaFond (1954). Alaskan Coastal water is formed by admixing of Bering Sea water setting through Bering Strait with runoff water from western Alaska.

From August 1 to 6 surface water off Cape Thompson and east of Ogotoruk Creek was unusually cold and saline (fig. 4). Temperatures as low as 7.5°C and salinities as high as 30.93°/oo were recorded. LaFond (ibid.) has assigned the term Intermediate water to water masses of this temperature and salinity. Intermediate water results from mixing of Alaskan Coastal water with cold and saline Deep Shelf water. The relationship of Alaskan Coastal and Intermediate water on August 10 and 11 is shown on figure 5.

Throughout the period of observation surface water near shore was almost consistently 3.0-0.2°C colder and 1.57-0.33°/oo more saline than surface water from 2 to 4 miles from shore. A single recording of a seaward decrease in temperature was made on August 10 and 11; surface isotherms for these 2 days and for August 1 to 6 are shown on figure 4.

Subsurface temperatures were measured only on August 10 and 11. In general, temperatures decreased from about 9°to 10.5°C at the surface to 5.2°C at a depth of 144 feet. Over the inner 10-11 miles of the shelf the water was nearly isothermal with depth but temperature decreased with distance from shore at any given depth. This relationship is shown on figure 5. At greater distances from shore a tongue of cold Intermediate water (less than 8.5°C) protruding shoreward caused the isotherms to be more nearly horizontal.

Currents

Coastal

During most of July and August the predominant surface current moved parallel to shore in a northwesterly direction. Velocities of this current ranged from 0.1 mile per hour to 0.8 mile per hour, and averaged 0.5 mile per hour. Current velocities and dates of measurement are shown on figure 4. South and southeast currents of low velocity were occasionally recorded on the up-current side of Cape Crowbill, which presumably indicates an eddy or swirl of water close to shore off the mouth of Ogotoruk Creek. From August 1 to 6 the northwesterly coastal current was reversed or appreciably reduced in velocity off Cape Thompson and east of Ogotoruk Creek. Currents east of Ogotoruk Creek slowed to 0.3 mile per hour and flowed to the south and southeast (fig. 4). Off Cape Thompson the northward-setting coastal current was reduced to about 0.2 mile per hour, which is nearly two-thirds lower than its typically recorded velocity.

Longshore

Longshore currents are set up by waves striking the beach at oblique angles and are strongest shoreward of the breaker zone (fig. 6). While the Survey party was in the field between July 7 and August 25, variable winds caused repeated reversals in wave approach and hence in longshore currents. Longshore currents flowed to the east for the greater part of the time (approximately 75 percent) and averaged 0.3 mile per hour 10-15 feet from shore; however, the highest velocities (as much as 1.1 miles per hour) were measured during east and southeast storms when the longshore currents moved to the west.

Velocity of longshore currents in general increased with wave height and with the angle formed by the breaking waves and the shoreline. Highest velocities occurred when waves 3-5 feet high struck the beach at angles between 15 and 20 degrees. Undoubtedly stronger currents accompany violent storms which strike this segment of the Alaskan coast during fall months prior to freeze-up. The general relationship of longshore current velocity to wave height and angle of approach for the Ogotoruk Creek area is diagrammed on figure 6.

Waves

At Ogotoruk Creek wave action is limited to the ice-free summer and fall months except for occasional severe winter storms. The characteristics of wave trains varied greatly in the Ogotoruk Creek area owing to frequent changes in wind velocity and direction. Throughout the period of study waves were typically 10 inches high, 25-30 feet in length, and had a period of 4-5 seconds. Waves with heights of 3-5 feet and periods of 6-7 seconds accompanied strong onshore winds (30-40 miles per hour) which blew for more than a day. Frequently waves of somewhat smaller height but similar period arrived from distant storms, and were not accompanied by strong onshore winds. Because the shoreface drops off rather steeply to a depth of 15-20 feet, most waves did not break until they were within a few feet of shore; only the larger waves (3-5 ft.) broke more than 20 feet from shore. Marked changes in the foreshore profile were produced by these larger waves; erosion and growth of the shoreline is taken up under a discussion of beaches.

Tide

Tides in the Ogotoruk Creek area were characterized by a one-half period of 6-6½ hours, a height of 9 inches, and a lag time of the arrival of tide crests of about 20-30 minutes per day. When strong onshore winds blew (30-40 miles per hour) sea level rose an additional 1-1½ feet; conversely, sea level fell 1-2 feet below mean low water at times of strong offshore winds. Driftwood at elevations of 10-15 feet is evidence that higher sea levels and waves than were recorded during July and August 1958 occur along this segment of the Alaskan coast. This belief is in part substantiated by published accounts of 10-foot rises in sea level during severe fall storms at Point Hope (Kindle, 1909b) and at Point Barrow (Schalk, 1957).

Water transparency

Transparency of the coastal water varied greatly owing to changes in the amount of suspended inorganic particles and plankton and to the concentration of soluble organic pigments. Water clarity increased with distance from shore. Secchi disk readings near shore were commonly only 15-20 feet; at a distance of 3-4 miles readings increased to 30-45 feet which is compatible with a measurement of 34 feet taken approximately 60 miles off the Ogotoruk Creek area in August of 1949 (Buffington, Carsola, and Dietz, 1950, p. 23). Water clarity from August 1 to 6 in areas of cold and saline water were 5-10 feet lower than at other times. Low transparency also accompanied storms when large amounts of detrital particles were stirred into the sea water by waves and stream discharge.

Discussion

Upwelling of subsurface water is indicated by the cold and saline Intermediate water present at the surface from August 1 to 6 off Cape Thompson and east of Ogotoruk Creek (figs. 4 and 5). During this time persistent north to northwest offshore winds of 10-30 miles per hour apparently caused Intermediate water to rise to the surface east of segments of the coast which are topographically low.

The consistent cold and saline surface water close to shore throughout July and August suggests that weak but almost constant upwelling was taking place. Unfortunately there are insufficient subsurface temperature and salinity data to substantiate this probability; however, the prevailing northerly winds of 10-15 miles per hour which blew during the period of observation could conceivably maintain such a general upwelling. Moreover, the single recording of a temperature decrease with distance from shore (fig. 4) was made on August 10 and 11 during a period of easterly winds when upwelling near shore theoretically should not have taken place.

Upwelling Intermediate water from August 1 to 6 also explains the reversal and slacking of speed of the coastal current. On figure 4 it can be seen that east of Ogotoruk Creek currents flowed to the right and parallel to the slope of the dynamic topography which can be roughly envisioned from the surface isotherms. An increase in concentration of zoo-phytoplankton in areas of upwelling water probably accounts for the lower water transparency from August 1 to 6. Similar relationships of low water transparency and upwelling water have been described by other authors (Emery, 1955a).

BATHYMETRY

Construction of the bathymetric chart

Approximately 3,000 soundings were used in constructing the bathymetric chart shown on figure 2. Sounding density varies considerably (fig. 7) and ranges from 1.4 soundings per square mile to 270 and averages 8.4 soundings per square mile. The chart comprises approximately 340 square miles of the shallow Chukchi shelf out to a depth of 145 feet.

Holmes and Narver, Inc., of Los Angeles, compiled the data used in contouring the submarine topography out to a depth of 55-65 feet for several miles east and west of Ogotoruk Creek (fig. 7). Soundings were made with a fathometer installed on a small coastal tug. Positions of the tug east of Cape Crowbill were determined by the range method with two onshore transits; soundings were located west of Cape Crowbill with horizontal sextant angles to surveyed onshore sighting stations.

Data east and west of the area surveyed by Holmes and Narver are lead line soundings made by the U. S. Geological Survey. Sounding positions were determined with horizontal sextant angles to onshore reference points. The Survey also established 188 depth readings within the area traversed by Holmes and Narver; these stations are shown on figure 2.

All bathymetric readings seaward of the 65-foot contour were made with the echo-sounding equipment of the U.S.S. Burton Island. Navigation was by radar fixes with coastal reference points.

Because different surveying methods were employed in collecting the bathymetric data, only areas comprising one navigation and one sounding technique are internally consistent; these areas are shown on figure 7. Dashed contours are used where only lead line information is available and where different surveys closely adjoin but do not overlap.

Figure 7 shows that the sounding density immediately seaward of the mouth of Ogotoruk Creek is more than 10 times greater than that to the east and west. Owing to this density the submarine topography off Ogotoruk Creek is better known and appears somewhat more irregular than the adjacent sea floor. Nearshore sounding lines trend south from shore between Cape Crowbill and Kisimulowk Creek, and in some areas there is a corresponding tendency for topographic features to follow the sounding lines. This relationship is evident in the well-sounded area off the mouth of Ogotoruk Creek. Northward-trending bathymetric features probably represent spurious alignments as they are oblique to the general slope of the submarine topography, and are inconsistent with the known northwest trend of the coastal physiography and geologic structure. Several authors have described in more detail the fictitious alignments of submarine features parallel with sounding lines (Kuenen, 1950, p. 488-491; and Dietz, 1954, p. 1201). In compilation of the chart, spurious alignments of the topography were reduced to a minimum by cooperation between geologists of the U. S. Geological Survey and topographic engineers of Holmes and Narver, Inc.

General

The floor of the Chukchi Sea is remarkably free from local or even regional relief. Submarine declivities over the central part of the shelf are as low as 00°00'12" (0.3 ft. per mile) and in the opinion of many geologists it is one of the flattest regions on the earth (Buffington, Carsola, and Dietz, 1950; and LaFond, 1954).

Submarine gradients near the Alaskan coast steepen somewhat and the topography is more irregular. Except in the vicinity of Point Barrow, the Chukchi shelf adjacent to the coast is poorly known. The inner 15 miles of the sea floor off the Ogotoruk Creek area, which is described below, is probably the most thoroughly known nearshore region of the Chukchi shelf.

The sea floor slopes very gently away from the Ogotoruk Creek area and is exceptionally flat to moderately irregular in local relief (fig. 2). The shelf is flattest between depths of 40-55 feet and somewhat steeper farther seaward. Near shore the bottom rises abruptly to the shoreline.

The most prominent bathymetric feature is a shallow and rather flat-bottomed trough leading seaward from the mouth of Ogotoruk Creek. This submarine channel is hereafter referred to as Ogotoruk Seavalley.

Topography of shelf

Submarine gradients extending from the shoreline average about 2°30' and the bottom descends quickly to a depth of 15-20 feet. Off cliffed headlands the initial declivities are as steep as 4°. The relatively steep slope near shore is termed shoreface by some authors (Price, 1954) and off gravelly beaches of the Ogotoruk Creek area it represents a slope adjusted to depositional and erosional forces. Schalk (1957) has shown that moderate storms in the vicinity of Point Barrow produce no major change in the shoreface, but that major storms result in profound changes in the shape and slope of the shoreface profile.

In the Ogotoruk Creek area the lower part of the shoreface below depths of 15-20 feet descends less steeply (0°17' to 0°30') to a depth of 40-45 feet. For approximately 2 miles seaward of this point, to a depth of 50-55 feet, the nearshore shelf is flattest and slopes are as low as $0^{o}01'$. The inner and outer edges of this terrace or flat part of the nearshore shelf are indicated by brackets on profiles B-B', C-C', and D-D' included on figure 8. At the outer edge of the shelf terrace gradients steepen to near $0^{o}06'$ and from this point seaward gradually fall to $0^{o}03'$. The overall declivity of the shelf seaward of the inner edge of the shelf terrace is $0^{o}04'$, or 6 feet per mile.

Seaward of Kisimulowk Creek at depths greater than 55-60 feet, the shelf is markedly more irregular than the nearly featureless bottom immediately to the west. The sea floor in this area is gently undulating and comprises a series of five southwestward-trending valleys and ridges (fig. 9) and a number of isolated knolls as much as 15 feet high.

Ridges and valleys range from one-half to one-quarter mile in width and have a relative relief of 10-12 feet. Gradients down the valleys are between $0^{o}04'$ and $0^{o}03'$. Near their inner reaches slopes leading into the valley are about $0^{o}30'$. At depths greater than about 85 feet the valleys and ridges gradually merge with the sea floor and virtually disappear at a depth of 105 feet.

Ogotoruk Seavalley heads approximately a quarter of a mile from shore at a depth of 30 feet and extends seaward for a distance of 15 miles to a depth of 135 feet. The valley axis is sinuous but in general trends southwestward. A principal channel can be traced along the floor of the seavalley but a number of converging channels or "tributaries" enter near its head. The seavalley has a maximum relief of about 15 feet which is at a depth of about 85 feet.

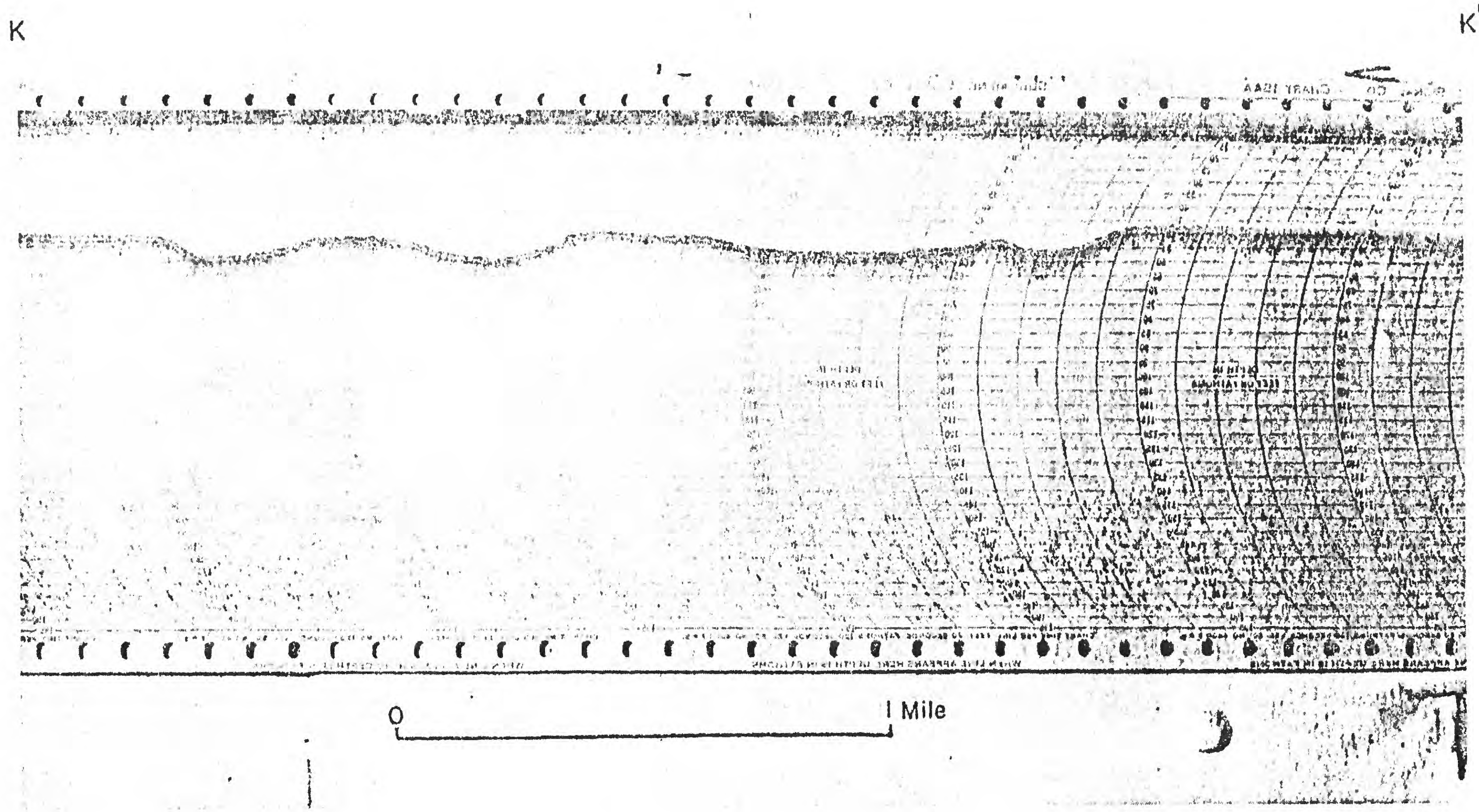

Figure 9. Fathogram K-K' across valley-and-ridge area off Kisimulowk Creek. Add 27 feet to indicated depth for correct depth reading. Line of trace shown on figure 2.

Near shore the seavalley is approximately 2 miles wide, but it gradually narrows to about $1\frac{1}{2}$ miles at a depth of 85 feet (fig. 10). Gradients along this part of the valley floor are rather uniform and average 0°07' (11 ft. per mile), which is about 0°03' greater than the slope of the adjacent sea floor (fig. 2, profile A-A'). The sides of the seavalley slope between 0°09' and 0°12', however, declivities leading into the valley from shore slope about 2°. A number of knolls rising 1-5 feet above the valley floor characterize the inner reaches of the seavalley.

At depths greater than 85 feet the seavalley narrows to a single channel approximately half a mile wide (fig. 11) and then widens to merge gradually with the adjacent sea floor at a depth of 135 feet. Between depths of 85 and 120 feet the gradient falls to about 0°03' and throughout the outer 5 miles the gradient decreases to near 0°02'.

Ogotoruk Seavalley is similar to other submarine valleys or canyons in that it has a gentle sinuous course, a smooth gradient, and "tributaries" enter at grade. Also like many other submarine valleys, Ogotoruk Seavalley has been cut directly into bedrock, and outcrops of Paleozoic and Mesozoic rocks have been located in many parts of the seavalley by bottom samplings and divers (fig. 12). The seavalley differs from others, however, in that transverse profiles are not V-shaped but are broad and, although somewhat hummocky, rather flat (figs. 10 and 11). Moreover, Ogotoruk Seavalley is not deeply entrenched in the Chukchi shelf but averages only 6 feet in

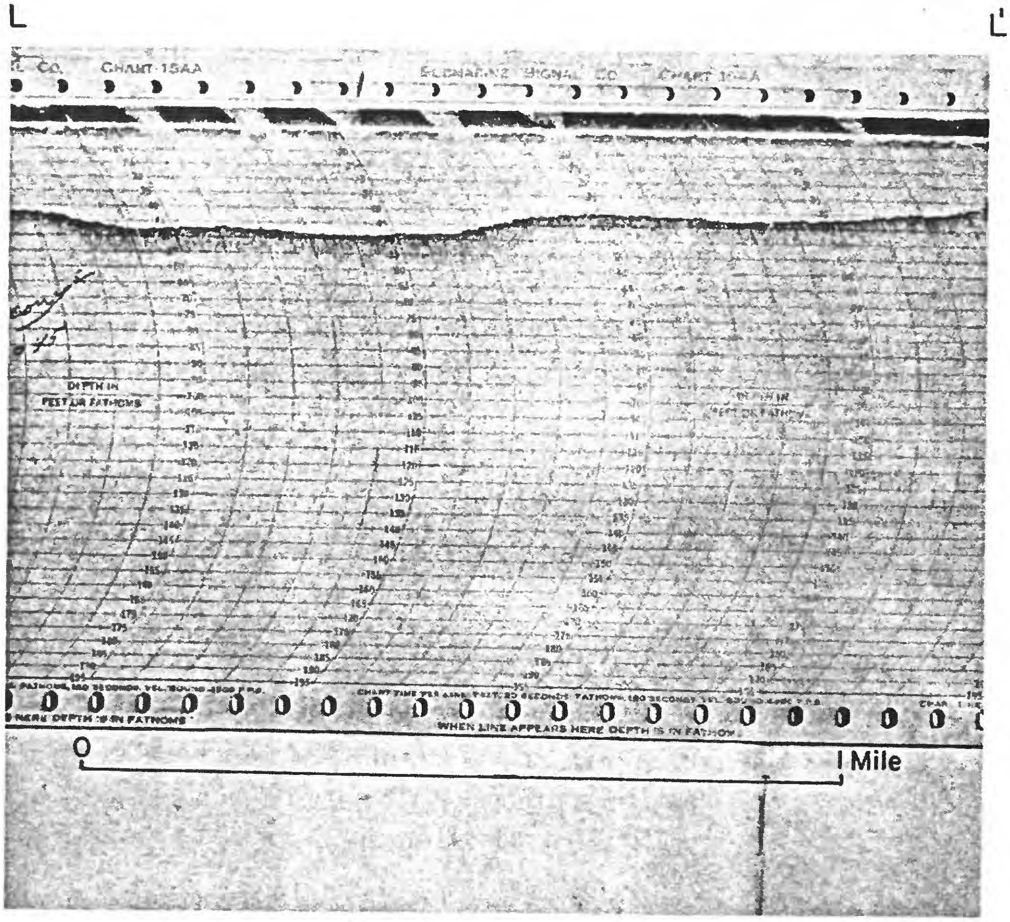

Figure 10. Fathogram L-L' across Ogotoruk Seavalley approximately 4 miles from shore. Add 27 feet to indicated depth for correct depth reading. Line of trace shown on figure 2.

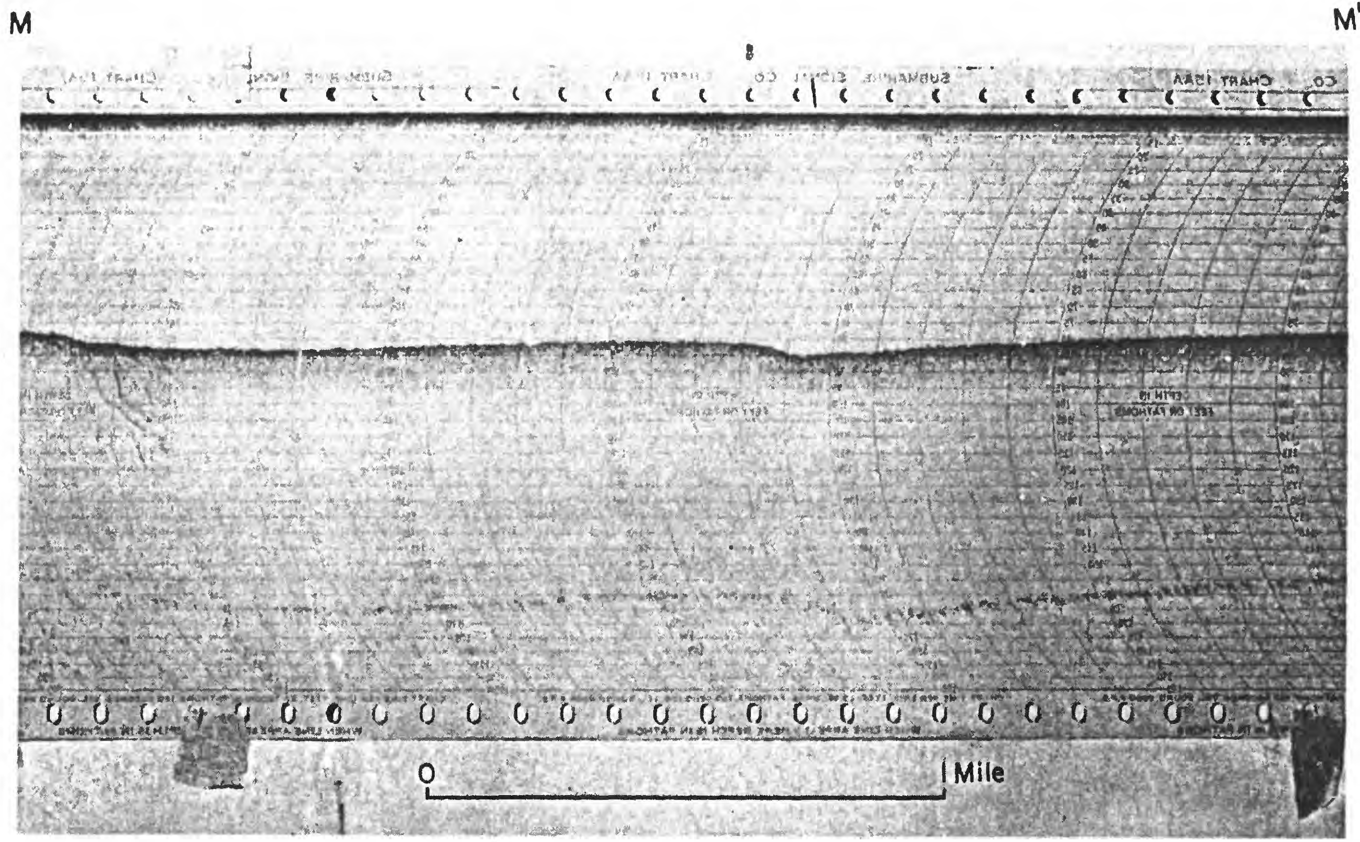

Figure 11. Fathogram M-M' across Ogotoruk Seavalley approximately 10 miles from shore. Add 27 feet to indicated depth for correct depth reading. Line of trace shown on figure 2.

relief. The overall gradient of the seavalley, $0^{\circ}03'$, stands in marked contrast to gradients of other submarine valleys which range from about 8° near their heads to about 2° in their lower courses (Kuenen, 1950, p. 487).

Other arctic submarine valleys have been described by Carsola (1953 and 1954c). These dissect the outer edges of the continental shelves of the Chukchi and Beaufort Seas and are similar to submarine valleys elsewhere in the world. One of these arctic canyons, Barrow Canyon, has an apparent broad and flat-bottomed extension which cuts across the upper part of the continental shelf northwest of Point Barrow. Carsola has termed this feature Barrow Seavalley to distinguish it from Barrow Canyon, which has the typical V-shaped profile. Barrow Seavalley is the only submarine feature yet described from the Alaskan arctic which is similar to the shallow trough of Ogotoruk Seavalley.

Although bathymetric data are scanty, and limited to lead line soundings, there is an indication of a broad shallow channel off Emmikroak Creek which heads in water 40 feet deep (fig. 2). The axis of this depression is not directly aligned with the creek, but rather is aligned with the synclinal infold of Mesozoic and Permian rocks. Much narrower submarine furrows, however, can be traced from the mouths of Nusoaruk Creek and the small stream entering the Chukchi Sea immediately west of Cape Crowbill.

Origin of submarine topography

The topography of the shelf to a distance of 15 miles from shore is believed to represent erosional forms cut on bedrock. Some of the initial topography has been buried or partly subdued by subsequent marine sedimentation.

Bottom sampling to a distance of 4 miles from shore indicates that bedrock crops out over most of the area of the nearshore shelf or is veneered thinly by unconsolidated sediments. Criteria for locating submarine outcrops from the nature of the bottom deposits are given in a discussion of the shelf stratigraphy; divers have also mapped exposed bedrock near the mouth of Ogotoruk Creek and in water 40 feet deep off Cape Crowbill, and visual sightings of outcrops were made by the writers on several occasions in shallow (as deep as 30-35 ft.) clear water. The flat and relatively smooth bedrock surface of the nearshore shelf is interpreted as a wave-planed platform.

Hopkins (1959) has given evidence that crustal downwarping formed the shallow Chukchi and Bering Seas in late Pliocene or early Pleistocene time. It is probable, therefore, that wave-planation of the nearshore shelf involved at least several and perhaps all of the Pleistocene sea level fluctuations. However, consideration of the age of an abandoned shore in the Ogotoruk Creek area tends to indicate that much of the planation took place during Sangamon and pre-Sangamon time (approximately 100,000 to 1,000,000 years ago). This ancient shoreline and deposits associated with it will be discussed more fully in a forthcoming paper by Sainsbury and others.

The ancient shore cuts across folded rocks of Jurassic and Cretaceous age at the base of the abandoned sea cliffs east of Ogotoruk Creek and is overlain by the seaward-thinning wedge of colluvium. The wave-planed surface of the old shore also lies beneath colluvium derived from the infolded Mesozoic rocks east of Emmikroak Creek and underlies the alluviated coastal plain in the vicinity of Eesook Creek. Beach gravels rest upon the old shore in many areas and driftwood had been collected from these sediments near Emmikroak Creek. The shore probably does not rise to elevations much exceeding 20-25 feet, but its gently sloping bedrock floor can be traced seaward where it probably merges with the bedrock surface of the nearshore shelf.

The authors believe that the shoreline was cut by a relatively high-standing sea level of Sangamon(?) age, and that the colluvium accumulated subaerially from the exposed Jurassic and Cretaceous rocks, during Wisconsin and Recent time. The Sangamon(?) age of the ancient shoreline implies that the nearshore shelf was carved by the end of Sangamon time. The terrace or flat area of the nearshore shelf at depths of 40 to 55 feet may have been caused by a temporary halt in a rising or falling Pleistocene sea level, or may represent the seaward continuation of the wave-planed platform. The nearshore shelf probably was subjected to marine planation prior to Sangamon time, but older Pleistocene sea level fluctuations are not clearly recorded in the Ogotoruk Creek area.

Ogotoruk Seavalley

Shepard and Emery (1941) discussed in detail six possible origins for submarine valleys or canyons. More recently geologists have come to believe that submarine valleys are (1) excavated by submarine erosion, such as by turbidity currents or strong water motion (Kuenen, 1950 and 1953); (2) are of composite origin involving both subaerial and subaqueous processes (Shepard, 1952); or (3) are drowned subaerial valleys. However, any hypothesis proposed for the origin of Ogotoruk Seavalley must adequately account for the following facts and relationships:

(1) The axis of Ogotoruk Seavalley and Ogotoruk Valley are perfectly aligned.

(2) The gradient profile of Ogotoruk Creek is continuous with only a slight decrease in slope ($0^{\circ}17'$ to $0^{\circ}07'$) with the gradient profile of the seavalley (fig. 2, profile A-A').

(3) Both valleys are primarily cut into relatively soft siltstone and shale flanked by more resistant rocks.

(4) The abundance of rock outcrops along the margins of the seavalley.

(5) Tributaries or minor channels near the head of the seavalley have increased its width to that of the valley of Ogotoruk Creek.

(6) A number of isolated knolls in the inner reaches of the seavalley suggest differentially eroded bedrock.

(7) The seavalley gradually merges with the adjacent sea floor and virtually disappears at a depth of 135 feet.

Carsola (1953, p. 41) has shown that Barrow Seavalley may have in part been scoured by strong currents directed along the axis of the valley. However, water motion over Ogotoruk Seavalley is oblique to the trend of the valley and current scouring cannot be postulated as an origin. Tidal currents, which must in part move along the axis of the valley, also could not have eroded the seavalley as the average tide range is less than one foot and it is not reasonable that attendant tidal currents are competent enough to scour a valley in bedrock.

Excavation by turbidity currents in the manner envisioned by Kuenen and Daly (Kuenen, 1950, p. 509) cannot be applied to Ogotoruk Seavalley. This hypothesis limits the time of cutting to periods of glacially lowered sea level, and therefore cannot be considered in this case as the Chukchi Sea was largely drained of marine waters during glacial ages of the Pleistocene epoch (Hopkins, 1959). It has also never been adequately demonstrated that turbidity currents are capable of eroding bedrock on very gentle submarine slopes (Kuenen, 1950, p. 526).

A composite origin seems more plausible as it only requires that turbidity currents periodically sweep the valley clear of unconsolidated sediments (Shepard, 1952). More fundamental to the composite hypothesis, however, is the drowning of subaerially carved valleys. Indeed, the perfect alignment of Ogotoruk Valley and Ogotoruk Seavalley, their similar gradients, and the fact that both valleys are cut in soft siltstone and shale beds of the Tiglukpuk formation, are considered strong evidence that the seavalley is simply a drowned segment of the valley of Ogotoruk Creek.

Because Ogotoruk Creek probably reached the sea coast in early Pleistocene time, excavation and drowning of the seavalley can be interpreted in two ways: (1) the seavalley may represent the inundated valley floor of an older subaerial valley whose sides were bevelled down during wave-planation of the nearshore shelf; or (2) the seavalley was excavated during periods of glacially lowered sea level when Ogotoruk Creek was free to extend out onto the exposed Chukchi shelf.

In regard to the first possibility, it is reasoned that wave-planation of the nearshore shelf would have cut beneath the steeper Pleistocene gradients of Ogotoruk Creek and would not have preserved the valley floor as a submerged depression. The best interpretation seems to be that the seavalley is a drowned segment of Ogotoruk Valley which was cut into an emerged continental shelf during glacial stages of the Pleistocene epoch. Near the head of the seavalley it is apparent that new tributaries also developed which appreciably broadened its shallower reaches. Differential stream and wave erosion of the rocks underlying the seavalley probably carved the isolated knolls. Since the last episode of stream erosion the head of the valley has been filled with beach sediments and Recent marine sedimentation has apparently buried and subdued the outer part of the seavalley. Farther out onto the Chukchi shelf a thick blanket of Recent sediments is thought to have formed one of the flattest regions on the earth.

Owing to a lack of a clear record of pre-Sangamon events, the time of initial shaping of Ogotoruk Seavalley cannot be precisely determined. There can be little doubt, however, that some stream erosion, and conceivably all of it, took place during the Wisconsin glacial stage.

Minor features

In view of the foregoing discussion, it is assumed that the small channels leading seaward from the mouths of Nusoaruk Creek and the small creek west of Cape Crowbill, are also probably drowned Pleistocene streambeds (fig. 2). The much broader submarine depression lying off Emmikroak Creek and the synclinal infold of Mesozoic and Permian rocks is probably also a Pleistocene subaerially eroded feature, but it may also reflect differential marine erosion of the less competent Jurassic rocks occupying the central part of the syncline (fig. 12).

Although bottom samples were not collected from the valley-and-ridge area off Kisimulowk Creek, it is probable that the low ridges reflect bedrock brought into relief by streams eroding an emerged shelf during a period of glacially depressed sea level. In support of this interpretation are the facts that the small valleys have gradients similar to those of Ogotoruk Seavalley and the southwestward-trending ridges are parallel to the strike of steeply dipping Mesozoic rocks in the coastal area. The outer reaches of the valley-and-ridge area have apparently been buried under a blanket of Recent marine sediments.

Rex (1955) and Carsola (1954d) have described small bathymetric structures gouged by pack ice in the shallow sea floor northwest of Point Barrow and over the inner shelf area off the Colville River. Divers have examined some of these features near Point Barrow (George Shumway, U. S. Navy Electronics Laboratory, San Diego, personal communication). Grounding of pack ice in water as deep as 120 feet (Carsola, ibid.) has been substantiated by many investigators and takes place along most of the Arctic coast (Transehe, 1928). Sounding lines were too widely spaced during the present study to contour microrelief gouged by pack ice, but it is likely that detailed sounding of the flat sea floor east of Ogotoruk Seavalley will delineate ice-gouged microrelief.

MARINE GEOLOGY

Discussion of the marine geology is divided into two parts; (1) a description of the bedrock geology or stratigraphy of the nearshore shelf, and (2) a description of the unconsolidated bottom sediments and beach deposits of Quaternary age.

Shelf stratigraphy

Coarse rock debris was collected at nearly 80 percent of all sampling stations off the Ogotoruk Creek area. This rock debris was classified as either transported, or indicating the close proximity of submerged outcrops. In making the distinction most of the criteria listed by Emery and Shepard (1945, p. 434) were used; these are:

Rocks collected at or near submerged outcrops

(1) Fresh fractures.

(2) Large size of individual rocks.

(3) Abundance of rocks of similar lithology.

(4) General angularity of rocks.

(5) Fragile or poorly consolidated rock.

(6) Catching of sampling device on bottom.

Transported rock

(1) Varied lithology

(2) General rounded character.

(3) Small size of individual rocks.

In addition, submarine outcrops were located by consistent inability to collect a bottom sample in a given area, by direct observation of submerged rock ledges in clear shallow water, and by divers.

The character of all rocky or gravelly sediments collected from the nearshore shelf is described under the discussion of unconsolidated bottom sediments; transported rock, such as ice-rafted debris, is also discussed here.

Submarine outcrops

Angular pebbles and cobbles indicating the close proximity of submerged bedrock were collected at 75 stations, visual sightings of outcrops ledges were made at 12 stations, apparent bedrock bottom which could not be sampled was located at 5 stations, and divers mapped submarine outcrops at 2 stations (table 1). The areas of known submarine outcrops are shown on figure 12; residual rock debris flanking submarine outcrops is shown on figures 13 and 14.

Submarine outcrops are most numerous off the precipitous sea cliffs and the coastal plain farther to the west. Exposed bedrock was found at 75 percent of all stations occupied off these areas; stations at which outcrops were not indicated were mostly near shore where bedrock is overlain by a thin veneer of sand and silt.

Exposed bedrock was located at 9 stations near the head of Ogotoruk Seavalley and at 5 stations on the slightly shallower shelf to the east (fig. 12). The series of submarine outcrops trending seaward from shore about one mile west of Kisimulowk Creek is associated with a topographic high which apparently represents a residual strike ridge. Probable reasons for the general paucity of exposed submarine outcrops east of the seavalley are discussed under unconsolidated bottom sediments. Although clear evidence of outcrops along the floor of Ogotoruk Seavalley was not obtained in many areas, the numerous isolated knolls and parallel ridges along the inner part of the seavalley suggest that bedrock is present beneath a thin veneer of unconsolidated gravelly sediments. An underwater photograph of the coarse angular rocks lying along

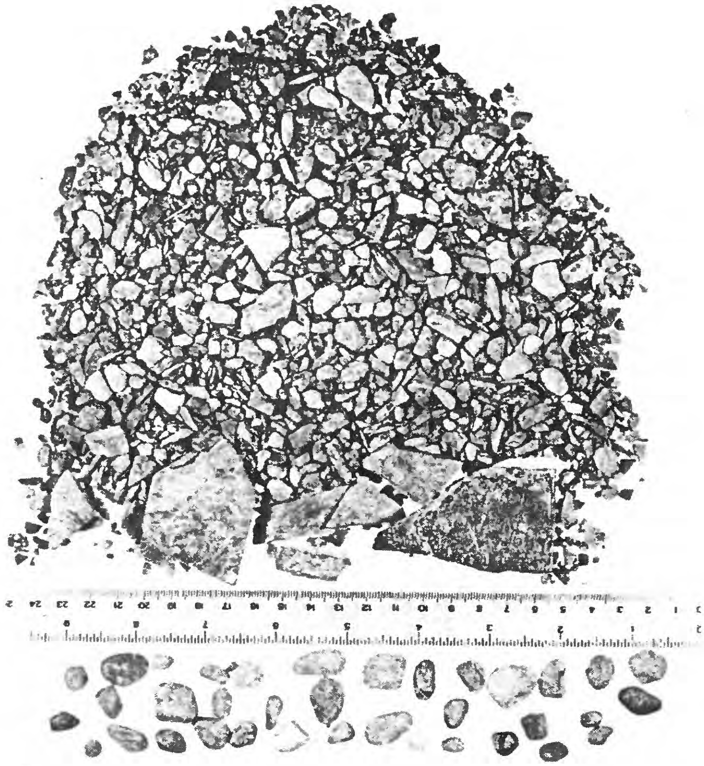

Figure 13. Angular shale fragments of Mississippian or Devonian age derived from submarine outcrops. Well-rounded clasts at top are mostly graywacke, limestone, and chert, and probably are ice rafted. Subrounded rocks at top are clasts of coarse-grained micaceous sandstone. These have apparently been derived from nearby submarine outcrops but have been somewhat rounded by wave-abrasion during Recent time. Sample was taken four miles off Eesook Creek at a depth of 50 feet. Scale reads in inches and centimeters.

Figure 14. Angular rock fragments of limestone and chert derived from submarine outcrops of the Lisburne group of Mississippian age. Sample was collected half a mile off Cape Crowbill at a depth of 34 feet. Scale reads in inches and centimeters.

the floor of the seavalley is given on figure 15.

The lithology of the submerged outcrops correlates readily with stratigraphic units exposed along the coastline. From the distribution of submerged outcrops of these stratigraphic units a general geologic map of the nearshore shelf has been prepared (fig. 12). Locations of submarine contacts as shown on figure 12 are only approximate and are based on abrupt changes in the lithology of the coarse angular gravel collected from the nearshore shelf. Stratigraphic and structural relationships of the submerged lithologic units are almost entirely extrapolated from knowledge of the coastal stratigraphy and geologic structure. The following lithologic units exposed in sea cliffs were recognized on the nearshore shelf.

Clastic rocks of Mississippian and Devonian age, undifferentiated.--Submarine exposures of fine-grained quartzite, silty shale, and calcareous sandstone and shale are widespread over the nearshore shelf off Eesook Creek (fig. 13). These outcrops can be correlated with beds of Mississippian age exposed at the base of low coastal bluffs a short distance east of Eesook Creek, and with unexposed clastic rocks of Devonian age(?) which are thought to underlie the Mississippian beds at shallow depths (Collier, 1906, pl. 1). These clastic rocks lie in apparent conformity beneath limestone of the Lisburne group which forms the prominent sea cliffs to the east. The submarine contact of the Lisburne group and the older clastic rocks can be traced for approximately 4 miles seaward from the northwest terminus of the coastal limestone cliffs (fig. 12).

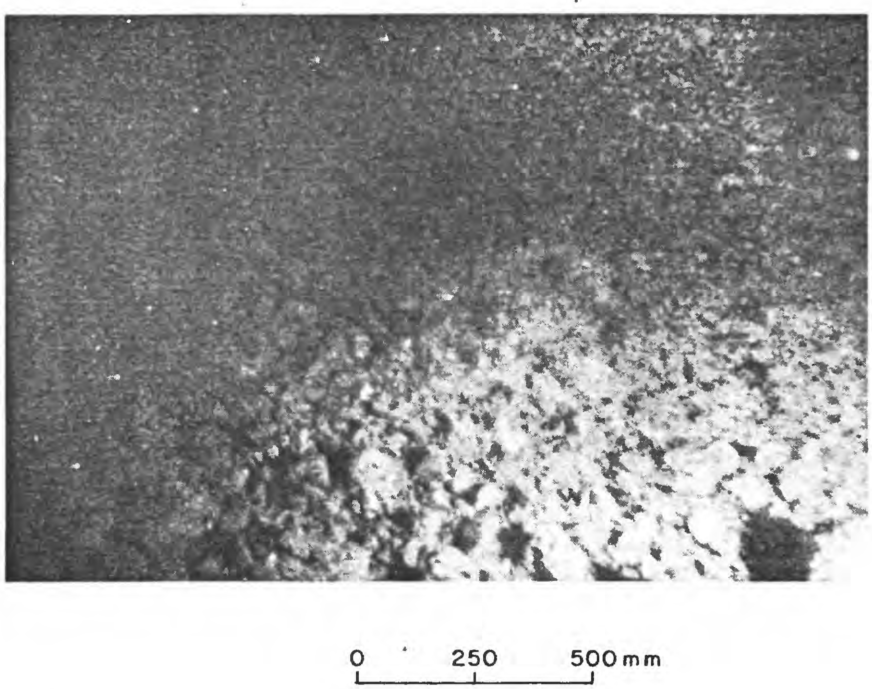

Figure 15. Underwater photograph of gravelly floor of Ogotoruk Seavalley at diving station 3 shown on figure 2. The dark areas are shadows cast by larger cobbles and boulders. See table 1 for description given by divers. Scale is approximate (photograph courtesy of U.S. Navy Electronics Laboratory, San Diego, California).

Lisburne group (Mississippian).--Submarine exposures of limestone, cherty limestone, and black chert of the Lisburne group of Mississippian age (Bowsher and Dutro, 1957) are very numerous on the sea floor west of Ogotoruk Seavalley (fig. 14). They are restricted, however, to the shelf area lying seaward of the precipitous cliffs of the Lisburne group. Near Emmikroak Creek the Lisburne group is thrust to the southeast over younger Mesozoic and Permian rocks and this thrust contact apparently continues for nearly 4 miles across the nearshore shelf. At Cape Crowbill a high-angle reverse fault is at the contact of overturned beds of the Lisburne group and younger Mesozoic and Permian rocks; this fault probably continues for several miles along the western flank of Ogotoruk Seavalley.

Shublik(?) formation (Triassic) and Siksikpuk(?) formation (Permian), undifferentiated.--Because the Siksikpuk formation of Permian age directly underlies the Shublik formation of Triassic age (Patton, 1957) and both formations contain thick-bedded green argillite, it was not possible to separate submarine outcrops of these formations and they are mapped as an undifferentiated unit (fig. 12). Outcrops of green argillite beds extend seaward as linear belts from outcrops of the Shublik and Siksikpuk formations near Cape Crowbill and from exposures on both flanks of the synclinal infold of Mesozoic and Permian rocks near the mouth of Emmikroak Creek. On the nearshore shelf off Emmikroak Creek and off Cape Crowbill the green argillite beds probably lie in fault contact with limestone and chert beds of the Lisburne group.

Clastic rocks of Jurassic and Cretaceous age, undifferentated.--Siltstone, shale, and fine-grained graywacke probably of Jurassic or Early Cretaceous age crop out seaward of the coastal area in the vicinity of Ogotoruk Creek and off the infolded Mesozoic rocks near Emmikroak Creek. Off the latter area submarine outcrops of the Jurassic and Cretaceous rocks are flanked by outcrops of the Siksikpuk(?) and Shublik(?) formations and it is apparent that the synclinal infold continues seaward for several miles. A high-angle fault, however, cuts obliquely across the eastern flank of the syncline, and limestone of the Lisburne group has apparently been brought into fault contact with the Jurassic and Cretaceous rocks. The thick black siltstone and shale near Emmikroak Creek conformably(?) overlies the Shublik formation of Triassic age, and may be Jurassic in age, an interpretation favored here, although the Cretaceous age is not ruled out.

Similar black siltstone overlies the Triassic rocks on the west side of Ogotoruk Valley. Eastward, the rocks contain progressively greater amounts of interbedded graywacke, and probably are Cretaceous in age. The rocks exposed on shore continue seaward, as indicated by submarine outcrops and bottom samples. On the map, all the rocks east of the Triassic rocks on the west side of Ogotoruk Valley are shown as undifferentiated rocks of Jurassic and Cretaceous age (KJsg).

Unconsolidated Quaternary sediments

Unconsolidated sediments on the shelf comprise marine deposits of late Pleistocene to Recent age, and beach sediments of Recent age. In this paper, Recent time is considered to begin with the last major sea level rise corresponding to the withdrawal of the Mankato ice fields approximately 10,000 years ago (Hopkins, 1959).

Most of the Quaternary sediments overlying the nearshore shelf are gravels. Near shore, a linear belt of sand is commonly present. Off the general vicinity of Kisimulowk Creek the shelf is overlain by sand and silty sand. Sandy gravel and gravelly sand are found in transition zones between deposits of sand and gravel and along the floor of Ogotoruk Seavalley.

Beach deposits are principally composed of small pebbles and coarse rock sand. Gravelly beaches are usually between 50 and 150 feet wide although they are absent below rocky headlands.

In order to determine the sources and deposition of the unconsolidated sediments, a number of analyses were performed on each sediment sample. In addition these data were used to differentiate and areally map sediment types.

Sediment analyses

Beach deposits and marine sediments were screened to separate gravel (greater than 2.00 mm), sand (2.00-0.062 mm), and silt-clay fractions. Textural parameters of gravel were obtained by the counting technique described by Emery (1955b) or by additional screening. Grain-size distribution of sand was determined with the Emery Settling Tube (Emery, 1938); mechanical analyses of the silt-clay fraction were made by the pipette method (Krumbein and Pettijohn, 1938, p. 166).

The sand fraction of all sediment samples was examined visually for calcareous organic matter, authigenic minerals, roundness of grains, and ratio of rock to mineral fragments. Roundness values of sand- and gravel-size clasts were determined with the aid of visual comparison charts (Krumbein, 1941).

Separation of light and heavy (greater than 2.96 sp gr) minerals were made on nearly all sediments containing more than 10 percent sand. Total calcium and magnesium carbonate and total organic matter were determined for many of the sand and finer grained sediments. Carbonate content was analyzed by leaching a known weight of sediment with dilute hydrochloric acid. This method of analysis inherently gives values which are about 2 percent too high, but it is rapid and useful for determining significant changes within a given area. Organic matter was calculated as the ignition loss at 450°C (Thompson, 1953, p. 64).

Marine sediments

Unconsolidated marine sediments are composed of three principal size grades; gravel, sand, and silt-clay. The relative proportions of these size grades were plotted on a triangular field for each sediment sample and 10 sediment types were differentiated (fig. 16). These are: (1) gravel, (2) sandy gravel, (3) silty-sandy gravel, (4) sand, (5) gravelly sand, (6) silty sand, (7) silt, (8) gravelly silt, (9) sandy silt, and (10) sandy-gravelly silt. Clay-size particles (less than 0.004 mm) have been combined with silt as a single size grade.

Figure 16 shows that 105 sediment samples contained less than one percent sand and silt. In situ, however, these bottom sediments probably contain slightly more sand and silt than indicated on this figure.

The loss of the sand and silt was due principally to winnowing of the sample when the grab was hauled up from the bottom. Such winnowing was indicated during the sampling operation by a trail of muddy water behind the grab. However, this sampling error is probably not large as the sediments as reported by divers (table 1) were essentially identical to those plotted on figure 16 and shown on table 2. Probably the greatest sampling error arises not from the loss of sand and silt but from the inability of the grab to adequately sample the entire size distribution of the gravel at any one station. Only the smaller rock clasts (less than about 200 mm in maximum length) were recovered, as larger cobbles and boulders could not be gathered easily by the grab. Visual observations in shallow water, underwater photographs (fig. 15) and reports of divers (table 1) show that large cobbles and boulders are common over certain areas of the shelf.

Only four of the sediment types--gravel, sandy gravel, sand, and silty sand--are common and overlie more than a few square miles of the nearshore shelf. The four silt sediment types are rare; two of these are represented by single sediment samples (fig. 16). The distribution of the sediment types is shown on figure 17. Typical cumulative curves of the finer-grained sediment types are given on figure 18, and table 2 lists some of the physical and chemical properties of the sediment types.

Table 1.--Sea floor description by divers

Diving station no. See fig. 2 for station positions	Depth (in ft.)	Description
1	63	Gravel of cobbles and pebbles in a matrix of silt and clay
2	58	Silt covering gravel of pebbles and cobbles as much as 150 mm in length
3	49	Gravel of pebbles and cobbles with a thin veneer of silt (see pl. 6 for bottom photograph)
4	37	Gravel of cobbles and boulders, sponges, and other animal life common on rocks. Silt about 2 inches thick overlies the gravel in small patches
5	39	Outcrops of limestone and chert beds of the Lisburne group. Residual cobbles and boulders surround the outcrops. Limestone beds strike N. 27° W. and dip about 35° to the west
6	46	Bottom of angular pebbles and cobbles with some silt between and atop rocks
7	20	Sand bottom with ripple marks parallel to shore; locally pebble gravels
8	0-25	75 feet from shore outcrops of Tigluk-puk formation, striking N. 50° E. and dipping 30° E. Ripple-marked sand out to 300 feet from shore locally is gravelly. Sand is about 9 inches thick and overlies gravel

* Information given in this table was made available by Dr. George Shumway, and Messrs. John Beagle, George Dowling and Park Richardson, civilian scientists stationed aboard the U.S.S. Burton Island.

Table 2.--Average character of unconsolidated marine sediments

Fine-grained sediments

Sediment type	Median diameter in mm Md.	Sorting coefficient So.	Skewness coefficient Sk.	Percent gravel (g) sand (s) silt (sl) clay (c)	Percent carbonates in sand-silt fraction	Dominant bioclast in order of abundance	Percent organic matter in sand-silt fraction	Percent heavy minerals in sand-silt fraction
Sand	0.125	1.15	1.06	2.1 g; 1.5 sl; 0.5 c	6.7	Mollusk, Foraminifera, Ostracods	1.1	5.9
Silty sand	0.088	1.40	0.89	14.9 sl; 4.9 c	3.8	Mollusk, Foraminifera, Ostracods	1.7	5.9
Gravelly sand	0.427	3.01	8.63	20.7 g; 1.4 sl; 0.4 c	---	Mollusk, Foraminifera, Barnacle	---	5.7
Silt	0.007	2.89	0.81	0.1 g; 7.1 s; 36.0 c	---	Foraminifera, Mollusk	3.4	---
Sandy silt	0.012	4.60	1.85	4.9 g; 25.4 s; 26.2 c	---	Foraminifera, Mollusk	3.4	---
Gravelly silt	0.017	13.9	28.7	23.4 g; 3.7 s; 18.7 c	---	Foraminifera, Mollusk, Ostracod	---	---
Sandy-gravelly silt	0.063	6.1	18.6	31.2 g; 20.0 s; 9.2 c	---	Foraminifera, Mollusk, Ostracod	---	---

Table 2.--Average character of unconsolidated marine sediments--continued

Coarse-grained sediments

Sediment type	Intermediate diameter of typical rock clast of gravel (mm)	Roudness value of gravel (1.0 maximum)	Common rock fragments composing gravel	Percent sand (s) silt (sl) clay (c)	Dominant bioclasts in order of abundance	Percent heavy minerals in sand-silt fraction
Gravel	20	0.40	Graywacke, siltstone, chert and limestone	1.4 s; sl + c less than 0.1	Foraminifera, Mollusk, Ostracods, barnacles	1.9
Sandy gravel	10	0.40	Principally graywacke, lesser amounts of limestone and chert	17.2 s; 2.9 sl; 0.9 c	Foraminifera, Mollusk, Ostracods, barnacles	2.0
Silty-sandy gravel	10	0.45	Principally graywacke, lesser amounts of limestone and chert	24.9 s; 8.1 sl; 2.6 c	Foraminifera, Ostracods, Mollusk	3.0

The sediment types are in general not discussed separately beyond this point; only the major sediment groups--gravel, sand, and silt--are discussed further.

Gravel.-- Bottom sediments containing more than 50 percent gravel overlie about 85 percent of the nearshore shelf or about 65 square miles of sea floor. West of Ogotoruk Seavalley and seaward of the precipitous sea cliffs gravels contain little sand and silt. However, gravel having more than 10 percent sand-silt lies along the floor of Ogotoruk Seavalley and is associated with accumulations of sand and silty sand farther to the east. Other areas of sandy gravel overlie the shelf seaward of Eesook Creek.

Owing to the inability of the sampling grab to adequately sample gravel, detailed mechanical analyses of the coarse fraction were not made of these sediments. Instead measurements were taken of the intermediate dimension of the estimated typical or average rock clast. These values ranged from 5 to 50 mm and averaged about 20 mm (table 2). Thus the recovered marine gravels are approximately 2 to 3 times coarser than the modern beach gravels which average about 7 mm in median diameter.

Gravels west of the seavalley have roundness values of 0.35 (1.0 is maximum), or are subangular to subrounded (Pettijohn, 1949, p. 51). Many of the rocks overlying this part of the shelf are quite angular and show virtually no effects of abrasion or rounding (figs. 13 and 14). Along the floor of the seavalley and to the east gravels are relatively better rounded and have values averaging 0.45. In a number of small areas over this part of the shelf are patches of unusually well rounded (0.6) gravel; these patches are shown on figure

19 as areas of relict beach sediments. Roundness of the bottom clasts increases rapidly in shallow water near shore where wave action is effective.

Sand and silt typically accompany the marine gravel but usually in amounts much less than 10 percent (table 2). The sand-silt fraction typically has two modes, a coarse mode which is composed of rock fragments and a fine mode consisting primarily of mineral grains and subordinate amounts of fine rock fragments (fig. 18, curve 4). The rock fragment mode is lithologically similar to the associated gravel size clasts and therefore is related to them. Mineralogically and texturally the fine mode is similar to deposits of sand and silty sand elsewhere on the shelf. The textural relationship is brought out on figure 19, which includes isopleths of median diameter. A progressive seaward decrease is shown by these isopleths which clearly relates the deposition of the fine mode to that of the sand and silty sand. The coarse rock fragment mode makes up from 80-45 percent of the total sand-silt content of most marine gravels. For deposits containing much more than 10 percent sand-silt (sandy and silty-sand gravel) the break to the fine mode averages near 0.200 mm, for gravels having much less than 10 percent sand-silt the break is coarser and averages at 0.280 mm.

The lithologic composition of the gravel is markedly different over different areas of the nearshore shelf. This is brought out on figure 19 and is particularly evident west of Ogotoruk Seavalley where the bottom gravel undergoes rapid lateral changes in composition and consists predominantly of either limestone and chert or fragments of clastic rocks. Along the axis of the seavalley and farther to the east gravel consists mainly of clastic rocks, principally fine-grained graywacke and siltstone, with lesser amounts of chert and rarely limestone. The lithologic composition of the bottom gravels differs greatly from the modern beach gravels directly shoreward except for the several areas of well-rounded gravel shown on figure 19.

Sand and silt.--Sand containing less than 10 percent silt is restricted to a discontinuous belt running parallel to shore at depths of 15-30 feet (fig. 17). The sand tract is approximately half a mile wide off the mouths of Eesook and Kisimulowk creeks. It is narrowest in slight reentrants of the shoreline west of Cape Crowbill, absent off cliffed headlands, and very narrow and discontinuous off the coastal bluffs east of Ogotoruk Creek. At a distance of approximately 200 yards from shore near the mouth of Ogotoruk Creek divers found the nearshore sand belt to be about 9 inches thick and to overlie gravel. Pebbles are common in the sand and near shore the deposits become gravelly; gravelly sands are also on the seaward sides of the sand belt. Silty sand forms a broad crescent-shaped tract over the sea floor off Kisimulowk Creek and nearly encompasses an area of bottom gravel (fig. 17).

Accumulations of silt and sandy silt are restricted to small patches with indefinite boundaries in shallow water off Cape Crowbill and seaward of Eesook Creek (fig. 18, curves 10 and 11). Small areas of gravelly silt and sandy-gravelly silt occur along the floor of Ogotoruk Seavalley.

Sand ranges from 0.117 to 0.135 mm in median diameter and averages 0.125 mm. The sand is nearly perfectly sorted and has Trask sorting coefficients ranging from 1.01 to 1.19 and averaging 1.15 (fig. 18, and table 2). Silty sand averages 0.088 mm in median grain size and is somewhat less well sorted with coefficients averaging 1.40. The silt in the sand causes the sediment to be slightly skewed toward the finer grains (table 2). The median diameter of the sand and silty sand decreases with distance from shore; this trend is shown by the isopleths on figure 19. Isopleths on this figure also indicate that sand and silt tend to settle along the floor of Ogotoruk Seavalley, and the bottom sediments become more silty with distance from shore along the valley axis (table 1 and fig. 17).

Silt deposits average 0.007 mm in median diameter and are relatively poorly sorted with coefficients near 3.00 (table 2); they are also slightly skewed to the finer grains (Sk less than 1.0). Sandy silt, gravelly silt, and sandy-gravelly silt are also poorly sorted but they are all bimodal (fig. 18, curves 10, 9, and 8) and show positive skewness, or an asymmetrical spread of the size distribution of the coarse fraction of the sediment. Clay-size particles form a significant part of the silt sediment types and range from about 10 to 40 percent (table 2); however, in relation to silt, clay decreases with distance from shore in most sediment types.

Rock and mineral grains constitute approximately 95 percent of deposits of sand and silty sand; rock fragments alone make up from 20 to 35 percent of these sediment types. Heavy minerals rarely form more than 10 percent of the sediments and average about 6 percent (table 2). The most abundant mineral grains in the sands are quartz, chert, feldspars, micas, and chlorites; the latter two mineral groups are more abundant with distance from shore.

Approximately 10 percent of the tests of species of Elphidium and Buccella contain light-green to dark-brown friable fillings or partial fillings in one or more chambers. The crumbly filling matter is thought to be glauconite of authigenic origin. Glauconite is used here as a field term in the sense suggested by Burst (1958, p. 311). Carsola (1954b, p. 1570) described coprolite pellets from nearshore samples taken in the Chukchi Sea which may be partially glauconitized; to the authors' knowledge this is the only previous reference to the occurrence of glauconite in sediments of the Chukchi Sea. In the Ogotoruk Creek area fecal pellets were rarely seen and these showed no physical evidence of glauconitization.

Carbonate mineral grains and bioclasts constitute about 4 percent of deposits of sand and silty sand east of Cape Crowbill. West of this point, and offshore from the limestone cliffs, sand accumulations have carbonate contents near 10 percent. Comparisons of estimated weight percentages of organic carbonate to the chemically determined total carbonate, indicate that east of Cape Crowbill recognizable bioclasts account for about 50 percent of the total calcareous matter. However, west of Cape Crowbill the carbonate content is approximately 70 percent detrital limestone and dolomite grains and unrecognizable comminuted bioclasts.

Tests and fragments of mollusks (chiefly pelecypods) and foraminiferal tests make up the greater part of the organic calcareous matter of sand and silty sand; foraminifera are relatively more abundant in sand associated with gravel deposits (table 2). Eggerella advena (an arenaceous form), Elphidium orbiculare, E. bartletti, and Buccella frigida, are the most abundant species of foraminifera (Mrs. Patsy Smith, USGS, written communication). The abundance of species of foraminifera with increasing depth off Kisimulowk are listed on table 3. Other commonly occurring bioclasts are bryozoan zoaria, ostracod valves, echinoid spines and plates, and fragments of barnacle plates and calcareous algae (table 2).

Sand contains the least amount of combustible organic matter and averages only 1.1 percent. Silty sand contains 1.7 percent organic detritus but the highest concentration is in silt deposits which average 3.4 percent organic matter. Although a number of factors are involved, concentration of organic substances in the finer grained sediments is usually attributed to the inherent fineness and slow settling rates of organic detritus (Trask, 1939, p. 434). The organic content of the finer sediment types is in general comparable to Trask's world-wide average of 2.5 percent for nearshore sediments, and is virtually identical to the amount of organic matter found in sediments from other areas of the Chukchi Sea and in the Beaufort Sea (Carsola, 1954b, p. 1573).

Table 3.--Relative abundance of species of Foraminifera at increasing depth off mouth of Kisimulowk Creek

Species (Showing number of specimens in approximately 50 cc of sample)	Depth in feet				
	20	28	38	43	50
Eggerella advena (Cushman)	6	34	156	300	160
Bigenerina arctica (Brady)			2		
Textularia torquata Parker				2	
Reophax arctica Brady					1
Ammobaculites cassis (Parker)				3	1
Trochammina nana (Brady)					8
Trochammina sp. (broken)		2	1	1	
Miliammina sp.					2
Quinqueloculina sp.					2
Lagena semilineata Wright			1		
Lagena mollis Cushman					1
Pseudopolymorphina curta Cushman & Ozawa					2
Glandulina laevigata d'Orbigny			1	3	
Elphidium clavatum Cushman	1			5	14
Elphidium bartletti Cushman				10	4
Elphidium frigidum Cushman	3				6
Elphidium orbiculare (Brady)	2	25	3		45
Elphidium oregonense Cushman & Grant?					13
Buccella frigida (Cushman)	1	7	47	97	59
Buccella inusitata Anderson		1	2	9	
Asterigerina sp.			5	6	
Discorbis baccata (Heron- Allen & Earland)					6
Patellina corrugata Williamson					2
Cassidulina sp.					1
Buliminella elegantissima (d'Orbigny)			2	1	
Globigerina bulloides d'Orbigny		1			

Foraminifera identified by Mrs. Patsy Smith of the U. S. Geological Survey.

Deposition of Marine Sediments

Discussion of the shelf stratigraphy emphasized that most of the rocks overlying the nearshore shelf are derived from submarine outcrops. Therefore, the lithologic composition of the bottom gravel undergoes abrupt lateral changes which match changes in the lithology of the outcropping rocks. This relationship is brought out sharply by comparing figure 19, which includes a plot of the ratio of chert and limestone to clastic rocks in the marine gravels, with figure 10, a general geologic map of the nearshore shelf.

The general subrounded nature of many of the rock clasts, however, indicates the effects of transportation or abrasion. Most probably this slight rounding was produced by moderate wave erosion of the nearshore shelf during Recent time. It is also possible that grounding pack ice abrades and rounds the bottom gravels in certain areas.

Immediately east of Ogotoruk Seavalley the marine gravels show the most pronounced rounding and few very angular pebbles and cobbles were recovered (fig. 20); primarily for this reason it is thought that submarine outcrops are not exposed over this area of the shelf (fig. 12). However, it is clear from the numerous submarine outcrops on the adjacent shelf area that bedrock must lie at shallow depths beneath (probably less than 5 feet) these moderately rounded residual gravels. The clasts forming these gravels may have been formed during Wisconsin time by frost action on the up-turned edges of truncated Mesozoic beds. The rounded and polished chert clasts (fig. 20) in these deposits may have been carried in by the returning post-Wisconsin sea, or possibly they have been emplaced by ice-rafting.

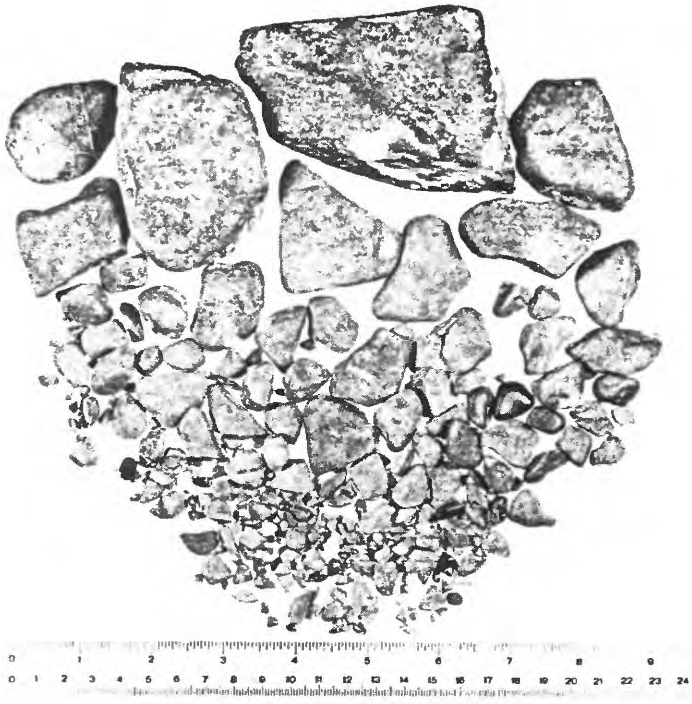

Figure 20. Typical example of moderately rounded bottom gravel overlying the shelf terrace immediately east of Ogotoruk Seavalley. Graywacke is the predominant rock clast; polished chert (approximately 20 percent) is also present. Scale reads in inches and centimeters.

The several areas of rounded and lithologically diversified gravels shown on figure 19 may represent relict beach deposits as they are more similar to the modern beach sediments directly shoreward than they are to the relatively angular and monolithologic adjacent gravels (fig. 21). Relict beach sediments may be of Recent age but they could also be as old as Sangamon, as beach sediments of this age are known in the coastal area.

Ice rafting has also deposited coarse rock clasts over the nearshore shelf. Rafted sediments have been described from other areas of the Chukchi Sea by Buffington, Carsola, and Dietz (1950) and Carsola (1954b), and from other polar and subpolar regions by Menard (1953), Hough (1956) and Lisitsin (1958); Kindle (1924) discussed in detail some of the mechanisms of ice-rafting.

In the Ogotoruk Creek area evidence for rafted rock is (1) association of rounded beach pebbles of foreign lithology with angular rocks derived from submarine outcrops (fig. 13); (2) rounded igneous and metamorphic rocks in bottom sediments; and (3) rounded pebbles with algae growing on one side associated with deposits of silt.

Rounded pebbles of foreign lithology form 5-20 percent by number of the residual angular gravels flanking submarine outcrops. Very angular rocks (roundness values less than 0.2) not of foreign lithology, which would not be easily recognized as rafted debris, may also be contributed to the nearshore shelf by pack ice which has been driven

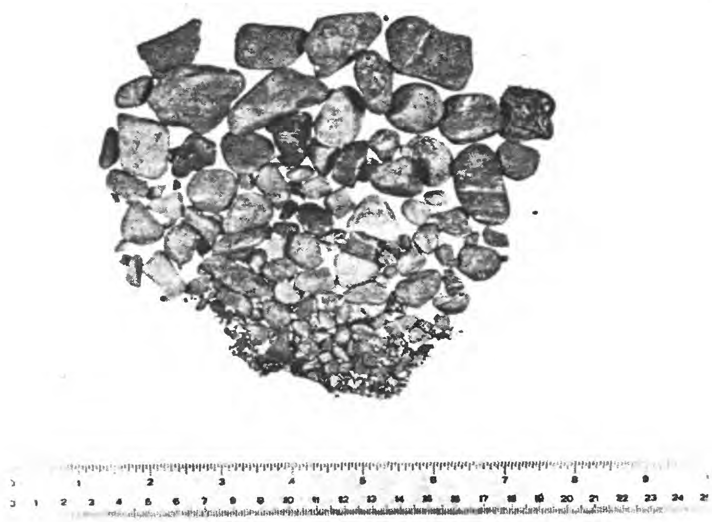

Figure 21. Rounded bottom gravel probably representing relict beach sediments; compare this sample with those shown on figures 14 and 24. Sample was collected near head of Ogotoruk Seavalley where shown on figure 19. Scale reads in inches and centimeters.

against the shear limestone cliffs and the colluvial bluffs east of Ogotoruk Creek. Similarly, angular pebbles with roundness values of 0.2-0.3 could be conveyed to offshore regions by local stream ice. Lisitsin (1958) reported, however, that a study of tens of thousands of rafted rocks in polar oceans indicates that they are characteristically well rounded and hence have been derived primarily from beach sediments. However, the ice-rafted deposits are in general not as maturely rounded as most beach sediments owing to the addition of angular talus and rock slide debris to the ice.

Ice-rafted rocks are not thought to be numerically significant on the nearshore shelf off the Ogotoruk Creek area in comparison to residual gravels derived from nearby outcrops. Facts indicating this interpretation are: (1) most of the rocks are neither well rounded nor very angular and therefore have not been derived from the present beaches nor from the nearby coastal promontories and streams; and (2) the lithologic composition of the bottom gravel has not been made uniform by the introduction of foreign debris, but changes rapidly and is directly related to submarine outcrops. Hunkins (1959) has recently emphasized the uniform lithology of ice-rafted gravel in the deep Arctic Ocean. Possibly a reasonable estimate would be that about 10 percent of the rock clasts overlying the nearshore shelf off the Ogotoruk Creek area have been dropped from transient ice floes.

Although the isopleths on figure 19 indicate that detrital sand sand and silt tend to accumulate in Ogotoruk Seavalley, the sandy and silty-sandy gravels overlying the valley floor are primarily due to an accumulation of residual rock fragments of sand size. Concentration of the small rock fragments may reflect the subaqueous breakdown of the fine-grained Mesozoic clastic rocks which underlie the seavalley, and possibly also accumulation of fine rock debris that formed during the Pleistocene subaerial erosion of the seavalley. Similar deposits east of the seavalley are thought to be relict beach sediments. The rock fragments forming the coarse mode of the sand-silt fraction of these drowned beach sediments were probably concentrated by shoreline processes, as is true of the modern beach gravels which contain about 10 percent coarse sand-size rock fragments. Sandy gravel near the head of the seavalley and farther to the west (fig. 17) is associated with submarine outcrops. The sand-size rock fragments forming the principal part of the sand fraction is very angular and represents a residual accumulation of fine outcrop debris.

The deposits of sand and silty sand shown on figure 17 are composed of detrital clasts derived from the nearby coastal area during Recent time. This conclusion is based on the facts that these sediments (1) are principally associated with segments of the coast drained by streams eroding fine-grained clastic rocks, (2) are mineralogically similar to these clastic rocks but show an increase in detrital carbonate grains seaward of the sheer limestone cliffs, (3) are well sorted and indicate deposition under current or wave action, and (4) decrease in grain size with distance from shore.

The fine mineral grain mode of the bimodal sand-silt content of gravel deposits is also of Recent deposition as this mode is texturally and mineralogically similar to the sand and silty sand.

The broad crescent-shaped tract of sand and silty sand off Kisimulowk Creek has apparently accumulated atop residual gravels. The sands are probably thin (not more than about 5 feet thick) as bedrock crops out near the center of the tract and the fine-grained sediments grade laterally into gravel. As mentioned earlier divers found less than one foot of sand overlying gravel near the mouth of Ogotoruk Creek.

Accumulations of sand are absent at depths greater than about 50 feet except off Kisimulowk Creek. This may indicate that sand is prevented from settling or remaining on the bottom farther from shore by swifter currents. However, this interpretation does not adequately explain the seaward decrease in grain size shown by the isopleths on figure 19. A more acceptable explanation is that competent currents are lacking which can transport sand-size clasts far from shore. Fine-grained detrital clasts introduced into offshore waters are carried parallel to shore by the predominant coastal current. The slight depression of Ogotoruk Seavalley apparently traps some of the sediment transported by this current. In most sediment types clay decreases relative to silt with distance from shore, and it is apparent that particles finer than about 0.004 mm tend to bypass the outer part of the nearshelf. Most likely much of the silt and clay contributed by local streams does not settle over the nearshore shelf but is carried along by the coastal current and eventually accumulates on deeper parts of the shelf or on the steep slopes leading into the Arctic basin.

Deposits of silt and sandy silt are associated with submarine outcrops and possibly represent localized trapping of fine-grained sediments by outcrop ledges. Melting of grounded sediment-laden sea ice could conceivably also form these deposits.

Observations during July and August 1958 indicate that fine detrital clasts are contributed to the nearshore shelf primarily by streams and winnowing of beach sediments. During and for several days after a 4-inch rain storm lasting from August 8 to 12, surface turbidity currents spread seaward from the mouths of the larger streams draining the coastal area. Discharge from Ogotoruk Creek, which at its maximum was about 600 cfs and carried a suspended load of 2,500 ppm (suspension data computed by George Porterfield, U. S. Geological Survey, 1958, written communication), flowed seaward for approximately half a mile as a distinct band of turbid water, before the coastal current turned the turbidity flow parallel to the coast. Sand and silt which becomes incorporated in the beach sediments is winnowed by storm waves and carried onto the nearshore shelf. Storm waves from 3 to 5 feet high during July and August typically produced a nearshore zone of turbid water several hundred yards in width.

The nearshore shelf of the Ogotoruk Creek area is in general a region of limited fine-grained detrital sedimentation. This fact can be determined from the paucity of fine sediments of Recent age, except very near shore and off areas of the coast drained by streams eroding fine-grained clastic rocks. Glauconite fillings in foraminiferal tests also signify poor or insignificant detrital sedimentation (Shepard, 1948, p. 162).

A low volume of detrital clasts shed from the coastal area is thought to be responsible for limiting fine-grained deposition on the nearshore shelf. This low volume is attributed to (1) the low annual rainfall of 8 to 12 inches and the short 4-5-month season of runoff and wave action; (2) drainage of much of the coast by streams eroding limestone and chert beds; (3) the low base suspension load of streams eroding regions of clastic rocks and the fact that particles are primarily fine silt and clay--Ogotoruk Creek has a suspension load of only 6-13 ppm at base flow (George Porterfield, written communication); and (4) a general lack of clastic rocks in the coastal area which supply a large volume of particles of sand size. This final point is important because sand tends to remain on the nearshore shelf and does not bypass it as does fine silt and clay. The small volume of sand contributed by the coastal rocks is emphasized by the facts that (1) only about 20 percent of the suspended load carried by Ogotoruk Creek during its highest period of discharge in August 1958 was coarser than 0.125 mm, which is the average median diameter of the nearshore sand belt; and (2) beach deposits are primarily composed of coarse rock fragments rather than of detrital mineral sands as are many of the world's beaches.

Beach Sediments

Distribution and form of deposits.--From Kisimulowk Creek westward to Cape Crowbill the shore is formed by gravel beaches 60-260 feet wide. Beaches are absent or are only 30-40 feet wide in front of the precipitous limestone cliffs west of Cape Crowbill; however, at the northwest terminus of the sea cliffs the beach widens to 200-300 feet and is continuous for approximately 40 miles to the mouth of the Kukpuk River (fig. 1).

In the vicinity of Ogotoruk Creek, beach gravels are about 25 feet thick and overlie an ancient wave-planed bedrock surface probably of Sangamon age. The estimated maximum thickness of beach sediments was determined by projecting the slope of the wave-planed surface beneath the profile of the beach deposits to a point a few hundred feet from shore where bedrock crops out on the sea floor. At the mouth of Kisimulowk Creek exposed beach deposits are about 10 feet thick. Gravel beaches fronting the sheer cliffs west of Cape Crowbill are thinner than elsewhere and exposures are less than 10 feet thick in most places.

Beach sediments are stratified in lens-shaped layers of different grain size ranging from about 3 inches to 3 feet in thickness (fig. 22). The thicker lenses probably represent the deposition of berms after erosion of the beach by storm waves.

Profiles constructed across the beach are not smooth but delineate a number of wave-built berms and bars or beach ridges at the mouths of large streams (fig. 23). The backshore, or the part of the beach which slopes most gently, has an overall seaward gradient of about 3°30', however, reverse or landward slopes are on the back sides of berms and beach ridges (fig. 23). Declivities on the steeper foreshore increase

Figure 22. Stream cut through stratified sandy beach gravels approximately midway between Ogotoruk Creek and Kisimulowk Creek. Staff is 5 feet long; driftwood atop backshore of beach is at an elevation of about 10 feet. Angular stream pebbles are derived from colluvium and outcrops of Mesozoic formations.

to 10-14° and merge with the more gently sloping subaqueous shoreface. Gravel beaches with grains having median diameters between 2 and 64 mm typically have foreshore depositional slopes near 12° (Shepard, 1948, p. 85). This slope is in good agreement with that of the foreshore sediments in the Ogotoruk Creek area which average 10-15 mm in median diameter.

During attack by storm waves of moderate height (3-5 feet) the foreshore is appreciably reduced in slope and small berms within 20 to 30 feet of the shoreline are removed. Profile G-G' on figure 23 shows the shape of the foreshore during a storm on July 26, 1958 and of a small berm constructed after the storm subsided; the steep outer face of this small berm is erosional and was being cut by small waves at the time of measurement. Much of the sediment removed from the frontal berms by storm waves is transported parallel to shore by longshore currents and accumulates as spits at stream mouths and as areas of new beach below cliffed headlands. During moderate storms in August 1958, spits at the mouth of Ogotoruk Creek accreted gravel and sand at rates of as much as 5 cubic yards per hour. Sediment not used in constructing spits or areas of new beach are thrown back upon the shore as berms during the waning phases of the storm.

Texture and lithologic composition.--Texturally the beach sediments are sandy pebble gravels (fig. 24); they are well sorted and well rounded. Coarse rock sand constitutes about 10 percent of the beach deposits. Included on figure 18 are three cumulative curves of beach gravels.

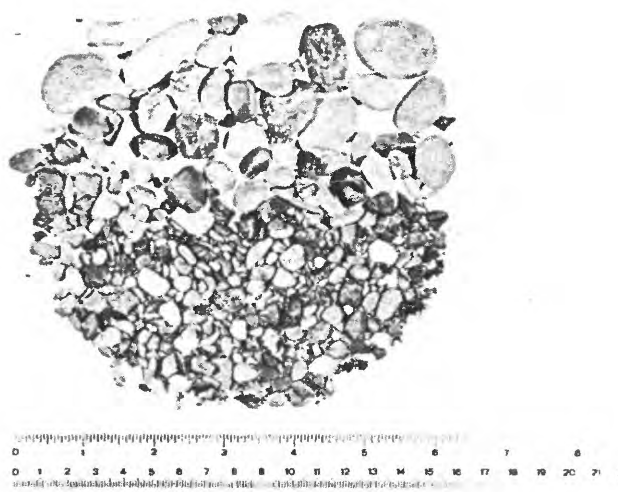

Figure 24. Portion of 10-foot vertical channel sample of beach gravel exposed near mouth of Ogotoruk Creek. Cumulative curve of this sample is included on figure 18. Scale reads in inches and centimeters.

The grain size distribution of the gravels is variable with depth. Surface gravels are in general much coarser than deeper sediments. On table 4 the median diameter of the surface gravel at the seaward edge of the backshore is given for a number of areas between Eesook and Kisimulowk creeks. Near Ogotoruk Creek the upper few inches of the foreshore gravels range from 15 to 30 mm in median diamter; 10 inches deeper the median falls to 7 mm. A vertical channel sample of the upper 10 feet of beach deposits near the mouth of Ogotoruk Creek also yielded a median grain size of approximately 7 mm (fig. 18, curve 2). The upper 5 feet of beach gravel near the mouth of Kisimulowk Creek has a median diameter near 5 mm (fig. 18, curve 3).

Sorting coefficients vary over a narrow range and average about 1.30, which is considerably less than Trask's (1932) well-sorted limit of 2.50, and nearly identical to the median sorting value of beach gravel from other areas of the world (Emery, 1955b). Roundness of the clasts ranges from about 0.3 to 0.9 and averages near 0.65, which falls within the well-rounded grade of Pettijohn (1949, p. 51). The excellent sorting and roundness values of the beach sediments attest to the vigor of wave action which is virtually limited to the ice-free summer and early fall months along this segment of the Arctic coast.

Rocks which compose the gravel are principally fragments of fine-grained graywacke, siltstone, chert, and limestone; shale and vein quartz are less abundant and igneous and metamorphic rocks occur rarely. The lithologic composition of the surface beach gravels is given on table 4 and indicated on figure 19 as the ratio of clastic rocks (chiefly graywacke) to limestone and chert. Inspection of figure 19 shows that clastic rocks form a greater percentage of the surface gravels east of Cape Crowbill; conversely limestone and chert constitute about 78 percent of the beach clasts fronting the sheer limestone cliffs and only about 42 percent of the beach rocks east of Cape Crowbill. However, west of the high sea cliffs limestone and chert form about 87 percent of the surface gravel. Kindle (1909b) also reported that the coarse material of the beach at Point Hope is composed of chert and limestone.

Sources and transportation of beach sediments.--Fragments of graywacke, siltstone, and shale are principally derived from outcrops of the Tiglukpuk formation and from colluvial bluffs east of Ogotoruk Creek (fig. 3). Limestone and chert are derived chiefly from outcrops of the Lisburne group west of Cape Crowbill and from outcrops about 20 miles east of Ogotoruk Creek near Cape Seppings.

Chert, limestone, and graywacke clasts which are far from possible source areas are attributed to littoral transportation by longshore currents. Throughout the present study the littoral transport was to the east for the greatest part of the time; however, the period of observation was too short to establish that the net annual transport is to the east. The progressive eastward decrease in graywacke clasts near Kisimulowk Creek, as indicated on figure 19, may denote the effects of westward-transported limestone and chert clasts from the Cape Seppings area.

Table 4.--Lithologic composition and median diameter of coarse surface gravel at seaward edge of the backshore

Sample number as shown on figure 17	Percent by number of: Graywacke and siltstone	Shale	Lime-stone	Chert	Vein Quartz	Median diameter, determined after Emery (1955)
L1	11	2	52	35	--	27.0
L2	23	-	64	13	--	24.0
L3	9	-	37	52	2	23.1
L4	56	p1/	13	30	p1/	24.3
L5	61	1	14	23	1	30.5
L6	68	6	10	16	-	----
L7	43	p1/	16	40	p1/	31.0

1/ p signifies less than 1 percent but greater than 0.1 percent

Ice rafting (Kindle, 1924) may also aid in conveying sediment along the coast; ice rafting is perhaps indicated by the large limestone cobbles 150-200 mm in length commonly found more than 10 miles from the nearest source. Igneous and metamorphic rocks constitute probably less than 0.1 percent of the beach deposits but they also signify distant transport, as sources are not known within a radius of 40 miles. Most probably these erratics were rafted by sea or river ice and possibly by driftwood (Emery, 1955c) which is very abundant along the western and northwestern Alaskan shores. Rafting has probably been from the south as the nearest outcrops of igneous and metamorphic rocks are to the south, and coastal currents prevent sediment-laden ice and driftwood from reaching the Ogotoruk Creek area from the north (see Carsola, 1954b, p. 1571, for a photograph of "dirty" sediment-bearing ice in the Chukchi Sea).

McCarthy (1958) has described erratic boulders along the northern Alaskan coasts which have been rafted into place by icebergs. It is not likely, however, that glacial ice conveys debris to the Ogotoruk Creek area, as the bergs would have to come from the north against the prevailing currents of the Chukchi Sea (LaFond, 1954, and MacGinitie, 1955). Moreover, icebergs much more than 20 feet high would not be able to enter the shallow Chukchi Sea, let alone reach the Ogotoruk Creek area.

SUMMARY

Salient points pertaining to the oceanography, bathymetry, and marine geology of the nearshore Chukchi Sea and shallow submerged shelf off the Ogotoruk Creek area are summarized below:

(1) A prevailing coastal current flows to the northwest; during July and August 1958 surface velocities of this current averaged 0.5 mile per hour.

(2) Persistent northerly winds cause general upwelling of cold subsurface water near shore. At times of pronounced upwelling the coastal current is locally reversed and reduced in velocity.

(3) During July and August 1958 longshore currents moved to the east for approximately 75 percent of the time; however, the highest velocities were measured during easterly storms when the longshore current was to the west.

(4) The nearshore shelf descends rather steeply to a depth of 15-20 feet and then gradually flattens to a depth of 40-45 feet. Beyond this point the nearshore shelf is flattest and gradients are as low as 0°01' out to a depth of 50-55 feet. Submarine declivities at the outer edge of this terrace, or flat part of the nearshore shelf, steepen slightly and then gradually fall with distance from shore. The overall gradient of the Chukchi shelf from the inner edge of the terrace to a depth of 135 feet is about 0°04', or about 6 feet per mile.

(5) A shallow and rather flat-bottomed trough, Ogotoruk Seavalley, heads about a quarter of a mile from shore off the mouth of

Ogotoruk Creek and extends seaward for a distance of 15 miles where it merges with the adjacent sea floor at a depth near 135 feet. A number of smaller channels are off Kisimulowk Creek and near shore west of Cape Crowbill.

(6) The nearshore shelf is a wave-planed platform cut across up-turned beds of Paleozoic and Mesozoic formations. Most of the planation is thought to have taken place in Sangamon time. Ogotoruk Seavalley and other smaller channels were excavated by streams during periods of glacially depressed sea level. The seavalley was cut into the emerged shelf by Ogotoruk Creek. The outer part of Ogotoruk Seavalley has been buried under a blanket of fine-grained Recent marine sediments, and the inner reaches have been filled with beach gravels.

(7) Most of the nearshore shelf is overlain by angular to slightly rounded rocky debris which has been derived primarily from nearby submerged outcrops. Four lithologic units crop out on the shelf which are readily correlated with formations of Paleozoic and Mesozoic age exposed in the coastal area.

(8) Some of the bottom gravel has been deposited by ice rafting. It is thought that about 10 percent of the rocky debris overlying the nearshore shelf is ice-rafted sediment.

(9) During Recent time (last 10,000 years) sand and silt shed from the nearby coastal area have accumulated near shore and over most of the shelf off Kisimulowk Creek. The latter area lies off a segment of the coast drained by streams eroding fine-grained

clastic rocks. Most of the marine gravels, in particular those lying along the floor of Ogotoruk Seavalley, also contain a small percentage of Recent sand and silt.

(10) The nearshore shelf is in general a region of slow fine-grained detrital sedimentation. Although a number of factors are involved in restricting detrital deposition, a low volume of fine sediments being shed from the nearby coastal area is thought to be the primary cause.

(11) Beaches in the Ogotoruk Creek area are 30-260 feet wide, less than 10 to about 25 feet thick, are stratified, and composed of sandy gravel having a median diameter near 10 mm. The surface gravel is much coarser than deeper sediments and averages about 25 mm in median grain size. Well-rounded rocks of graywacke, siltstone, limestone, and chert are the principal constituents of the beach gravels.

(12) During moderate storms (waves 3-5 feet high), gravel is transported parallel to shore by longshore currents and the outer 20-30 feet of beach sediments are removed. Some of the sediment carried parallel to shore accumulates as spits at stream mouths and as areas of new beach below rocky headlands. After subsidence of the storm waves, gravel is returned to the beach and berms are constructed.

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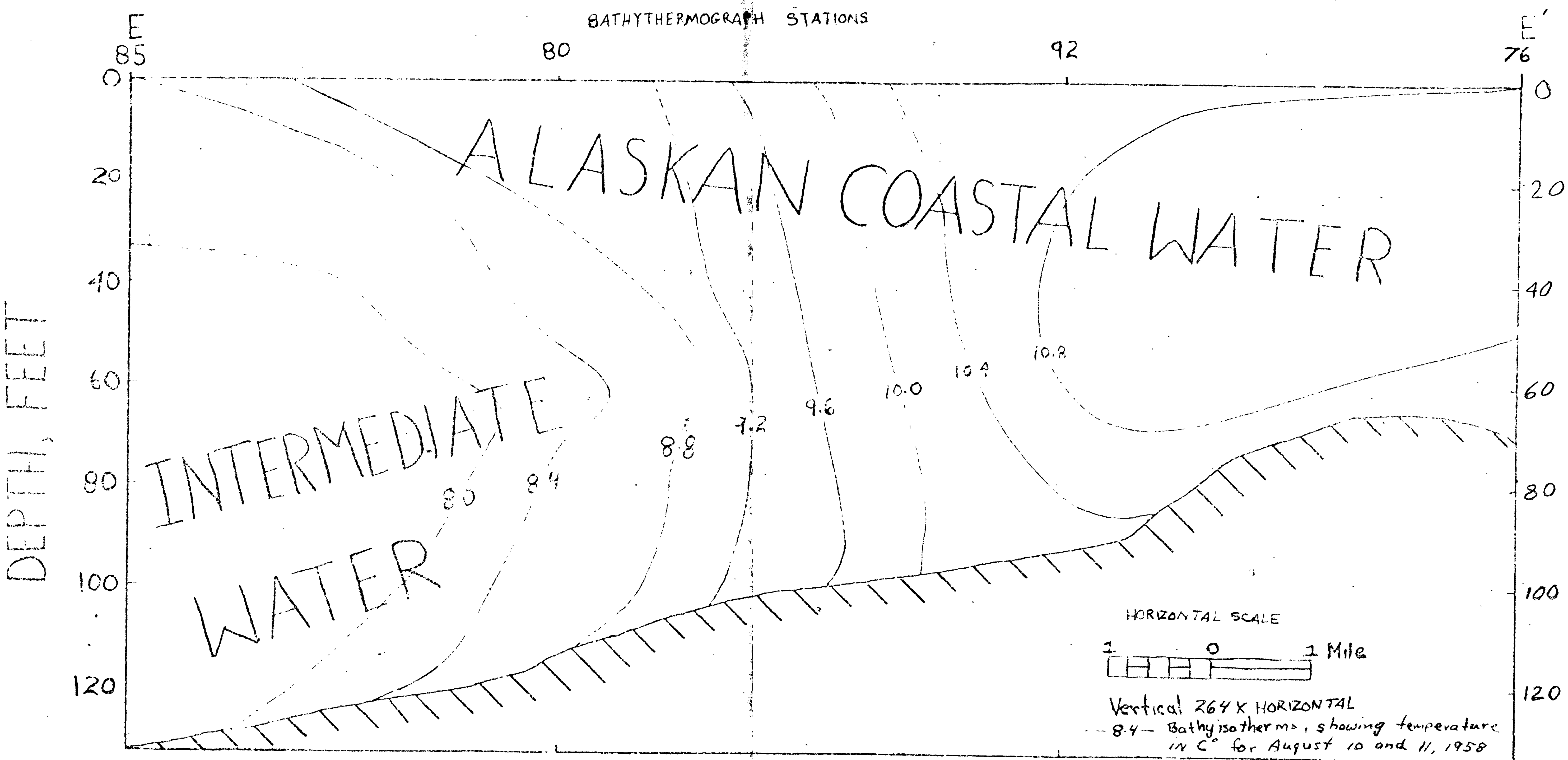

Figure 5 Vertical temperature section E-E'; positions of bathythermograph stations and section line are shown on figure 2.

This map is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature

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TEI-606 FIGURE 6

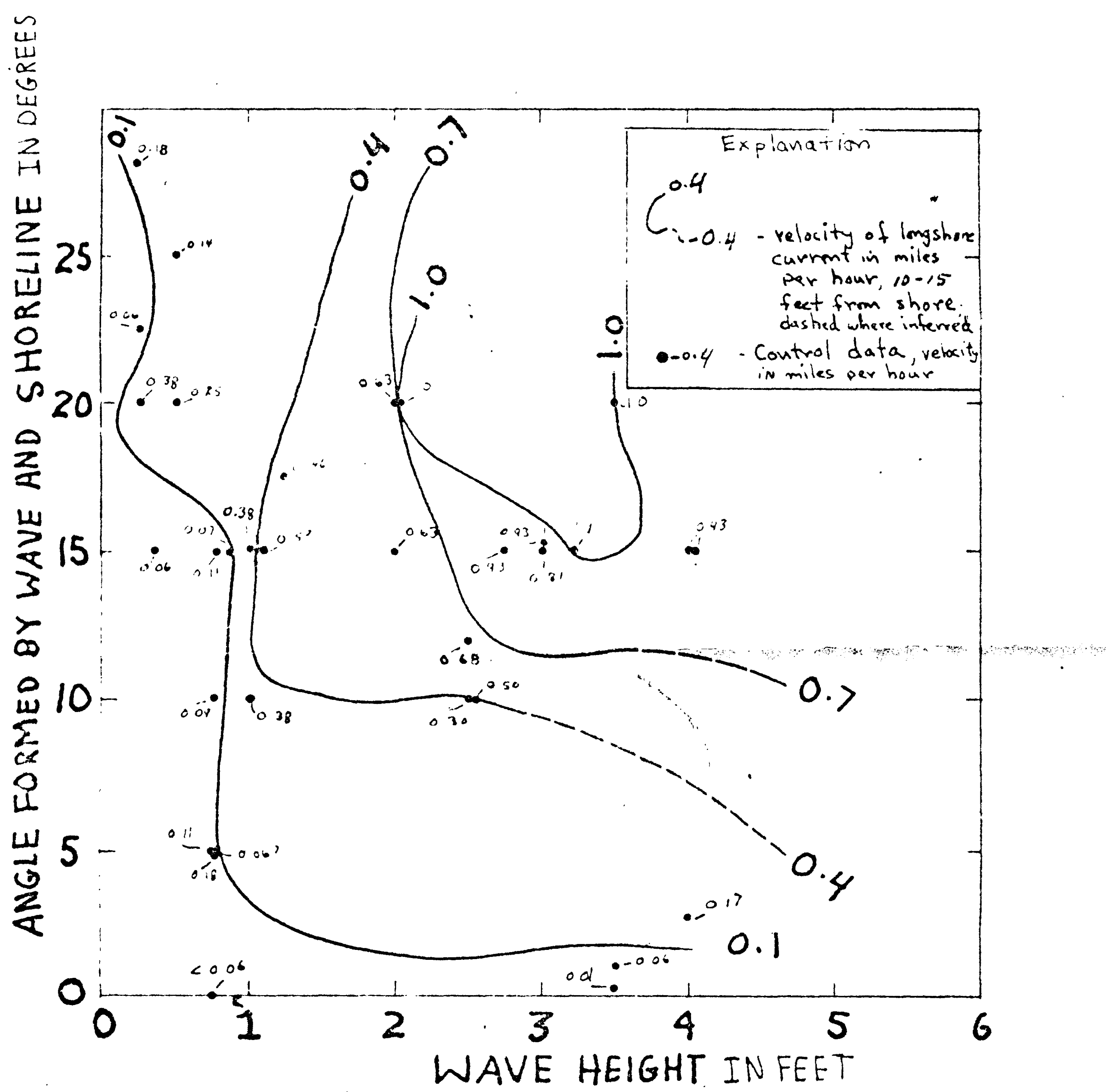

FIGURE 6. General Relationship of Longshore Current Velocity to Wave Height and Angle of Approach

This map is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature

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TEI-606 FIGURE 18

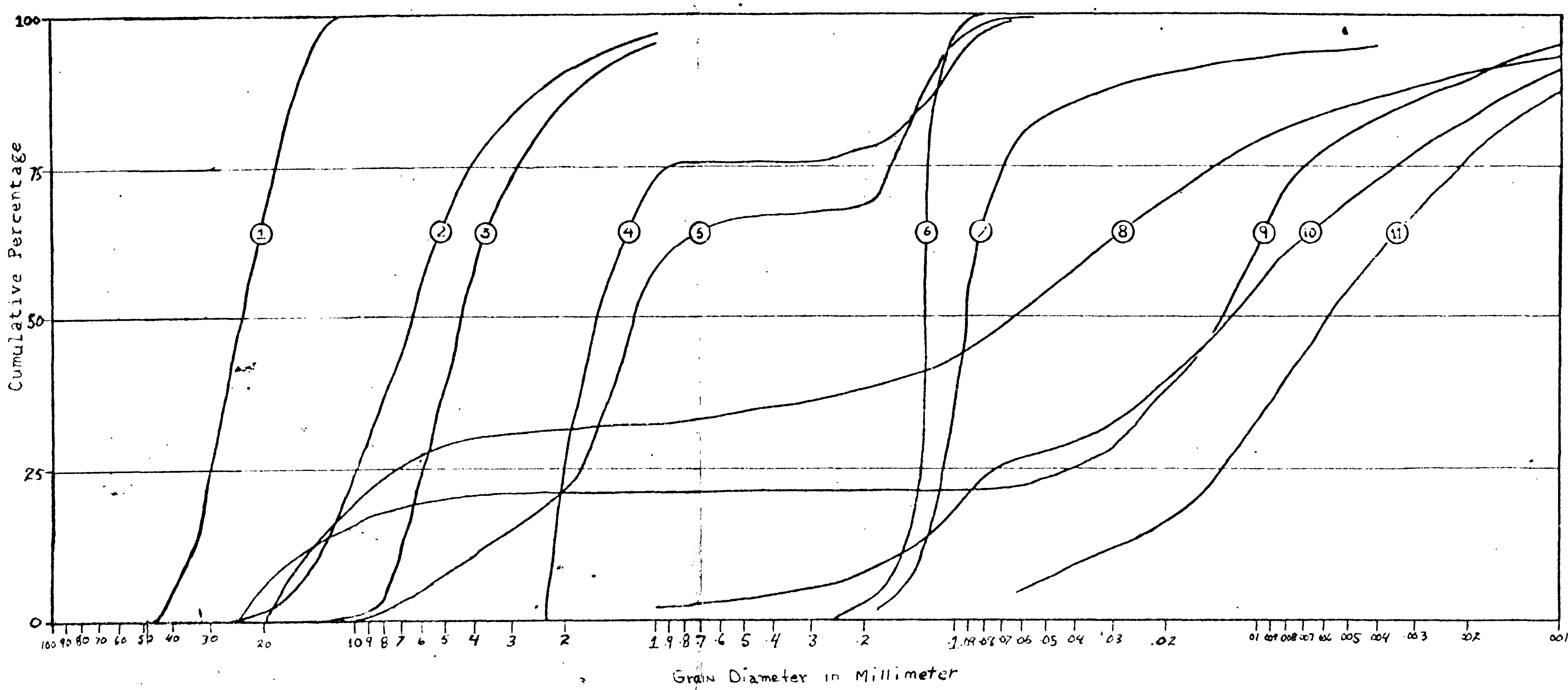

Figure 18. Typical cumulative curves of unconsolidated marine sediments. (1) Surface gravel of small berm built near mouth of Ogotoruk Creek after storm on July 26, 1958, profile G-G' on figure 7 shows this berm, grain size distribution determined in the field by the method devised by Emery (1955); (2) channel sample of upper 10 feet of beach sediments near the mouth of Ogotoruk Creek; (3) channel sample of upper 5 feet of beach gravel near mouth of Kisimulowk Creek; (4) bimodal curve of sand-silt fraction of sandy gravel; (5) gravelly sand; (6) sand; (7) silty sand; (8) sandy-gravelly silt; (9) gravelly silt; (10) sandy silt; and (11) silt.

This map is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature