UNIVERSITY OF CALIFORNIA, LOS ANGELES

Marine Geology of the Near Islands Shelf, Alaska

A thesis submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Oceanography

53-245

by

Philip C. Scruton

February 1953

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ABSTRACT

During the summer of 1950 on the insular shelf surrounding the Near Islands, Alaska, 193 oceanographic stations were occupied from aboard the U. S. Geological Survey vessel EIDER. Bottom character and temperature observations were made at these stations. The composition and size distribution characteristics of the bottom samples have been determined. Components of terrigenous origin are angular to subangular sand and silt and angular to well rounded granules, pebbles, and cobbles, all composed of little-altered fragments of the fine grained insular rocks. Components of marine origin are the skeletons of Foraminifera, diatoms, and sponges and the broken shells of a few species of mollusks and of one echinoid species. A chart, based also on the study of approximately 600 USC&GS bottom notations, was prepared to show the distribution of these components of the sediments. Bed rock is exposed on most of the shelf; where sediment occurs terrigenous components are generally most important near shore, whereas marine components are more important seaward of the islands. Studies of the Foraminifera fauna and the diatom flora (identified by K. E. Lohman) and the few mollusks of quantitative importance show these organisms to be forms characteristic of cold or deep water or occurring in a wide range of temperature conditions. The Foraminifera exhibit depth zonation which seems to be controlled in part by temperature and in part by depth or some other variable which is a function of depth. Sphericity and roundness studies made on pebbles from the shelf, the beaches, and the fluvio-glacial deposits together

with shelf topographic features and Foraminifera from sediment deposited before ice wastage was complete suggest the shelf was not subjected to prolonged surf action during the post-glacial rise of sea level.

To aid in interpreting the sediments and their distribution several subaerial and marine environmental factors were investigated. Those factors found to be of most importance in determining sediment character and distribution are recent geologic history, nature of terrigenous source material, temperature, topography, rainfall, size of source area, history of the water mass, waves, and currents. The data derived from this study show the importance of climate as an important variable in determining sediment character and distribution in the Near Islands.

INTRODUCTION

General Statement

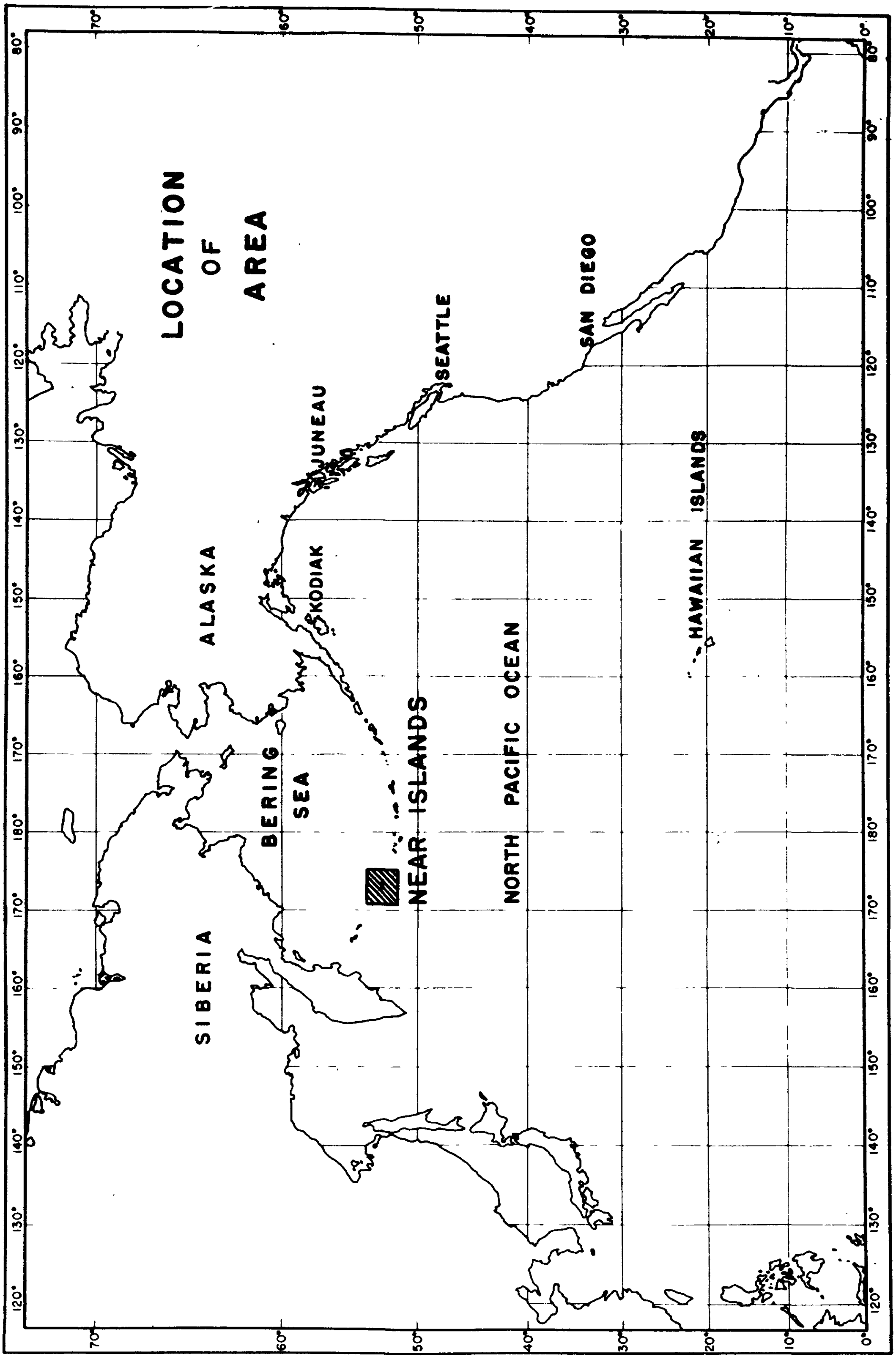
An opportunity was extended to the Scripps Institution of Oceanography by the Volcano Investigation Unit of the U. S. Geological Survey working in the Near Islands, Alaska, to study oceanographic conditions in this area during the summer of 1950. Because the emphasis of the expedition was geological, it was felt that the marine investigation should augment the work of the field parties ashore. It was intended that this work should provide information of value in interpretation of the glacial and post-glacial history of the island mass from a study of the shelf sediments in addition to that which could be obtained from charts of the U. S. Coast and Geodetic Survey. In addition to providing information for interpreting local history, this study was undertaken with the hope that through a detailed investigation of sediments and the environment in which they are created and deposited, something of the relationships between them might be learned. Subaerial and marine environmental factors which seem to be of importance in determining character and distribution of the sediments are subaerial and marine topography, glacial and post-glacial history, climate, vegetation, soils, agents of subaerial transportation, properties of the water mass surrounding the Near Islands including temperature, salinity, and nutrient characteristics, also large scale semi-permanent currents, tidal currents, and wind waves at different seasons of the year. Interaction of these environmental characteristics controls the production of terrigenous and marine components of the sediments and their distribution.

The field work was carried out aboard the motor-vessel EIDER, a 90 foot converted halibut schooner, whose primary purpose was to transport the U. S. Geological Survey personnel and gear from the continental United States to the area of investigation. The vessel was outfitted in Seattle with a regular electric bathythermograph winch, 1,000 feet of 3/32 inch wire line, and a davit to serve as a boon for handling the oceanographic equipment. The EIDER departed Seattle on July 1, 1950, and proceeded via the Inside Passage to Ketchikan, Wrangell, Petersburg, and Juneau, Alaska. From Juneau the route led across the Gulf of Alaska to Kodiak and thence along the Alaskan Peninsula, through Unimak Pass into the Bering Sea and west along the Aleutian Chain. Stops along the chain were made only at the islands of Unalaska, Umnak, Adak and Kiska for stores or to seek shelter from storms. Massacre Bay on Attu Island, the base of operations in the Near Islands, was reached on July 28.

Field Methods

Information on distribution of bottom types is based primarily on the 193 stations made by the EIDER during the summer of 1950 and on approximately 600 bottom notations which appear on the unpublished "smooth" manuscript sheets of the U.S. Coast and Geodetic Survey. The locations of EIDER stations are shown in figure 2. A large portion of the U.S. Coast Survey observations are in the shallower waters which surround the islands, although many are at greater

FIGURE 1


LOCATION
OF
AREA
ALASKA
SIBERIA
BERING
SEA
NEAR ISLANDS
NORTH PACIFIC OCEAN
HAWAIIAN ISLANDS
SAN DIEGO
SEATTLE
JUNEAU
KODIAK

depths. The character of the bottom also was directly observed at many places in the clear shallow waters close to shore. In addition to these direct observations of bottom character, it is possible to infer the character of the bottom from the topography in many areas.

Sampling was done on a grid system laid out on the insular shelf in order to cover the area insofar as possible during the time available. The axes of this grid are aligned approximately NNE and SSW to conform with the elongation of the shelf area. Stations are spaced at a distance of two to three and one-half miles within the grid and at greater distances where sampling is less complete. The sample network was amplified by numerous, closely spaced samples in the vicinity of Massacre Bay on Attu Island.

Navigation was with compass bearings, dead reckoning, and echo-sounding methods. Traverses were adjusted, where necessary, by distributing the navigation error among the sample stations on the traverse in proportion to the total time elapsed, assuming a constant source of error throughout the traverse. Positions assigned in this manner were controlled by station depths.

Bottom sampling was with either a light coring rig designed by Phleger (1951, pp. 3-4) or a clam-shell snapper similar to that figured by Shepard (1948, p. 21, fig. 7). The Phleger coring apparatus obtains a core 1.375 inches in diameter up to 18 inches long. It will not sample pure sand or gravel, however, and when these bottom types were encountered the clam shell snapper was used. The clam shell snapper obtains approximately one pint of the surface material and also was used in all areas of rock bottom. The samples were stored for shipment in either glass jars, plastic core liners, or cloth sample bags.

Evaluation of a chart showing bottom character should be based on the type of sampling apparatus employed as well as the density of sampling. The question should be asked: "How well adapted is a particular device for providing a sample for suitable representation of the bottom type?" In the present investigation it is apparent that the equipment was only partially adequate. Neither of the primary sampling instruments used is ideal for study of the distribution of very coarse sediments or ledge (bed) rock. A dredge capable of bringing to the surface very large samples or of breaking off fragments of ledge rock is desirable equipment, but such a device was impractical with the facilities of the EIDER.

On the chart showing bottom types (fig. 4, in pocket) the inshore areas are the most accurate because of density of sampling, the distinctive topography, and the ability, in many places, to observe the bottom. The accuracy decreases seaward and in some areas (as around the Semichi Islands) is based entirely on chart notations and topography. Details of distribution of bottom types are infinitely more complex over most of the shelf than is shown on figure 4, and the chart indicates only the most probable bottom type to be found at a particular place.

Surface temperature measurements were made at all stations using a bucket thermometer. In addition, a bathythermograph, a device for measuring water temperature versus depth, was used at a large number of stations, furnishing considerable detailed information on the

Pages - Figure 2

subsurface distribution of temperature.

Acknowledgments

Many people were helpful during various stages of the work. Roger R. Revelle of the Scripps Institution and Robert S. Diets of the Navy Electronics Laboratory made the preliminary arrangments with the U. S. Geological Survey. Drs. Revelle and F. B. Phleger were helpful with suggestions for a field program and made it possible to obtain the necessary equipment for the field work and some of the funds for the ensuing laboratory studies. Howard A. Powers, Ray E. Wilcox, and Olcott Gates of the U. S. Geological Survey were generous with their time, ideas, and encouragement during the field season and while the manuscript was being prepared. Funds for the work also were derived from the U. S. Geological Survey. Miss Frances L. Parker of the Scripps Institution aided in the identification of the Foraminifera and verified a number of the identifications with type material at the U.S. National Museum. Captain Carl Vevlestad and Chief Engineer Charles A. Best assisted in a variety of ways in making the EIDER suitable for oceanographic work. Richard J. Bongey and C. D. Rhinhart, graduate students employed by the Geological Survey, gave generously of their ideas and efforts while serving as field assistants. Mr. Donald P. Saynor has been of unfailing assistance in problems related to illustration. Finally, all or parts of the manuscript have been read and criticized by R. S. Arthur, M. N. Bramlette, J. Wyatt Durham, Olcott Gates, U. S. Grant, IV, D. L. Inman, E. B. Phleger, H. A. Powers, H. V. Rakestraw, J. P. P. Saur, and F. F. Shepard. To all of these interested participants grateful acknowledgment of their aid is made and appreciation extended.

PHYSIOGRAPHY OF THE NEAR ISLANDS AREA

General Physiography of Near Islands Section of Aleutian Ridge

The Aleutian Ridge is a long arcuate projection from the Alaskan Peninsula which is more or less continuous the entire-distance to the Kamchatka Peninsula of Siberia. This ridge forms the boundary between the North Pacific Ocean on the south and the Bering Sea on the north and in most areas limits the exchange of marine water between these regions to the uppermost layers. The Aleutian Ridge, the adjacent Aleutian Trench to the south, and the Bering Sea basin have been discussed at some length by Murray (1945) who utilized all available topographic data.

The general form of the ridge in the Near Islands region is similar in cross section to that of the Sierra Nevada of California with the north face of the ridge corresponding to the east face of the Sierra Nevada. The sea bottom rises toward the north from the maximum depth of 4,200 fathoms in the Aleutian Trench with an average gradient of approximately 5°. The descent to the bottom of the Bering Sea on the north is at an average slope of approximately 12° to almost 2200 fathoms. This is the inverse of the condition which exists farther to the west. A cross section through Umnak Island shows the steep slope to be to the south and the more gentle one to the north (Murray, 1945). The slope north of the Near Islands between the 100 and the 1000 fathom curves is greater than the average slope on either the north or south sides. On the south this slope between 100 and 1000 fathoms averages approximately 10° and on the north it averages about 17 1/2°.

The submarine topography, as well as the magnitude of the slopes, is different on the north from that on the south. To the south the slope is irregular, being intersected along its length by a great deep trough and several lesser valleys together with numerous sea mounts which rise to considerable elevations above the adjacent sea floor. The slope on the northern side for much of the distance is along a straight line which trends approximately W20°N and shows neither pronounced valleys nor mountains. North of the western portion of Attu this slope is more irregular: the trend changes somewhat in direction to between west and W10°N, but maintains an approximately straight line.

Transverse sags which occur more frequently and in greater magnitude toward the west divide the Aleutian Ridge into natural geographic units. The Near Islands are the relatively small subaerial portions of one of these natural geographic units. The Near Islands segment is separated from Buldir Island to the east by a sag which reaches a maximum depth of some 350 fathoms. The Komandorski Islands to the northwest along the continuation of the ridge are separated from the Near Islands by the deepest sag in the ridge which attains a maximum depth of slightly over 1800 fathoms.

The summit of the Near Islands segment of the Aleutian Ridge is an area, within the 100 fathom curve, of 2363 square nautical miles. Located on this broad platform are the five islands which make up the Near Islands group. The islands have an aggregate area above sea level of 330 square miles, so that approximately one-seventh of the geographic unit is available for direct study and more than 2800 square miles are below sea level.

In general, the relief of the islands is greatest on the northern sides of the islands (see figs. 21, 22, in pocket). Agattu Island has a small range of mountains along its northern coast, the remainder being a lower gently rolling plateau of relatively insignificant relief (see also Sharp, 1946). The greatest subaerial relief, however, is located along the northern margin of theshelf area. On the east the three small Semichi Islands and the Ingenstrom Rocks form a continuous trend of maximum elevation, and on the west the mass of Attu lies on the same trend and exhibits the same tendencies. The summit elevations of Attu form a relatively horizontal accordant plateau; slopes from this plateau are generally less abrupt to sea level along the southern coast than on the north.

The surface of the subaerial plateau of Attu has been insized deeply by the combined action of streams and glaciers, as have been the surfaces of the other islands to a lesser extent. Glaciers followed the courses of the many feeder and trunk streams, eroded heavily, and produced its present contour from the youthful pre-glacial topography. Most of the undulating pre-glacial surface has been eroded away leaving here and there smooth remnants which appear to be unglaciated. These remnants are found along the tops of the highest ridges and are separated from each other by deep U-shaped valleys. All of the lower slopes of Attu, Agattu, and the Semichis have been extensively glaciated.

Most of the modern streams on Attu are small and have a steep gradient at the inner portions of their courses, coalence to form larger streams, and water the sea at a gentle grade which appears to be the result of post-glacial deposition. On the smaller islands, Agattu and the Semichis, the streams are numerous and small.

The physiographic age of the land surface of Attu is that of late youth to early maturity. The mountainous northern portion of Agatta is at a similar stage of development, but the lower plateau of the south is in a stage of early youth. This plateau is almost completely undisected except at the margins and is covered by numerous lakes and swamps.

All of the islands are surrounded by sea cliffs which seem to be in part the result of post-glacial wave action (Plates I, II). This is indicated by the truncation of the walls of the glaciated valleys by the sea cliffs. These cliffs vary in height from 50 feet to a maximum of about 750 feet. The cliffs vary in height from 50 feet to a maximum of about 750 feet. The cliffs are virtually continuous except where they are broken by the trunk stream valleys, although in many instances they extend up into the valleys (Plate II). The small streams on Attu and the smaller islands either fall in a series of cascades down these cliffs or have cut short, shallow, precipitous, V-shaped canyons leading to the sea.

The extensive sea cliffs of the Near Islands are not in equilibrium with the present level of the sea. All the most recently cut large cliffs stand 10-30 feet above the present zone of wave attack and are separated from the sea by varying widths of coarse shingle or boulders and/or bare rock, sometimes with narrow grass-covered coastal plains. Stacks and sea arches, no longer subject to wave erosion, are common in this low coastal zone.

Plate I

Fig. 1. Abandoned sea cliffs, narrow grass-covered coastal plain, and wave-cut bench, southern Attu.

Fig. 2. Wide wave-cut bench off Mikhail Point, southern Attu.

Plate II

Fig. 1. Bay head, northeastern Attu, showing sand beach, beach ridges, and sea cliffs extending up-valley.

Fig. 2. Dead sea cliffs and wave-cut bench, eastern Attu. Note road at base of cliff.

Near Islands Shelf Topography

The insular shelf area of some 2100 square miles can be divided into several separate provinces for purposes of discussion. In general the topography of all the provinces is quite irregular when seen in detail, but when viewed on a smaller scale, the irregularities of some of the provinces become less important (see fig. 3, in pocket). The field sheets of the U.S. Coast and Geodetic Survey constructed during the summers of 1943-45 constitute the basic material for a discussion of the topography. These sheets are prepared on a scale as large as 1:20,000 from echo-sounding profiles taken at short intervals so that the coverage is complete and detailed. A complete treatment of the submarine topography with special regard to the similarities with the subaerial topography currently is being undertaken by the Volcano Investigation Unit of the U.S. Geological Survey. For this reason the detailed features will not be stressed here, but only these aspects which are of significance in an interpretation of the history of the insular shelf or in controlling volume sedimentation.

Four provinces can be established on the basis of somewhat similar topography. These provinces are : 1) the narrow shelf areas north and southwest of Attu and the wider shelf east and south of Agattu, 2) the zone of highly irregular hummocky topography lying in general in a belt between Attu and the Semichis and Agattu, 3) the relatively smooth area both north and south of the Semichis, and 4) the inshore zone surrounding all of the islands.

Narrow Shelves Around Attu and Agattu.

Broad valleys are the chief features of the topography of the area north and southwest of Attu and east and south of Agattu which differentiate this type from the others. These valleys are three to seven miles wide and generally have rather flat bottoms. The sides usually are steep in the inshore portion but may be low and gentle. The valleys radiate from the inlands in directions nearly at right angles to the shores. They are narrower and deeper on the inshore ends and become wider and more shallow toward the edge of the shelf, most of them losing the character of valleys and merge with the shelf before the break in slope is reached. These valleys originate in bays or bights in the coast line of the islands and in most cases are the seaward extension of the heavily glaciated valleys of the islands.

Valleys of this type are best developed southwest of Attu. Here the floors are in general quite flat with only minor irregularities which are distributed in random fashion. The large valleys east and south of Agattu are quite similar in characteristics to them but are on a grander scale. North of Attu their development is not so pronounced, but their existence can be detected easily off the two large bays on the northeast coast. Extensive morainal ridges of rock bars characteristic of areas off valley glaciers which have extended for a limited distance into the sea (Tarr and Martin, 1914, pp. 221-22; Davis and Mathews, 1944, p. 409) are nowhere to be found in these submarine valleys.

The submarine valleys are separated by ridges or "noses" of varying size. The ridge which runs southeast from Agattu is well developed and continuous to the edge of the shelf, whereas the inter-valley ridges southwest of Attu are smaller and lose their identity a short distance from the land.

North of the central portion of Attu, coinciding with the change in trend of the insular slope, is an area of more complex basin-type topography. The basin is elongated transverse to the general valley trend and is roughly parallel to the trend of the insular slope a short distance to the north. There is general topographic discontinuity along the extension of this basin which is particularly evident, even at considerable depths, to the east but is also present to the west.

The break in slope at the shelf margin is pronounced around the entire insular shelf. This break is much sharper on the north and east, with the inclination of the upper insular slope below the break as great as 45° in some places. The depth of the shelf break on the north averages approximately 65 fathoms. On the south the break in slope is more gentle and occurs at about 80 to 85 fathoms.

Shelf Between Attu, Agattu, and the Semichi Islands.

Lying to the south and east of the southeast corner of Attu and extending eastward almost to the Semichi Islands and Agattu is an area of very complex topography. Viewed on the broadest scale the topographic form is that of a large compound ridge which extends irregularly to the east and south, becomes flatter, and ultimately merges with the smoother sea floor. This broad ridge is broken into more or less distinct segments by equally irregular valleys of varying lengths which more or less radiate from the southeastern segment of Attu. The valley which limits this area on the west can be traced to near the island, but the other valleys originate at some distance offshore. The surface of the ridge has on it an irregular pattern of hills, depressions, and closed basins of various sizes. Many of the larger hills on the ridge are as much as 150 feet high above the immediate area, but some are very small. In the northern half of the area some of these higher hills extend to the surface at lowest tide and constitute reefs which are dangerous to navigation. The basin depressions on the ridge generally are not as large as the hills but are equally erratic in their distribution. This area is the only portion of the insular shelf which exhibits this type of topography on a large scale.

The large ridge is bordered on the west, southeast, and the east by deep elongate basins in which are found depths as great as 90 fathoms, the greatest on the insular shelf. These deep shelf-basins lie in the general trend of the larger irregular valleys which divide the ridge. The larger of these basins southeast of the ridge is actually a compound basin separated into two portions by a narrow ridge which runs in a direction roughly parallel to the northwestern shore of Agattu and is crowned near its center by two small hills.

Shelf North and South of the Semichi Islands.

The area which lies to the north and south of the Semichi Islands can be considered to constitute a third general type of topography on the insular shelf. It is similar to the broad valley type of topography, and on the west it merges with the irregular lobe southeast of Attu. The distinguishing feature of this province is the general regularity of the bottom. None of the large flat-floored valleys or irregular hills and depressions are found, although lying on the southern margin of the province are the elongate basins north and east of Agattu similar in character to those on other parts of the shelf. The break in slope on the northern part of this province is similar to that north of Attu. On the east the break in slope is somewhat less abrupt and varies in depth from 65 to 75 fathoms.

Inshore Shelves.

The near shore zone surrounding all of the islands has a similar topography, a characteristic feature of which is the wave-cut platform. The platform or terraces which can be definitely assigned to the near shore zone vary in width from a maximum of one-half mile to almost nothing, and have their greatest development off the sharp headlands separating the deep bays on Attu and surrounding the Semichi Islands. They often form long, jagged, boulder-studded reefs extending outward from shore which may be expected throughout much of their length at low tide.

Associated with these wave-cut platforms are the many stacks and isolated boulders of the near shore zone. These features form a complicated fringe around much of the shore which extends outward to a depth of approximately 10 fathoms. They are better developed in connection with the wide wave-cut platforms but are not limited to them, occurring wherever wave erosion has been sufficient to erode sea cliffs and where the country rocks are sufficiently variable in resistance to wave action. This combination of circumstances occurs with such frequency that only in the heads of the main bays which are relatively protected from wave action do sand or sand and shingle beaches occur.

According to Shepard's classification (1937, 1948, pp. 68-79) some of the shore of Attu is a youthful coast line which has been shaped by glacial erosion and subsequently drowned. Much of the configuration of the coast line, however, may be the result of faulting (fig. 21). Superimposed on these is the outline of a more mature coast which has been made irregular by marine erosion. The coast line of Agattu also fits the modified drowned glacial valley classification although somewhat less satisfactorily as the glacial valleys are not prominent. The coast line of the Semichi Islands may be considered a mature coast line which has been made irregular by marine erosion.

Submarine Troughs

Other features of the physiography of the ridge which should be mentioned are the great submarine valleys or troughs which exist on the south insular slope. There are two of these troughs, one which virtually bisects the Aleutian Ridge between Buldir Island and the Near Islands (see USC&GS Chart 8863, 1944) and the other which originates off the southwest coast of Attu and extends in a southwesterly direction to great depths.

Charts (USC&GS No. 9198, 1947 ed.) and the field sheets of the

U.S. Coast and Geodetic Survey are sufficiently detailed to permit the construction of a contoured chart of much of the trough lying southwest of Attu. Such a chart furnishes the basis for a description of this topographic feature. The trough originates just within the break in slope, lies along the axial extension of one of the major valleys on the island, and continues to great depths with only minor deviations from this trend. There is no topographic continuation between the two valleys; the insular shelf in the intermediate area is devoid of any indication of a major valley. The head of the trough has a trend of S38°W, but with increasing depth, the axis shifts in direction toward the west until at 2500 to 2800 fathoms the axis trends N66°W. This shift in axial alignment is evenly distributed along 22 miles of the course of the trough.

The trough is approximately two and one half miles across the 500 fathom contour at the head and at this point has a relief of 550 to 600 fathoms. The width becomes progressively greater, and at the seaward limit of the 500 fathom curve it is 13 miles wide and has a relief of 1000 fathoms. A maximum vertical relief of over 1800 fathoms (over 7200 feet) exists in the trough.

The cross section of the trough is uniform in character throughout the length with the sides sloping down smoothly to the flat valley floor. Only the dimensions of the slope and the width of the valley floor show significant differences. The eastern wall is the steeper, averaging approximately 25° in slope through the upper length of the trough. The west wall has a slope of about 11° throughout much of its length. The valley floor varies in width from about one-half mile at 900 fathoms to a maximum within the well defined trough limits of 3 miles at 1500 fathoms.

The longitudinal profile of the trough is a series of trends and risers which descend to a maximum known depth of slightly more than 2800 fathoms below sea level. Three nearly horizontal treads are separated by the risers which have a maximum inclination of 15° between 1700 and 2800 fathoms. The average gradient throughout the length of 23 1/2 miles between 100 and 2800 fathoms is between six and seven degrees. A basin appears to exist below 2800 fathoms on the deepest of the relatively horizontal treads.

This description of the dimensions of the Attu Trough indicates something of its size and overall characteristics. The trough, a major topographic feature of the area, is somewhat larger than the Monterey Canyon located off the coast of California. In addition it is very similar in many of its details to the deeper portions of the Monterey Canyon which lie below a depth of 850 fathoms (cf. Shepard and Emery, 1941, pp. 72-78).

Little information is available on the trough between the Near Islands and Buldir, but judging from the chart, it is very similar to the one off Attu. Both of the troughs have a similar northeast-southwest trend, both descend to great depths, both are wide with relatively steep walls, and both apparently have similar bottom topography, although details shown on the published chart are not sufficient to evaluate these characteristics definitely in the eastern trough.

Extent and Duration of Glaciation

Study of the sea floor adjacent to the Near Islands affords important evidence of the former extent of Pleistocene ice on the shelf. Part of this evidence was discussed in connection with shelf topography; other parts are considered below in appropriate sections. Distribution of ice deduced from the direct evidence available is a minimum, however, and actual extent of ice must be inferred from other considerations. Extensive moraines and areas of cobbles and gravel and the shelf-basins show that ice must have extended to the shelf margin for considerable distances south of Attu and virtually to the margin for the entire distance. South of Agattu the only direct evidence to suggest glaciation is the wide rocky valley; southeast and east of Agattu, however, cobbles and gravel and irregular hummocks were encountered scattered on the shelf and below the break in slope. North and northeast of Agattu shelf-basins and cobbles also are found. These occurrences show the former presence of glaciers on the insular shelf around Agattu, and the existence of a very extensive body of ice can be inferred from this evidence.

One looks in vain on the shelf for extensive development of topographic features which could be interpreted as terminal moraine. A volume of rock probably measured in terms of cubic miles was removed from the islands alone by glacial action, yet the only glacial deposits reflecting to any degree such extreme erosion are those found south of eastern Attu. Moreover, the low (250-300 feet in elevation) Semichi Islands were extensively glaciated as is evidenced by both erosional and depositional features, despite the fact

That they were apparently too low to serve as primary catchment areas for snow. Glacial features of the Semichi Islands have a southeast-northeast trend which has led to speculation as to the former existence of a high land mass to the northeast of the present shelf area which served as a source of glacial ice and has disappeared without a trace in post-glacial time (H. A. Powers, personal communication).

This idea seems neither probable nor reasonable, however, is an alternate suggestion, to explain the lack of voluminous terminal moraine and the glaciation of the Semichi Islands, the hypothesis is advanced that the entire insular shelf was buried beneath a Pleistocene ice cap of considerable thickness. This hypothesis is suggested also from consideration of the dimensions of the ice sheet as shown by submarine investigation and topographic features of Attu and Agattu. The present climate of the region in relation to nearby areas where large glaciers exist and the former extent of Pleistocene glaciers in adjacent areas support such an hypothesis.

Glaciers begin to form when the rate of formation of ice exceeds the rate of removal on some portion of the land surface. If such a land surface is mountainous the excess ice accumulates and begins to flow down pre-existing valleys and to erode the bed. The floors of cirques which are formed in this process lie at a level which has been called the orographic snow line (Flint, 1945, p. 32) and furnish a close, although generally somewhat low, approximation to the level of the climatic snowline.

Elevation of the orographic snow line in the Near Islands obtained from a study of elevation of cirque floors varies (see figs.

21, 22). In the interior of Attu it lies at the maximum elevation of 1250 to 1500 feet, descending to 1000 to 1250 feet in western Attu and 700 to 1000 feet on the eastern portion of the island. On Agattu the level is between 700 and 900 feet in elevation. From these data it appears that the climatic snow line most probably lay between 1000 and 1500 feet elevation on Attu. The lower elevation of approximately 900 to 1000 feet on Agattu (Sharp, 1946, p. 198, suggests 800 to 1000 feet) suggests that glaciation may have been initiated at a slightly later period than on Attu when conditions had become more favorable for the accumulation of ice.

The present snow line on Attu under most favorable circumstances lies no lower than approximately 2400 feet, although small patches of snow may persist the entire summer at half this elevation. One small glacier lies at approximately the 2400-foot level on the northeastern flank of Attu Mountain, the highest peak in the islands. The elevation of climatic snow line is somewhat higher than that of the Alaskan Peninsula and the outer St. Elias Range where it has been placed at 2000 to 3000 feet by Tarr and Martin (1914, p. 199), 2300 feet by Flint (1945, p. 55), and 2000 feet by Capps (1932, p. 146), and is lower than that of the eastern Aleutians which is at a level of approximately 3300 feet (cited in Sharp, 1946, p. 198). Climates of these regions today are similar (Encyclopaedia Britannica World Atlas, 1951) although rainfall is somewhat higher and temperatures somewhat lower in the northern Gulf of Alaska along the St. Elias Range than in the Aleutians.

Thickness of ice can be inferred from the elevation at which peaks appear to have been glaciated. Where peaks were entirely covered by ice this method gives a minimum rather than a maximum thickness, however, as valley glaciers which exist during the period of wastage tend to sap the peaks and ridges and destroy evidence of former higher ice stands. Sharp (1946, p. 198) suggests from this type of information that ice buried all of Agattu below at least 1000 feet in elevation. Similar observations on Attu suggest that the ice surface was above 2500 feet in the interior and 1700 to 1800 feet along the coast. Only the high peaks and perhaps the highest ridges of Attu seem to have been above the glacier surface during the maximum extension of the ice.

Ice flowed out of the confining valleys onto the shelf, spread laterally forming great piedmont lobes which ultimately coalesced. Originally nourishment was derived from the high interior regions, but as these sources gradually filled the valleys until the ice surface lay above the climatic snowline, the coalesced piedmont lobes became independent of the original insular sources and behaved as a true ice cap. To the north, west, and south of Attu the limit to which ice could extend is restricted by a nearby shelf margin. To the east, however, a large area for expansion exists. Ice flowing radially from Agattu joined with the growing ice cap on the north and flowed southwest and east toward the sea. South and east of Agattu it is probable that the primary source still lay on the higher elevations of the island, but the supply of ice was sufficient to permit a solid sheet to extend to the shelf margin.

Ice flowing northward and northeastward from Agattu joined with the mass spreading to the east from Attu and moved outward to the shelf margins on the northeast and east, burying the Semichi Islands in the process. If a minimum thickness of 200 to 300 feet was necessary for flowage over the Semichi Islands and their abrasion, the total thickness of ice on the present sea floor south of these islands must have been at least 750 feet and the surface at an elevation of 450 feet above present sea level. The thickness of ice undoubtedly decreased toward the east in the direction of flow.

These considerations suggest that the center of the ice accumulation for the eastern shelf moved to the east of Attu at the glacial maximum and probably centered in the area between Agattu, eastern Attu, and the western-most Semichi Island. Elevation of this center of eastward dispersal was probably somewhat higher than the ice of Agattu, perhaps 1400 to 1600 feet in elevation above present sea level. From this maximum the elevation of the ice cap surface decreased to the north, east, and south, passed below the climatic snow line, and was dependent on the central sources for nourishment.

Shelf glaciation in the Near Islands was indicated by Sharp (1946, p. 198) when he suggested the lack of glacial drift on Agattu was due to the ice flooding off of the present island on all sides. Capps (1932, p. 146-147) also recognized the probability of ice cap formation and shelf glaciation when he stated (p. 167):

> "In such of the larger and more rugged of the Aleutian Islands as were visited it is evident that each island developed a separate, individual ice cap, in which only the higher peaks and ridges stood above the glacial ice, and the glacial movement was radially away from the divides toward the sea. Thus, Unalaska, Atka, Adak, Kiska, and Attu Islands were each almost completely covered by glacial ice that not

> only filled the higher valleys but pushed out over the lowlands to the sea, and it seems certain that the other large islands not visited, including Unimak, Akun, Akutan, Umnak, Kanaga, Tanaga, Amchitka, and Agattu, each supported a separate ice cap that covered most of the land surface."

Neither Capps or Sharp could have known the true extent of the ice in the Near Islands, but their observations and inferences were accurate.

These observations of Capps and Sharp, the interpretation of extent of Near Islands glaciation, and the bottom topography surrounding the major Aleutian Islands suggest that the entire Aleutian Arc was buried beneath a continuous expanse of ice broken only at the widest and deepest passes. The demonstrations of widespread shelf glaciation south of the Alaskan Peninsula and Kodiak Island (Capps, 1931, p. 4; Murray, 1945) and the work of Tarr and Martin (1914) and others on shelf glaciation farther to the east, suggest that a tremendous mass of ice extended far to the west along the Alaskan Peninsula and Aleutian Arc. This ice must have blocked to a large extent circulation of the surface water between the Bering Sea and the North Pacific. A similar though less extensive tongue of ice extended to the east from the Kamchatka Peninsula where the eastern shelf also has been glaciated (Antevs, 1928, p. 5; Flint, 1945, p. 355). Study of charts and photographs of the Komandorski Islands presented by Stejneger (1896) in a report on fur seal rookeries of these islands leaves little doubt that a similar condition has existed on the insular shelves around these islands.

Glaciers which covered the insular shelf transported the large volumes of rock eroded from the Near Islands to the shelf margin. To some extent this material was deposited on the insular slope, but large proportions of it undoubtedly were rafted into the adjacent oceans and deposited over wide areas by melting of the entraining ice. Tarr and Martin (1914, p. 203) suggest that the majority of debris borne to the front of tidal glaciers is distributed in this manner. Kerr (1936, p. 684) has shown from studies in Glacier Bay, Alaska, which was recently occupied by a large body of ice, that the bottom is kept scoured to bedrock so that deposits of drift which would be expected are those produced during wastage of the glacier ice.

Sharp (1946, p. 198-99) has speculated on the recency of glaciation and concludes, after a consideration of the erosion of sea cliffs and post-glacial stream gorges, that ice covered much of Agattu at the outset of the post-glacial "climatic optimus" approximately 7500 years ago but was gone completely by its maximum. Study of the shape and roundness of bottom pebbles, the unaltered submarine topographic features formed by glacial deposition southeast of Attu, and the Foraminifera fauna contained in sediment deposited in deep water when ice wastage was virtually complete (see below) suggest that extensive shelf ice was still present when sea level returned to essentially its present level. These interpretations seem also to be in agreement with Kerr (1936, p. 691) who feels that the intense alpine stage of glaciation persisted in British Columbia until 4500 to 9000 years ago. They also appear reasonable in light of the presently existing glaciers in the Gulf of Alaska where even the small ones formed at low elevations extend virtually to sea level (Tarr and Martin, 1914, p. 199).

It is probable that wastage of shelf ice, once initiated by climatic change, was accelerated by melting induced by the sea and by wave action and may have been very rapid. An extensive tidal glacier probably remained for some time southeast of Attu, however, to develop the large moraine which is present. Valley glaciers feeding to the sea from southeastern Attu could have been nourished by flow from approximately one-fifth of the island. This is the largest drainage basin in the islands and originates in the highest reaches. Such a combination of conditions could have been sufficient to prolong the life of the southeastern Attu tidal glacier and make its retreat relatively slow.

Post-Glacial Changes of Sea Level

Sea cliffs around the Near Islands generally are separated from the zone of present-day wave action by a raised beach or a rock bench so that they apparently were formed under conditions of a relatively high sea level which has ceased to exist. The vertical displacement above intensive present-day wave action is between 10 and 30 feet. Approximately this same elevation separates many sea cliffs in the Aleutian Islands from the zone of modern wave action. Study of photographs of the shore features of the Komandorski Islands in Stejneger's (1896) report indicates approximately the same displacement of sea cliffs above the zone of active wave abrasion also exists in that region. This apparently higher level of the sea has been tentatively correlated by many geologists with a eustatic rise in sea level presumed to have occurred at the time of the post-glacial climatic optimum. This climatic optimum is said to have begun 6000 to 7500 years ago (Kerr, 1936, p. 694; Sharp, 1946, p. 198) and to have ended not later than 2500 years ago (Kerr, 1936, p. 694). From the amount of erosion which has occurred since the sea cliffs have ceased to be out this correlation does not appear unreasonable.

Such a correlation is circumstantial, however, and is fraught with danger. Daly (1934, p. 163-164) recognized this and pointed out that the apparent lowering of sea level since a post-glacial higher stand also could be explained by a readjustment of the sub-oceanic crust of the earth to the shifting of water load from land to sea associated with deglaciation. Evidence from wave-cut benches at elevations above present attack only tells us that a relative change of level has occurred since the bench was cut.

In the Aleutian Islands the weight of a great volume of ice recently has been removed with an accompanying relaxation of crustal stresses. The removal of concentrated load may be presumed to have an effect on the relative elevation of the land. In addition, changes in relative elevation may be occurring due to tectonic activity. The effects of these changes of elevation of the land are superimposed on those due to sea level changes.

Twenhofel (1952) has recently presented evidence from detailed study to show that relative changes of level varying from 50 to 500 feet have occurred along the Alaskan coast since the period of maximum glaciation. The maximum figure agrees well with Kerr's figure of 600 feet maximum change in relative elevation on the same coast (1936, p. 694). As a result of his study Twenhofel states (1952,

p. 523):

> "Present evidence is insufficient to conclude whether the shoreline uplift of the land relative to the sea was caused principally by postglacial rebound of the earth's crust as a result of deglaciation or principally by orogenic movement. A general lowering of sea level also may be involved."

Marner in another recent paper (Marner, 1952) has given evidence from long period tidal observations which seems to suggest, however, that sea level is generally rising relative to the land along the East, Gulf, and Pacific coasts of the United States. Less detailed information suggests a relative fall of sea level in southeastern Alaska which would seem to correlate with known tectonic activity or deglaciation of the Alaskan region.

In summary, a relative change of level between the sea and the land is indicated on the Aleutian Ridge. The data are insufficient to indicate the cause, however. It may be due to 1) actual lowering of sea level because of climatic changes in the past 2000 to 3000 years, 2) tectonic uplift of the ridge, 3) rebound and uplift of the ridge following deglaciation, 4) readjustment of the crust of the earth beneath the sea floor due to increased weight of water in the ocean basins following deglaciation, or 5) to any combination of these and perhaps other causes.

DISTRIBUTION OF BED ROCK AND BOULDERS

A large portion (63.0%) of the insular shelf of the Near Islands is shown on the chart of bottom characteristics (fig. 4, in pocket) as bed (ledge) rock or large boulders. In the field this bottom type was assigned at stations when repeated lowerings of the snapper failed to recover any sample or when the sample which was recovered in several lowerings was made up of a few small grains of rock which could be best explained as scattered fragments lying on a rock bottom. It is possible that a pavement of cobbles and gravel would fail to yield a sample. U. S. Coast and Geodetic Survey chart notations of "rock", "rocky", "foul", "stony", or "boulders" or where symbols for kelp are present were all considered to indicate bottoms classified as rock. Either highly irregular topography or angular but relatively smooth topography associated with these notations was used as additional evidence. In some instances isolated pinnacles which extend to considerable elevations above the adjacent floor were considered to be rock or boulders, even though surrounded by other bottom types.

Bed rock or boulder bottom is found surrounding all of the islands to depths which average more than 50 fathoms. The island-girdling belts of rock bottom extend entirely across the shelf and to an unknown depth below the break in slope along much of the northern margin of the insular area. The broad belt of rock is also found across the shelf and below the break in slope east and southeast of the Semichi Islands and east of Agattu. Exceptions to this generalized distribution within the 50 fathom curve are found at the heads and along the axes of the deep bays off the mouths of the rivers or along the extension of such an axis and in the region of hummocky topography which lies southeast of Attu. Table I gives the distribution of rock bottom as a percentage of the area contained within successive 25 fathom depth increments. The general association of rock or large boulders with the flat floored bottoms and sloping sides of the wide submarine valleys and with much of the great lobate mound lying southeast of Attu is of interest.

Table I

Depth Distribution of Bottom Types

Depth Increment (in fathoms)	Area Within Depth Increment 1/	Per Cent of Total Area	Per Cent of Area Rock	Per Cent of Area Cobbles and Gravel	Per Cent of Area Rock Sand 2/	Per Cent of Area Diatomaceous sand	Per Cent of Area Glacial-Marine
0-25	260	12.4	72.7	8.9	18.0	0.0	0.0
25-50	577	27.4	74.4	17.9	8.2	0.0	0.0
50-75	968	46.1	62.8	20.9	2.2	7.1	6.4
75-100	225	10.5	36.9	2.7	0.6	27.4	32.4
below 100	75	3.5	15.7	1.4	0.0	0.0	83.0

1/ In square nautical miles.

2/ Including shell fragments.

DESCRIPTION OF COARSE MARINE SEDIMENTS

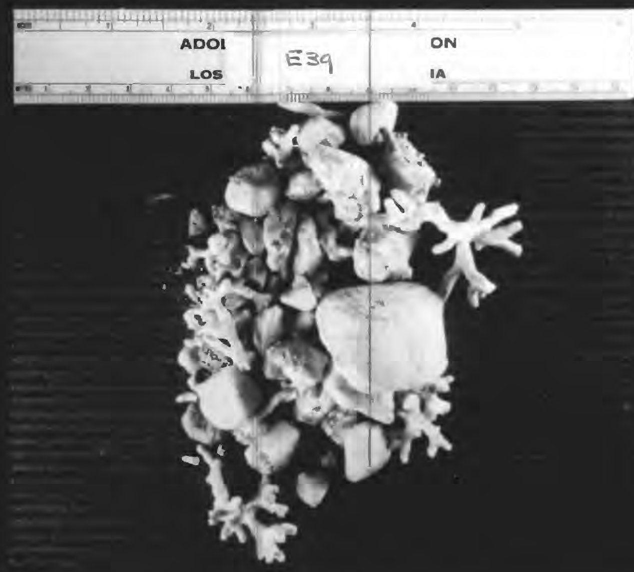
Size Range

Coarse marine sediments of the Near Islands are cobbles and gravel (Plates III, IV); those collected varied in size from a cobble with maximum dimensions of 11.7 x 10.5 x 6.2 cm. to gravels with a maximum diameter of about 0.5 cm. Samples of this material were characteristically well sorted within these dimensions; finer material of sand or silt size was almost never present. The maximum size of collected cobbles is close to the maximum size which could be collected with the sampling gear, so that the failure to recover larger objects does not necessarily indicate their absence. The maximum size of cobble which can be collected with the sampling equipment in effect determines the minimum size of the boulders of the rock bottom classification. However, repeated sampling attempts insure that fragments of this size or larger must floor the bottom where the term rock was applied.

Distribution

The areal distribution of cobbles and gravel is shown on figure 4, and the depth distribution is given in Table I. The largest zone of cobbles and gravel occurs south and southeast of Attu extending in to a small area inshore. The inner portions of this zone are marked by the extremely irregular topography characterized by abundant relatively small hillocks and basin depressions associated with the topographic lobe southeast of Attu. To the south the lobate topographic

Plate IV. Cobbles and Gravel.



E 39. Note incrusting algae and branching bryozoa.

E 64

Plate III. Cobbles and Gravel.

E 38

E 43

mass is flanked by areas of cobbles and gravel which do not exhibit the irregular topography to a marked degree. On the east the topography also is relatively subdued. Beyond the limits of the irregular lobe in this direction several small, isolated hillocks and depressions are found; in general, however, there is no marked topographic form associated with the deeper areas of cobbles and gravel.

South of the central portion of Attu off the mouths of the deep bays isolated areas of cobbles and gravel are found. No marked irregularities of topography are associated with these deposits, although a number of low, rocky or bouldery eminences are present nearby. Several small patches of cobbles and gravel are present southeast of Agattu. No marked topographic features are associated with the deposits, but here also low isolated hillocks are present in the general area.

Table I shows the slight concentration of the area of cobbles and gravel in the 25-75 fathom depth increment relative to the percentage of area between these depths. Cobbles and gravel are most abundant in the 50-75 fathom increment where 60.1 per cent of the total area of cobbles and gravel occurs. None of the cobble and gravel areas between 50 and 75 fathoms is associated with major topographic features aside from low isolated sounds and small basin-like depressions.

Petrography

Rock types represented by the cobbles and gravel are of great variety. The rocks of the islands, of which the bottom samples are representative, were originally igneous of intermediate to basis character or sedimentary of the graywacke suite and generally fine grained to aphanitic in texture. These rocks are hornblende andesite and related intrusive rocks, basaltic hornblende-augite andesites, gabbro and associated intrusives, basaltic lavas, siliceous sodic andesite to latite lavas, siliceous siltstone and fine grained sandstone, some carbonate and chert, and fine to medium grained tuffs (H. A. Powers, personal communication). Conglomerates containing these petrographic types also exist on the islands but no samples of the conglomerate were collected from the shelf. The rocks have been subjected to low grade metamorphism involving rather extensive albitization and silicification. No high or medium grade metamorphism has been found in rocks of the islands. Despite the original differences in composition which were present, metamorphism has resulted in the formation of a number of rock types which are quite homogeneous in hardness and resistance to mechanical erosion.

Incrustations

Many of the cobbles and gravels are heavily incrusted with calcareous and other organisms, particularly those pebbles from shallow water in somewhat protected areas, some of which are well rounded. Bryozoa and calcareous algae are most abundant as incrustations, but sponges, mussels, small solitary corals, gastropods, calcareous worm tubes, and Foraminifera also are common. Many of these incrustations are quite delicate, those formed by the bryozoans often consisting of lengthy, branching, calcareous projections (see Plate

IV, fig. 1). The incrustations are found normally on only one side of pebbles collected from water deeper than 50 fathoms; however, some of the pebbles from shallow water, usually less than 25 fathoms, are almost entirely enveloped by calcareous material.

Shape and Roundness

Shape and roundness of a large number of the cobbles and gravels collected from the bottom have been measured. The determination of shape was made on pebbles from 5 to 50 mm. in maximum diameter by measuring the lengths of the three mutually perpendicular axes of the pebbles, labeled a, b, and c where $a > b > c$ and plotting the ratio of b/a against c/b. This measurement of shape has been used by Krumbein (1941) and correlated by him with Zingg's (1935) shape classification. In this classification pebbles with values of $b/a < 2/3$ and $c/b < 2/3$ are termed "bladed", those with $b/a > 2/3$ and $c/b < 2/3$ are "diace", those with $b/a < 2/3$, $c/b > 2/3$ are "cylinders", and those with values of b/a and $c/b > 2/3$ are "spheres" (see fig. 5D). Roundness on the same pebbles was determined by visual comparison with a scale ranging from 0.1 to 0.9 also published by Krumbein (1941).

Shape and roundness of pebbles of similar size collected from different beaches and fluvio-glacial deposits on Attu also were measured in order to provide comparison with the shelf pebbles. Figure 5A, B, and C shows the results of these measurements. Figure 5D gives the averages of the shelf pebbles, beach pebbles, and fluvio-glacial pebbles with different degrees of roundness and the average of all Near Islands pebbles with roundness of 0.5 or less.

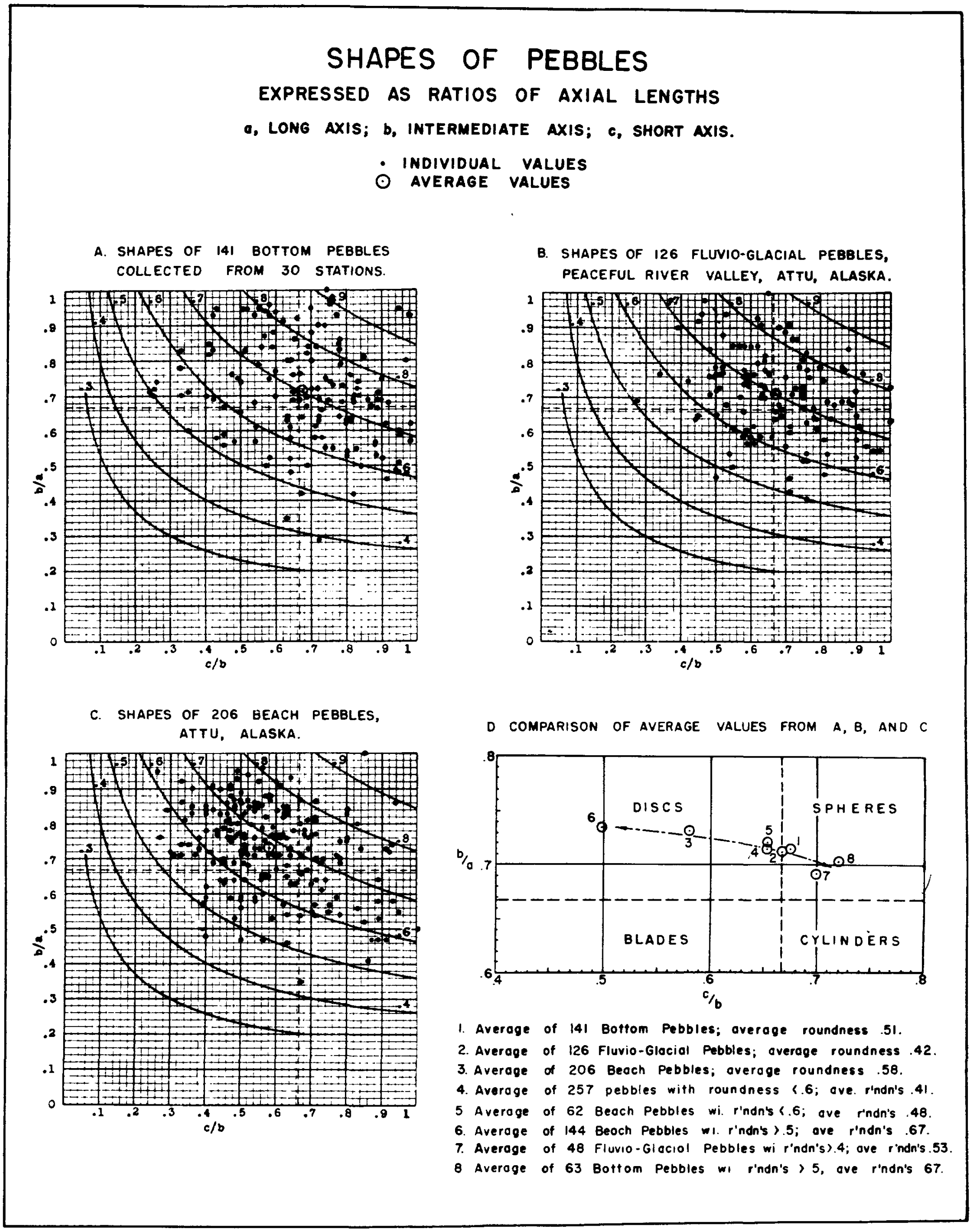
Discussion of Shape and Roundness

The shape and roundness of pebbles from beach and fluvio-glacial deposits in the Near Islands have been studied in an attempt to gain insight into the abrasion history of the shelf pebbles. Scatter diagrams of shapes of pebbles, together with average values appear in figure 5. The average shape of relatively unworn pebbles also is indicated. The positions of the average values (fig. 5D) differ by amounts which appear to be significant, with the beach pebbles being considerably more discoid in shape than either the fluvio-glacial pebbles or the shelf pebbles.

This apparent significance has been investigated further by separating the beach, fluvio-glacial, and shelf pebble collections into fractions depending upon the degree of roundness. In order to do this, pebbles of roundness 0.6 and above were grouped together, as were those with roundness of 0.5 or less. This separation was arbitrarily chosen in order to note the relationship between shape and roundness of pebbles which have suffered different degrees of wear. Figure 5D gives the average shapes of all the well rounded pebbles from each environment determined in this manner. Several interesting relationships are apparent from a study of this graph.

1. The average shape of poorly rounded beach pebbles is very similar to the average shape of all the poorly rounded pebbles (and presumably with the average initial shape of detrital pebbles).
2. The shape of the average well rounded beach pebble is much more discoid than the shape of the average beach

FIGURE 5


SHAPES OF PEBBLES
EXPRESSED AS RATIOS OF AXIAL LENGTHS
a, LONG AXIS; b, INTERMEDIATE AXIS; c, SHORT AXIS.
• INDIVIDUAL VALUES
⊙ AVERAGE VALUES
A. SHAPES OF 141 BOTTOM PEBBLES COLLECTED FROM 30 STATIONS.
B. SHAPES OF 126 FLUVIO-GLACIAL PEBBLES, PEACEFUL RIVER VALLEY, ATTU, ALASKA.
C. SHAPES OF 206 BEACH PEBBLES, ATTU, ALASKA.
D COMPARISON OF AVERAGE VALUES FROM A, B, AND C
b/a
c/b
DISCS
SPHERES
BLADES
CYLINDERS
1. Average of 141 Bottom Pebbles; average roundness .51.
2. Average of 126 Fluvio-Glacial Pebbles; average roundness .42.
3. Average of 206 Beach Pebbles; average roundness .58.
4. Average of 257 pebbles with roundness <.6; ave. r'ndn's .41.
5 Average of 62 Beach Pebbles wi. r'ndn's <.6; ave r'ndn's .48.
6. Average of 144 Beach Pebbles wi. r'ndn's >.5; ave r'ndn's .67.
7. Average of 48 Fluvio-Glacial Pebbles wi r'ndn's>.4; ave r'ndn's .53.
8 Average of 63 Bottom Pebbles wi r'ndn's > 5, ave r'ndn's 67.

pebble or the average poorly rounded pebble.

3. The average shape of all well rounded fluvio-glacial pebbles or bottom pebbles is more spherical than is the average shape of all pebbles from either of these types of deposits. It also is more spherical in shape than the average of all poorly rounded pebbles.

4. The average, poorly rounded, fluvio-glacial or bottom pebble is more discoid than is the average of all the pebbles from either of these environments (not plotted).

5. The displacement of the average well rounded and worn pebbles from any of the deposits from the shape of the average poorly rounded, little worn pebble is, in all cases, principally a horizontal displacement on the graph involving the ratio of the ahort to the intermediate axes. The displacement of the beach pebbles is toward smaller values of c/b from the position of the average unworn pebble, whereas the fluvio-glacial and bottom pebbles are displaced toward larger values of this ratio. It should be noted specifically in connection with this point that values of sphericity (interpolated from the curves of fig. 5A, B, and C) are often not adapted to show this change. Two pebbles, one a disc and the other a cylinder, can have the same sphericity value, so that this measure of shape alone is not sufficient, nor perhaps even significant.

The question of the effect of beach wear on pebbles is one which often has been discussed by geologists. Wentworth (1922b) studied pebbles on two New England beaches and concluded, after comparing the roundness and sphericity, that beach wear produces a pebble which is more spherical than originally. His study does not include an investigation of the original shape of the pebbles nor of the effect of sorting on pebble shape in the deposit. Landon (1930) studied the effect of beach transportation and wear on pebbles on the western shore of Lake Michigan. His work involved, not only a study of original shapes and the change in shape in the direction of transport, but also laboratory experiments to test the effect of sorting on discs and more spherical pebbles. He concluded that pebbles being worn on the beach are first made more spherical but, with still longer wear, become more discoid (flatter), and that the more spherical pebbles are carried more quickly to deeper water. Grogan (1945, p. 9) reached somewhat the same conclusions on the effect of abrasion on shape after studying some Lake Superior beach pebbles.

These three studies of beach pebbles, together with the present study, have one point in common. They are all based on a statistical analysis of what is present on the beach <u>at the time of sampling</u> and report, correctly, that beach pebbles tend to be discoid in shape. The experiments of Landon, however, should serve to emphasize the danger of drawing definite conclusions regarding the effect of beach wear on shape based on a study of indigenous populations. His demonstration of the tendency for spherical pebbles to move out of the beach zone and discoid ones to remain can be corroborated on any beach by throwing a handful of pebbles of various shapes into the zone of wave action and observing the effects. The passage of two or three waves is sufficient to remove the pebbles which roll easily, whereas the discoid pebbles tend to remain behind.

Statistical studies of what is present at a particular time ignore the effect of source in determining the measured shape, because they do not consider the number of pebbles involved in producing the observed distribution, nor the characteristics of this original material. Any large number of pebbles contains some which are more or less discoid. If these are passed through the beach zone, and the discoid pebbles are the only ones which remain, the average shape will be that of a disc. This does not mean that the discs were produced from all the available shapes by wear on the beach, however. A familiar example in point is the effect of wave action on a recently collapsed segment of a sea cliff. All possible shapes are produced by the mechanical disintegration of the original rock body. Continued wave and current action reduces the rubble pile at the cliff base until finally there remains only discoid fragments or blocks too large to move. These particles increase in roundness with continued wear. Agitation on the beach, however, has not made discs of all available particles but has removed all those which were not in equilibrium with the existing conditions. Some fundamental difference should exist between beach and stream wear for discs to be produced on one and spheres or cylinders to be produced in the other (see Wentworth, 1922, 1922a). This fundamental difference is not apparent.

This is not to say, however, that the shape of objects which can stay in the beach zone is unmodified by beach processes. Sliding action of pebbles over a sand bottom or the rush of smaller sized particles striking a larger one in the smash of a returning wave are capable of producing some flattening of the larger pebbles. This effect would be of primary importance to those pebbles which could exist in the beach zone for the longest time, an ability which appears to be a function of their discoidality. It is little wonder that the most rounded pebbles in the beach zone are normally the flattest.

These observations suggest that the shapes of abraded pebbles are principally a function of their original shapes and their cleavage tendencies, and that beach pebbles are discoidal in shape primarily because of the effect of sorting and secondarily because of beach wear. This suggestion can be proved only when homogeneous objects of known initial shape have been subjected to beach wear over a period of time and the effects of this wear measured.

Inability to arrive at definite conclusions as to the effect of beach wear on pebble shape does not prevent use of the shape and roundness data to evaluate the abrasion history of the Near Island shelf pebbles. A correlation between a high degree of roundness and discoidality (low values of c/b) and a low degree of roundness and lower discoidality (higher values of c/b) has been demonstrated for the Near Islands beach pebbles. An opposite relationship (high degree of roundness with high values of c/b and low degree of roundness with lower values of c/b) exists between roundness and shape in the bottom pebbles. These relationships and the foregoing analysis show that the bottom pebbles could not have been subjected to beach wear for any period of time. On the other hand, the bottom pebbles show close affinities with the fluvio-glacial pebbles in the relationships between roundness and the ratio c/b.

The presence of abundant incrustations produced by marine organisms also must be evaluated. The occurrance of these forms on only one side of pebbles found at considerable depths indicates that the pebbles at depth, many of which are well rounded, are not being agitated at present. At shallower depths some of the rounded pebbles have incrustations, often long and branching, on only one side, whereas others are almost enveloped by a calcareous layer. This evidence suggests that the pebbles at shallow depths may or may not be agitated, depending on local circumstances; nevertheless, the agitation appears to be too gentle and/or sporadic to produce the roundness observed. These considerations indicate that the bottom pebbles have not been abraded to any appreciable degree by marine agents. The development of the high degree of rounding which is observed on many of the bottom pebbles must have been produced in an earlier cycle by agents similar to those which produced the fluvio-glacial pebbles.

Summary on Coarse Marine Sediments

Topographic evidence, both subaerial and submarine, and lithologic evidence from the deposits themselves indicate the cobbles and gravel of the shelf must have been emplaced by glaciers which flowed out from the island centers and coalesced on the shelf. In the area south and east of eastern Attu a large moraine is indicated. Around the periphery of this moraine, and in other areas where the cobbles and gravels are associated with no striking topographic feature, ground moraine or possibly fluvio-glacial deposits occur. These deposits seem to be thin as suggested by the lack of any distinctive topographic expression. Where fine material originally was present in the deposit it has been removed by winnowing action of currents, leaving a lag concentrate of coarse material on the surface. It appears that marine processes have not been able to alter the topographic expression of the deposits, and neither have they rounded the pebbles by abrasion. This is a situation similar to that existing in the deposits off the northeastern coast of the United States described by Shepard, et al (1934), Shepard (1948), Stetson and Schalk (1935), and Stetson (1938, 1939), and in the North Sea by Lüders (1939). Continental glaciers invaded parts of these areas now covered by the sea and left deposits of glacial moraine and outwash which have maintained their topographic form despite action by the sea.

Deposits of cobbles and gravel are considered to be marine sediments because they have been modified by marine agents and occur in a marine environment. Original emplacement of such sediments by glaciers or agents associated with glaciers means that the bulk of the deposit in a thick section would exhibit the characteristics of glacial drift. However, winnowing of fine sediments from the surface layers and addition of the remains of marine organisms to the winnowed layer produces a deposit with the characteristics of a basal conglomerate to younger sediments overlying the glacial drift. Such a conglomerate, if exposed in the geologic column, might be interpreted to indicate sinking of the land and a resulting marine invasion.

DESCRIPTION OF FINE GRAINED MARINE SEDIMENTS

General Statement

Marine sediments of the Near Islands shelf offer an opportunity to study the relationship between the environment and the sediment components and distributions which are produced. Terrigenous components of the sediments have as their only important source the nearby island masses of known characteristics. This single source removes the possibility of mixing of terrigenous sediments from a variety of environments such as are found near mouths of many large rivers. Similarly, biological components of marine origin are produced under conditions which do not appear to vary widely from year to year, although these conditions are not entirely of local origin.

Within fine grained marine sediments are included deposits which are considerably finer in average particle size than the cobbles and gravel discussed above. Marine deposits constitute, so far as is known, a relatively thin blanket of material which is generally discontinuous in areal distribution. The components are partly terrigenous and partly marine in origin. Terrigenous constituents are the result of rock destruction, and the marine components are skeletons of various types of marine invertebrate organisms.

A classification tetrahedron as discussed by Pettijohn (1949, p. 187-191) may be used as a framework for a primary classification of the components of the fine grained marine sediments. This device makes use of the end member concept in which different sediments are considered as being composed of varying percentages of the same four end members. The composition of a sediment sample which contains all four end members plots as a point in space within the tetrahedron; the position depends on the relative proportions of each end member. More common are sediments which contain no more than three of the possible primary components. The composition of such a sample is represented on one of the four equilateral triangles composing the faces of the tetrahedron and appears as a point on a conventional triangular diagram. Tetrahedrons and triangular diagrams of this type are shown in figures 6 and 7. The four end members into which the insular shelf and uppermost slope sediments have been divided are: 1) terrigenous sand consisting principally of rock fragments, 2) shell fragments, mostly of larger organisms, chiefly echinoids and pelecypods, 3) smaller organic remains consisting of the tests of diatoms and Foraminifera and the spicules of sponges, and 4) pebbles and granules which are found intimately intermixed with (1) and (3) in some areas.

Components of Fine Grained Marine Sediments

Rock Fragment Sand.

Detritus of this type is found in varying proportions in all marine sediments of the Near Islands shelf. It constitutes the major portion of deposits occurring close to shore and is abundant in all sedimentary types. The chief distinguishing feature of this material is its composition. Fresh to somewhat weathered fragments of the diversified fine-grained to aphanitic rocks of the islands are the dominant constituents. This material constitutes almost 100 per cent of the sand-sized fractions larger than 0.25 mm. in diameter. Small amounts of plagioclase feldspar and chert fragments also occur in the coarser sand. Monomineralic grains are more abundant in sizes smaller than 0.25 mm. This trend continues with decreasing grain size, so that the size fraction between 0.088 and 0.062 mm. in diameter has plagioclase feldspar the most abundant constituent followed in order by rock fragments,chert, augite, black opaque minerals (principally magnetite), and hypersthene. Other minerals are comparatively rare and are found only in the smallest size fractions.

Rock fragment sand ranges from 2 mm. in maximum diameter to coarse silt, approximately 0.04 mm. in diameter, and is angular to sub-angular, generally exhibiting little effect of wear.

Rock fragment sand may be derived from present-day erosion of the islands by streams or waves, from older glacial deposits, either subaerial or submarine, or stream deposits by reworking. It also may come from erosion of the bottom by waves and currents.

Shell Fragments.

Broken and comminute fragments of the shells of various invertebrate marine organisms which live on the Near Islands shelf constitute a significant proportion of the marine sediments in certain areas. This material generally is of coarse sand size or somewhat larger, and in some places may consist in part of unbroken shells, although such occurrences are not common. The areas of shell fragment occurrence coincide with the inshore regions of rock fragment sand where the shell fragments occur as a dilutent. Shell fragments normally constitute a small proportion of such deposits and only in isolated instances constitute a relatively pure sediment. Shells are included with rock fragment sand where rock sand alone is indicated on the chart of sediment types and no attempt is made to designate specifically shell fragment distribution (see fig. 4).

The shells of a number of megascopic organisms such as pelecypods, echinoids, gastropods, calcareous worms, and bryozoans contribute to the deposits. Of these, however, the common edible mussel, Nytilus edulis Linnaeus (W. R. Coe, personal communication) and the small spiny echinoid, Strongylocentrotus purpuratus (Stimpson)[1/] are generally the most abundant. Mytilus edulia is extremely tolerant to temperature, being able to survive for protracted periods in water ranging in temperature from 0° to 32°C and for a limited time in water as cold as -1°C. This organism has a wide geographic range, occurring from Patagonia to Peru in the Southern Pacific, Mexico to the Arctic Ocean and Japan in the Northern Pacific, and in the Atlantic from New Jersey to the Arctic Ocean and south to Madeira. Strongylocentrotus purpuratus also is a tolerant form, living strictly in the littoral zone of outer coasts from Alaska to Cedros Island off the coast of Baja California (Mortensen, 1943, Vol. III, Pt. 3, pp. 236-47; Pratt, 1935, p. 723; Ricketts and Calvin, 1948, p. 130).

1/ There is some uncertainty as to the specific identification of this echinoid; specimens collected for identification were crushed during transport. The identification is based chiefly on the universal purple color of the living specimens. The alternative is Strongylocentrotus dropachiensis (Miller) which is a common circumpolar Arctic form with a bathymetric range from the littoral zone to considerable depths (Hortensen, Th., 1943, Vol. III, Pt. 3, pp. 198-215).

Diatoms, Foraminifera, Sponge Spicules.

These components of the marine sediments are found in all of the deposits studied. Small amounts occur in the inshore deposits which consist chiefly of rock fragment sand, but the principal occurrence is in the offshore sediments. Both the shelf basin and the outer shelf and upper slope sediments along the southern margin of the area contain relatively high percentages of these micro-organisms. Where relatively pure, the material occurs as a fine grained, slightly yellowish green (when dry) massof diatoms and Foraminifera laced through and held together in a coherent mat by a framework of siliceous sponge spicules. Dilution by other components destroys the tendency of the material to cohere, but the greenish color persists because the color of the common dilutents is also greenish.

Diatoms. Diatoms from one bottom sample were identified by K. E. Lohman of the U. S. Geological Survey. This sample (E 198) yielded the following assemblage of diatom species.

(R = rare; F = frequent; C = common; A = abundant)

Actinoptychus senarius Ehrenberg	R
sp.	R
Arachnoidisons camaruensis (Schmidt) Brown	F
sp.	F
Asteromphalus brookei Bailey	F
Aulaeodiscus sp.	R
Biddulphia aurita (Lyngbye) Brebisson and Godey	C
sp.	R

Cocconsis cf. C. antiqua Tempera and Brun	R
Baldjikiana Grunow	F
sp. aff. C. baldjikiana Grunow	R
costata Gregory	F
decipiens Cleve	F
fulgar Brun	F
cf. C. grata Schmidt	R
hetoroidea var. curvirotunda Tempara and Brun	R
inflexa Schmidt	F
pellucida Grunow	F
placentula Ehrenberg	R
sp. aff. C. sigma Pantocsek	F
sp.	F
Coscinodiscus crenulatus var. nodulifer Lohman	R
curvatulus Grunow	F
curvatulus var. minor (Ehrenberg) Grunow	F
excentricus Ehrenberg	C
lineatus Ehrenberg	C
cf. C. marginatus Ehrenberg	F
oculus-iridis Ehrenberg	A
oculus-iridis var. borsalis (Bailey) Cleve	F
radiatus Ehrenberg	F
subconcavus Grunow	R
sp.	F
Centicula lauta Bailey	A
Diploneis cf. D. smithii (Brebisson) Cleve	R

Endictya robusta (Greville) Hanna and Grant	F
Intoplya sp.	R
Comphenema exigun Kntsing	R
Hyaloiiscus sp.	F
Isthmia sp.	R
Liradiscus sp.	R
Malosira clavigera Grunow	R
sp.	R
Mastoglia sp.	R
Navicula pennata Schmidt	F
sp.	R
Podosira hormoides var. adriatiea Grunow	R
Ahabdonena cf. R. arcuatum (Lynghye, Agardh) Kutsing	R
cf. R. arcuatum var. robustum (Grunow) Hustedt	R
aroziari (Ehrenberg) Fricke	R
Rhizosclenia sp.	F
Stephanopyxis turris (Greville and Arnott) Ralf's	R
turris var. intermedia Grunow	R
Synedra kamtschatica Grunow	R
Thalassiosira sp.	F
Thalassiothrix longissima Cleve and Grunow	A
Trachyneis aspera (Ehrenberg) Cleve	R
Triceratium articum Brightwell	R
cf. T. formosum Brun	R
Xanthiopyxis ovalis Lohman	F

In his covering report, Lohman makes the following statements concerning the age of this flora.

"A large proportion of the diatoms in the assemblage are extinct and occur in beds in the vicinity of Sendai, Japan which were originally called Pliocene in age by Tempere and Brun in 1889. A study of the assemblage obtained by Tempere and Brun from Sendai indicates, on the basis of the diatoms themselves, that many of their species are confined to rocks of middle and upper Miocene age in California and Hungary. It is entirely possible that the Sendai beds may contain both Miocene and Pliocene rocks. The Japanese refer to them merely as "Tertiary" and "Neogene".

"With the exception of Arachnoidiscus oamaruensis, which is known only from lower middle Miocene rocks in Java and Oligocene rocks in New Zealand, the other extinct species in the present assemblage also occur in the lower Pliocene Sisquoc formation in the Purisima and Casmalia Hills, Santa Barbara County, California. Although I have studied the diatoma throughout a stratigraphic thickness of 2600 feet in the Sisquoc formation, Arachnoidiscus oamaruensis has never been found there. Furthermore, the Sisquoc formation contains many species which Tempere and Brun described from the Sendai beds, but does not contain those Sendai species which are known only from Miocene rocks elsewhere. The Monterey formation of Miocene age underlying the Sisquoc formation in the same region does contain those other species of Tempere and Brun which have caused several workers, including myself, to believe that the Sendai beds include rocks of both lower Pliocene and upper to middle Miocene ages."

"The sample submitted, although a dredging taken from the 'surface material on sea bottom' appears to be a rock outcrop and not recent sediment. If it is recent sediment, it has almost surely been reworked from a rock outcrop nearby. The large number of extinct species precludes a Recent deposit of living species. The state of preservation of the individuals, many of which are broken, is further evidence of compaction following sedimentation."

"Hence, the best age assignment that can be made is lower Pliocene to Miocene, with most of the evidence favoring lower Pliocene."

An age of Miocene or lower Pliocene for these deposits is incompatible with the other data available, nor does it necessarily seem warranted on the basis of the diatoms. Evidence from other lines points overwhelmingly to a post-glacial age for the sediments. The geologic evidence for this statement has been discussed under Cobbles and Gravel and will be considered further below. Samples of the sediment, when placed in water, disaggregate quickly and completely from the dried state showing that no lithification has occurred. Foraminifera evidence does not suggest any age for these deposits greater than post-glacial. The sparse literature on the modern assemblage of diatoms in the general area of the Near Islands was consulted (Mann, 1907; Erlandsson, 1930; Gran and Thompson, 1930; Aikawa, 1936; Phifer, 1937; and Cupp, 1943; also Hustedt, 1930 and 1931), and it has been found that only 2 of the 28 genera and 10 of the species reported by Lohman have not been reported previously from either the plankton or the bottom deposits of the general region. The unreported genera are *Endictya* and *Liradiscus* and the species which have not been reported heretofore are:

Actinoptychus senarius	R
Arachnoidiscus oamaruensis	F
Cocooneis fulgur	F
C. heteroidea var. *curvirotunda*	R
C. inflexa	R
Coscinodiscus subconeavus	R
Denticula lauta	A
Endictya robusta	F
Priceratium arctisum	R
Xanthiopyxis ovalis	F

Of these species, Arachnoidiscus oamaruensis, Denticular lauta, Coscinodiscus subconcavus, and Xanthiopyxis ovalia apparently have not been reported as living (Cleve and Grunow, 1880; Cleve, 1894; Boyer, 1927; Mills, 1934).

The possibility that certain of the elements of the flora may have been introduced by reworking of older rocks cannot be disposed of with certainty. The character of the rocks found in the Near Islands, however, is not such as to promote removal of organisms intact by natural means. In Lohman's report on fossils referred to him by H. A. Powers (Report dated Feb. 14, 1951 on Diatom Shipment No. GG-50-24) several representative notations furnish a basis for this suggestion. In this report Lohman states (p. 3):

> "(3416) 49-P-28d contained the diatom Triceratium sp. This sample was found to be highly siliceous and required such drastic methods of disintegration that no recovery of diatoms was possible."

On page 4 in discussing sample 49-P-28y (3417) the following statements were made:

> "All of the diatoms in this sample occurred as fragments and all have been altered. It appears that the original clear, isotropic, hydrous silica of which the diatoms are composed has been leached out and the cavity filled with a finely granular anisotropic substance. This material is not calcite (as it resists boiling in hydrochloric acid) and may possibly be quartz."

It does not seem likely that delicate organisms, extracted with such difficulty in the laboratory, would be possible to identify with any certainty if extracted by natural agents of erosion. The existence of a local outcrop of easily eroded Miocene or Pliocene rocks bearing these organisms is not a probability, as, so far as is known, all rocks of the islands which might be expected to yield fossils of this age have been albitized and silicified (H. A. Powers letter of 29 August, 1952).

In discussing the state of knowledge concerning the diatom flora of the Aleutian Islands, Phifer (1937, p. 11) states:

> "The sketchiness of this general picture shows the necessity for regular sampling throughout a whole year or longer, if a thorough going study is to be made."

This statement seems to point to the heart of the difficulty. The lack of detailed sampling in this remote area does not permit a definite statement at this time on the diatom flora.

Regardless of the geologic age of the organisms in question, the species of the flora about which no doubt exists permits a generalization on the ecological characteristics exhibited. These organisms represent a mixture of Arctic and lower latitude neritic and oceanic forms. Phifer (1937) classified the flora from the eastern Bering Sea into three temperature groupings: Arctic, Boreal, and Temperate. Most of his species were what he called "boreal". General similarity of geographic position and environmental conditions between the two areas suggests that the Near Islands diatom flora also be termed boreal in character to indicate the mixture of Arctic and lower latitude forms, although the floras of the two regions do not seem to be entirely the same.

Foraminifera. The species of Foraminifera which were found to constitute a significant proportion of the fauna are discussed below. Faunal studies were made on 80 samples collected either with the snapper sampler or the light coring tube. Small cuts of the snapper samples or obtained from the upper 1 cm. of the short cores were analyzed for frequency of occurrence by making counts of the dead fauna. Discussion of the species is concerned both with their geographic range as compiled from the literature and with their vertical (depth) distribution as found in the Near Islands.

The planktonic fauna is a small one, consisting entirely of two species which occur in abundance in most samples. The most common species is *Globigerina pachyderma* (Ehrenberg), a typically Arctic and Subarctic form. *Globigerina bulloides* d'Orbigny, the other species, is widespread in the Atlantic and Pacific oceans from temperate to high latitudes. The average ratio of the occurrence of *G. pachyderma* to *G. bulloides* is 5:2. Planktonic Foraminifera together with the diatoms are normally the most abundant of the organisms constituting the diatom, Foraminifera, sponge spicule component.

The planktonic fauna of the Near Islands is unlike that reported by Hanzawa (1928, pp. 61-63) from bottom deposits below the Kuroshiwo Current off Japan. Here the planktonic fauna included the following species:

Globigerina bulloides d'Orbigny
G. inflata d'Orbigny
G. subcretacea Chapman
Globigerinoides sacculifera (H. B. Brady)
G. conglobata (R. B. Brady)
Globigerinella aequilateralis (H. B. Brady)
Orbulina universa d'Orbigny

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Pulleniatina obliquiloculata Parker and Jones

Sphaeroidinella dehiscens Parker and Jones

(material from 53°21'N, 135°47'E)

The benthonic fauna consists of at least 35 species, a number of which are rare. The more common species are:

Angulogerina angulosa (Williamson)

Astrononion stellatum Cushman and Edwards

Bolivina decussata H. B. Brady

Cassidulina californica Cushman and Hughes

C. cf. C. islandica Nørvang var. minuta Nørvang

C. limbata Cushman and Hughes

C. subglobosa H. B. Brady

Cibicides lobatulus (Walker and Jacob)

Elphidium subarcticum Cushman

Eponides columbiensis (Cushman)

E. frigidus (Cushman)

Karreriella baccata (Schwager) var. alaskensis Cushman and Todd

Laticarinina tenuimargo altocamerata (Heron-Allen and Earland)

Nonion labradoricum (Dawson)

Pullenia salisburyi R. E. and K. C. Stewart

Quinqueloculina arctica Cushman

Uvigerina juncea Cushman and Todd.

Table II gives the distribution of the species at each station. Table III is a summary of the distribution chart and gives the average frequency of occurrence of the species within 25 fathom (45 meter)

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Table III

Average Frequency of Occurrence of Most Abundant Foraminifera Species

(Arranged into groups according to apparent depth significance)

Species	Depth Increments				
	0-25	25-50	50-75	75-100	Over 100 fm.
	0-45	45-90	90-135	135-180	Over 180 m.
Shallow Forms					
Astrononion stellatum	2-5.5	1-1.0	13-1.4	7-1.3	6-0.5
Eggerella advena	2-4.0	1-0.3	1-0.7	1-0.2	0-0.0
Elphidiella nitida	3-29.3	5-4.4	6-2.1	1-0.9	0-0.0
Elphidium alaskense	2-5.5	6-3.6	2-1.0	1-0.2	0-0.0
E. subarcticum	6-39.4	4-3.5	13-0.9	1-0.8	3-0.5
E. translucens	3-9.0	1-2.0	4-1.6	1-0.9	2-0.3
Eponides columbiensis	8-29.0	5-7.2	4-0.6	1-0.2	2-6.5
Labrospira jeffreysii	1-7.0	2-3.2	5-0.6	1-0.2	2-0.5
Polymorphinids	2-2.5	5-4.9	16-1.3	5-0.6	4-0.6
Quinqueloculina arctica	6-32.0	10-11.3	9-1.8	0-0.0	0-0.0
Q. cf. vulgaris	1-8.0	5-5.5	5-2.9	1-0.4	1-0.4
Q. sp.	2-5.0	2-1.5	1-0.5	0-0.0	0-0.0
Intermediate Forms					
Cassidulina californica	5.4	22.0	14.6	8.3	6.3
Cibicides lobatulus	6.6	15.4	15.6	6.8	1.9
Karreriella baccata var. alaskensis	0.0	2.6	2.8	1.9	1.9
Labrospira crassimargo	0-0	2-11.6	1-1.0	1-0.2	0-0
Laticarinina tenuimargo altocamerata	0-0	5-2.7	14-1.3	5-1.0	8-0.5
Nonion labradoricum	1-3.0	0-0	15-4.8	6-3.1	11-0.7
Planulina alaskensis	1-3.0	3-2.3	8-1.5	4-5.5	1-0.3
Pullenia salisburyi	0-0	3-2.9	20-2.2	8-0.9	10-0.8
Pyrgo spp.	0-0	4-1.2	4-0.8	1-0.4	0-0
Recurvoides spp.	0-0	0-0	2-0.9	3-0.4	0-0
Reophax cf. curtus	0-0	1-0.3	3-2.3	0-0	1-0.3
Deep Forms					
Angulogerina angulosa	0.1	2.3	7.9	6.5	7.5
Bolivina decussata	0.2	1.0	10.8	16.4	26.4
Carpenteria monticularis	0-0	0-0	1-15	2-0.6	7-2.2
Cassidulina cf. islandica var. minuta	0.6	0.3	9.5	13.1	17.8
C. limbata	0.0	0.9	4.1	6.0	8.7
C. subglobosa	0.0	24.5	20.7	21.0	20.5
Ehrenbergina cf. compressa	0-0	1-0.3	8-1.8	6-2.5	12-2.7
Eponides frigidus	1.9	1.6	4.1	5.0	3.8
E. sp.	0-0	0-0	11-1.1	3-1.1	3-0.6
Uvigerina juncea	0-0	1-0.3	13-1.7	5-1.3	10-1.3
Total number of stations, each depth increment	10	18	27	9	16

Page 64 - Table II

depth increments. In this table the species are listed which appear to have some depth significance. In computing the average values shown in table III two schemes have been used. If a species occurs in 2/3 or more of the samples all of the occurrences were averaged. These frequencies are noted in the table with a single number. When less than 2/3 of the samples contain the particular species, only the number of samples in which the species was found were averaged. These frequencies are noted by two numbers separated by a dash, the first indicating the number of stations used in obtaining the average and the second the computed average frequency. The total number of samples in each depth increment is given at the bottom of the table. This method of handling the occurrences makes possible the use of statistical concepts in treating species distribution within a given depth zone because it divides the population into classes which permits the application moment measures. For example, the standary deviation of the frequency curve of percentage occurrence of a species within a class limit could be computed to test the reliability of the species as an indicator of the class. Species with frequency curves giving a high standard deviation would be less suitable as class indicators than those with a narrow range of percentage occurrences. It is probable that measures such as those devized by Inman (1952) for expressing the results of grain size analysis can be devised for use in foraminiferal investigations of this kind.

The species are discussed below in alphabetical order.

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ANGULOGERINA ANGULOSA (Williamson)

Uvigerina angulosa Williamson, 1859, Rec. Foram. Great Britain, p. 67, Pl. 5, fig. 140.

Common around British Isles, Norwegian coast, off Iceland, Bay of Kola, California, Canadian Arctic, off the coast of Washington. Important constituent of Near Islands fauna. Increases in percentage occurrence with depth.

ASTRONONION STELLATUM Cushman and Edwards

Cushman and Edwards, 1937, Contrib. Cushman Lab. Foram. Res., Vol. 13, p. 32, Pl. 3, figs. 9-11.

Widely distributed in northern portion of North Atlantic from British Isles northward. Found in Canadian and Greenland Arctic in low frequency. Not found south of Cape Cod. Eastern Pacific from all depth zones off California and in shallow water off Washington coast. Found sporadically in Near Islands sediments. Highest frequencies in shallow water but occurs at all depths sampled.

BOLIVINA DECUSSATA H. B. Brady

Brady, H. B., 1881, Quart. Jour. Micr. Sci., Vol. 21, p. 58.

Brady, H. B., 1884, Rept. Voy. Challenger, Zoology, Vol. 9, p. 423, Pl. 53, figs. 12, 13.

Found originally off Juan Fernandez Is. in South Pacific. Also occurs in 140 fathoms (260 meters) and deeper off Japan. One of the most abundant species in Near Islands sediments, occurring in high frequency at depths.

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BOLIVINA sp.

Found in low frequency in three samples distributed through total depth range studied.

CARPENTERIA MONTICULARIS Carter

Carter, 1877, Ann. Mag. Nat. Hist., Ser. 4, Vol. 19, p. 211, Pl. 13, figs. 9-12.

Brady, H. B., 1884, Rept. Voy. Challenger, Zoology, Vol. 9, p. 677, Pl. 97, figs. 1-5.

Found off Australia, Zamboanga, P.I. at 102 fathoms (180 m.), Honolulu, Hawaii, 40 fathoms (73 m.), off Japan in 817 fathoms (1500 m.). Occurs only sporadically and generally in low frequency in Near Islands sediments, only deeper than 50 fathoms (90 m.).

CASSIDULINA CALIFORNICA Cushman and Hughes

Cushman and Hughes, 1925, Contrib. Cushman Lab. Foram. Res., Vol. 1, No. 5, p. 12, Pl. 2, fig. 1.

Occurs in low frequencies at depths to at least 550 fathoms (1000 m.) off California. Also found off Washington, British Columbia, and Japan. Found at all depths in Near Islands, highest frequencies at 25-75 fathoms (45-135 m.), but common both above and below this depth range.

CASSIDULINA cf. ISLANDICA Nørvang var. MINUTA Nørvang

Nørvang, 1945, Zoology Iceland, Vol. 2, Pt. 2, Foraminifera, p. 43, text figs. 8a-c.

This species reported from off Iceland, Portsmouth, N. H., Gulf

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of Maine. Common in parts of Canadian and Greenland Arctic. Off Near Islands found at all depths studied; increases in frequency with increasing depth. Common only below 50 fathoms (90 m.).

CASSIDULINA LIMBATA Cushman and Hughes

Cushman and Hughes, 1925, Contrib. Cushman Lab. Foram. Res., Vol. 1, No. 5, p. 12, fig. 2.

Found off coast of California in abundance to 300 meters and at all depths to at least 1000 meters. Common off coast of Washington. Common off Near Islands below 50 fathoms (90 m.), increases in frequency with depth, not found above 25 fathoms (45 m.).

CASSIDULINA SUBGLOBOSA H. B. Brady

Brady, H. B., 1884, Rept. Voy. Challenger, Zoology, vol. 9, p. 430, Pl. 54, fig. 17.

Found widely distributed in North Pacific from 130 to 2950 fathoms (240 to 5350 m.). Abundant in Near Islands sediments below 25 fathoms (45 m.), not found above this depth.

CIBICIDES LOBATULUS (Walker and Jacob)

<u>Nautilus lobatulus</u> Walker and Jacob, 1798, Adams Essays, Kanmacher's ed., p. 642, Pl. 14, fig. 36.

Common species in North Atlantic, North Pacific, and Bering Sea at depths from very shallow to 2100 fathoms (3700 m.). Occurs at all depths studied in Near Islands area. Most abundant from 25-75 fathoms (45-135 m.).

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EGGERELLA ADVENA (Cushman)

Verneuilina advena Cushman, 1921 (1922), Contrib. Canadian Biol., No. 9, p. 141.

This species occurs in Atlantic from Arctic to south of Cape Cod at depths of less than 50 fathoms (90 m.). Also frequently found off coast of Washington. Found only rarely in Near Islands sediments with highest frequencies at shallow depths.

EHRENBERGINA cf. COMPRESSA Cushman

Cushman, 1927, Calif. Univ. Scripps Inst. Oceanogr. Bull., Berkeley, Calif., Tech. Series, Vol. 1, p. 162, Pl. 6, fig. 7.

Found in North Pacific off Panama and off California to 440 fathoms (800 m.). In Near Islands sediments is rarely found above 50 fathoms (90 m.); mainly occurs below this depth in low frequencies.

ELPHIDIELLA NITIDA Cushman

Cushman, 1941, Contrib. Cushman Lab. Foram. Res., Vol. 17, Pt. 2, p. 35, Pl. 9, fig. 4.

Found along the west coast of North America from Alaska to California. Near Islands occurrences not common and only above 100 fathoms (180 m.). Most frequent at shallow depths.

ELPHIDIUM ALASKENSE Cushman and Todd

Cushman and Todd, 1947, Contrib. Cushman Lab. Foram. Res., Vol. 23, Pt. 3, p. 63, Pl. 15, figs. 18, 19.

Described from Pliocene (?) of Amchitka Is., Aleutians. Occurs

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uncommonly in Near Islands sediments, principally at shallower localities.

ELPHIDIUM SUBARCTICUM Cushman

Cushman, 1944, Spec. Publ. 12, Cushman Lab. Foram. Res., p. 27, Pl. 3, figs. 34, 35.

Widely distributed in North Atlantic and Arctic, in shallow water off Portsmouth, N. H., and at all depths on Atlantic continental shelf and upper continental slope. Found at all depths sampled in Near Islands, most frequent occurrence in shallow water.

ELPHIDIUM TRANSLUCENS Natland

Natland, 1938, Bull. Scripps Inst. of Oceanogr., Univ. of Calif., Berkeley, Tech. Series, Vol. 4, No. 5, p. 144, Pl. 5, figs. 3, 4.

Collected originally in normal marine water, 17.26°C, at shallow depths off southern California where it is common. Occurs principally in shallow water off Near Islands but found in low frequencies throughout depth range investigated.

EPONIDES COLUMBIENSIS (Cushman)

Pulvinulina columbiensis Cushman, 1925, Contrib. Cushman Lab. Foram. Res., Vol. 1, Pt. 2, p. 40, Pl. 7, fig. 1.

Species known only from coasts of British Columbia and Washington. Near Islands occurrences principally in water above 50 fathoms (90 m.), although specimens found throughout depth range sampled.

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EPONIDES FRIGIDUS (Cushman)

Pulvinulina frigida Cushman, 1921 (1922), Contrib. Canadian Biol., p. 12.

Present in shallow water off Portsmouth, N. H., in Long Island Sound, Hudson Bay, Iceland, Gaspe Bay, Atlantic continental shelf, also off coast of Washington and British Columbia. A common Bear Islands species found at all depths, highest frequencies at greater depths.

EPONIDES sp.

Uncommon species found only below 50 fathoms.

KARRERIELLA BACCATA (Schwager) var. ALASKENSIS Cushman and Todd

Cushman and Todd, 1947, Contrib. Cushman Lab. Foram. Res., Vol. 23, Pt. 3, p. 61, Pl. 14, figs. 10, 11.

Described from Pliocene (?) of Amchitka Is., Aleutians. Common off Bear Islands with all occurrences below 25 fathoms (45 m.) at low frequencies.

LABROSPIRA CRASSIMARGO (Norman)

Haplophragmium crassimargo Norman, 1892, Mus. Normanianum, Pt. 8, p. 17.

Common off Portsmouth, N. H. at shallow depths. Rare farther south. Common in Arctic and off coast of northern Europe. Occurs rarely between 25 and 100 fathoms (45-180 m.) in Bear Islands area.

LABROSPIRA JEFFREYSII (Williamson)

Nonionina jeffreysii Williamson, 1858, Rec. Foram. Great Britain,

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p. 34, Pl. 3, figs. 72, 73.

This species occurs widespread along Atlantic coast of U. S. north of Cape Cod. Also found in Arctic and Antarctic and off northern Europe. Occurs at all sampled depths in low frequency off Near Islands.

LATICARININA TERQUEMI ALTOCAMERATA (Heron-Allen and Earland)

Truncatulina tenuimargo var. altocamerata Heron-Allen and Earland, 1922, British Antarct. Exped., 1910, Nat. Hist. Rept. Zool., Vol. 6, p. 209, Pl. 7, figs. 24-27.

Occurs at all depths below 25 fathoms (45 m.) off Near Islands.

NONION LABRADORICUM (Dawson)

Nonionina labradorica Dawson, 1860, Canadian Nat., Vol. 5, p. 191, fig. 4.

A widespread species in western North Atlantic and Arctic. Most common in colder waters. Not found south of Cape Cod. Occurs commonly below 50 fathoms (90 m.) off Near Islands, rarely above this depth.

PLANULINA ALASKENSIS Cushman and Todd

Cushman and Todd, 1947, Contrib. Cushman Lab. Foram Res., Vol. 23, Pt. 3, p. 71, Pl. 16, figs. 25, 26.

Described from Pliocene (?) of Amchitka Is., Aleutians. Occurs uncommonly at all sampled depths off Near Islands.

POLYMORPHINIDS

A number of genera and species occur in very small amounts. Most abundant above 75 fathoms (135 m.) off Near Islands.

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PULLENIA SALISBURYI R. E. and K. C. Stewart

Stewart, R. E. and K. C., 1930, Jour. Paleo., Vol. 4, p. 72,
Pl. 8, figs. 2a, b.

Found off southern California to 440 fathoms (800 m.) depth. Off Near Islands present below 25 fathoms (45 m.), most common at intermediate depths.

PYRGO spp.

Occur rarely off Near Islands between 25 and 100 fathoms (45-180 m.).

QUINQUELOCULINA ARCTICA Cushman

Cushman, 1933, Smithsonian Misc. Coll., Vol. 89, No. 9, p. 2,
Pl. 1, figs. 3a-c.

Common Arctic species, also found off Portsmouth, N. H., occasional occurrence near Block Island. Off Near Islands common in shallow waters, not found below 75 fathoms (135 m.).

QUINQUELOCULINA cf. VENUSTA Karrer

Cushman and Todd, 1947, Contrib. Cushman Lab. Foram. Res., Vol.
23, Pt. 3, p. 61, Pl. 14, figs. 16, 17.

Uncommon species probably occurring at all depths off Near Islands.

QUINQUELOCULINA cf. VULGARIS d'Orbigny

Cushman and Todd, 1947, Contribs. Cushman Lab. Foram. Res.,
Vol. 23, Pt. 3, p. 62, Pl. 14, figs. 14, 15.

This species occurs off west coast of North America. Found off

Near Islands at all depths sampled but principally from 25 to 75 fathoms (45-135 m.).

QUINQUELOCULINA sp.

Occurs rarely at depths up to 75 fathoms off Near Islands.

P[illegible]OIDES spp.

In general a widely distributed genus which occurs rarely at intermediate depths off Near Islands.

REOPHAX cf. CURTUS Cushman

Cushman, 1920, Bull. 104, U.S. Nat. Mus., Pt. 2, p. 8, Pl. 2, figs. 2, 3.

This species reported from Canadian arctic, British Isles, northeastern coast of United States, off southern California. Rare off Near Islands. Probably occurs at all depths sampled.

UVIGERINA JUNCEA Cushman and Todd

Cushman and Todd, 1941, Contrib. Cushman Lab. Foram. Res., Vol. 17, Pt. 3, p. 78, Pl. 20, figs. 1-11.

Found off southern California to 500 fathoms (900 m.) and rarely off the coast of Washington. Off Near Islands does not occur above 25 fathoms (45 m.), found mainly below 50 fathoms (90 m.) in low frequencies.

Discussion of Fauna. Table IV gives comparisons of depth and temperature ranges for several species which occur in the Pacific Ocean off southern California and off the Near Islands. The data

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from southern California have been compiled from Butcher (1951), Natland (1933), and unpublished material of Phleger and Parker. The minimum depth of occurrence in the Near Islands is used because the entire range for the species is uncertain. Temperature ranges off southern California give the range with depth, whereas the temperature range given for the Near Islands is the annual range at the minimum depth of occurrence. Study of the table shows that some species appear to be controlled in vertical distribution by temperature and others by depth or some other variable which is also a function of depth. Data for comparison of salinity ranges are not detailed, but the small variation between the Near Islands and southern California (maximum of 2-3 ‰) does not seem adequate to account for the differences between the faunas (Butcher, 1951, Pt. II, p. 41; Natland, 1933). Those species which seem to be controlled in vertical distribution by depth are:

<u>Angulogerina angulosa</u>

<u>Cassidulina subglobosa</u>

<u>Cibicides lobatulus</u>

<u>Ehrenbergina compressa</u>

<u>Pullenia salisburyi</u>

<u>Uvigerina juncea</u>

Although depth may exert the principal control on the vertical distribution of these organisms, they are found in water of similar temperature characteristics in the two areas. This suggests that temperature exerts a broad general control on the distribution of these organisms and within the broad tolerance other factors, perhaps themselves

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Table IV

Temperature and Depth Ranges of Foraminifera Species

From Southern California and Bear Islands Regions.

Species	Southern California[1]		Bear Islands	
	Depth Range	Temp. Range	Minimum Depth	Temp. Range[2]
Angulogerina angulosa	50– 900 m.	13°-4° C	30 m.	8.5°-2.8°C
Astrononion stellatum	80– 600 m.	11°-5.5°	18 "	8.5°-2.8°
Cassidulina californica	50–1000 "	12°-4°	30 "	8.5°-2.8°
C. limbata	15–1000 "	15°-4°	70 "	5.5°-2.8°
C. subglobosa	50–1150 "	12.5°-3.5°	50 "	8.5°-2.8°
Cibicides lobatulus	45– 120 "	12.5°-10°	18 "	8.5°-2.2°
Ehrenbergina compressa	100– 750 "	10°-5°	90 "	5.5°-2.8°
Eponides frigidus	100– 800 "	9°-4.5°	18 "	8.5°-2.5°
Nonion labradoricum	170– 640 "	8.5°-5°	18 "	8.5°-2.8°
Pullenia salisburyi	45– 900 "	13°-4°	50 "	8.5°-2.8°
Uvigerina juncea	125– 900 "	10°-4°	90 "	5.5°-2.8°

1/ Compiled from Butcher, 1951; Natland, 1933; and unpublished data of Phleger and Parker. Maximum vertical temperature range between known limiting depths of occurrence.

2/ Seasonal temperature range at minimum depth indicated.

controlled by depth, are important in determining the vertical distribution.

Those species whose depth distribution appears to be controlled primarily by temperature are:

<u>Eponides frigidus</u>

<u>Nonion labradoricum</u>

<u>Summary</u>. The Foraminifera fauna of the Near Islands is a relatively small one deminated by a few species which occur in abundance. Most of the benthonic fauna is made up of species which, so far as is known, are primarily of Pacific Ocean distribution, but there are affinities with the Arctic and Subarctic regions of the North Atlantic Ocean. The forms which occur are either those which have been found only in cold or deep water or those with a wide isographic and vertical distribution. These wide ranging forms apparently are tolerant to an equally wide range of environmental conditions. The small number of species also is characteristic of cold waters. In general the low water temperatures on the Near Islands shelf seem to determine which Foraminifera species will compose the fauna. Depth of some variable other than temperature which is a function of depth appears to be a control on the vertical distribution of some species, whereas temperature seems to control vertical distribution of others. Finally, the benthic fauna is susceptible to vertical zonation into three zones, shallow, intermediate, and deep, within the depth range studied.

<u>Sponge Spicules</u>. Sponge spicules make up only a small portion

of the diatom, Foraminifera, sponge spicule component. Because of their usual shape and size, however, they are often quite prominent. They are siliceous in composition and may be two to three millimeters in maximum length. They are characteristically of the tetraxon or triaxon type, with one long straight spine and the remainder relatively short and either straight or curved. In addition to these types, there are also small, siliceous, ovoid forms with a pebbled surface.

Accessory Materials. Diatoms, Foraminifera, and sponge spicules make up the great majority of the micro-organism component; however, other materials also may be present. Madiolarians are rarely seen and constitute no appreciable portion of the deposits. A peculiar light yellowish green very fine grained material, however, commonly was observed in small amounts associated with deposits rich in the micro-organisms component. This material is siliceous in composition and appears to consist of small fragments of diatom frustules. The light yellowish green color apparently is due to organic matter, since treatment with hydrogen peroxide bleaches the siliceous fragments to white. Very little calcium carbonate is present. This material forms a suspension in the water above the core on sampling, being stirred up by the impact of the core barrel, but later settles to form a thin surface film. This does not seem to be the flocculent material described by Neaverson (1934, p. 299) from samples of diatomaceous and collected by the Discovery which he suggests is composed entirely of organic compounds.

Pebbles and Granules

Pebbles and granules form a major component of the marine sediments along the southern margin of the insular shelf and the uppermost part of the adjacent slope and rarely in the sheltered bays. In the shelf margin area they occur persistently and in some samples make up a considerable proportion of the sediment. In all samples containing this component it is intimately intermixed and scattered through the deposit along with rock sand and diatoms, Foraminifera, and sponge spicules.

Material of this type is made up entirely of particles of the variety of rock types found on the Near Islands. A range in size from pebbles with maximum diameter of 2.5 cm. to granulee exists. The size-frequency curves of samples containing this component exhibit a variable number of modes.

Pebbles and granules are separated from deposits of cobbles and gravel on the basis of the matrix. The size ranges of the two components overlap, but in no case was extensive matrix of rock sand and small marine organisms associated with cobbles and gravel. Many of the pebbles and granules are well rounded indicating a considerable abrasion history.

There can be little doubt that this component has been transported to the site of deposition by drifting surface ice. No other explanation for its origin can account satisfactorily for the size range which is present, the polymodal character of the frequency distribution curves, and the random occurrence of the pebbles in a matrix of finer marine sediments. The glacial history of the Near

Islands makes this interpretation more cogent. An origin by deposition from drifting ice suggests that the true upper limit of the size of this component is unknown, and that the reported upper limit probably indicates only the upper limit which could be collected with the available apparatus. Material of this type, where found in deposits of cobbles and gravel, cannot be recognized.

Environmental Occurrences and Characteristics

General Statement

The marine sediments which occur on the Near Islands shelf are mixtures of two or three of the end-member components, rock sand, shell sand, diatoms, Foraminifera, and sponge spicules, and pebbles and granules discussed above. Sediments composed of all four of the components are rarely found, and where they do occur, one of the components is relatively insignificant. Composition of the sediments in terms of the frequency of occurrence of each component was determined by making counts of 300 to 500 particles in each sample. This method is satisfactory where the sediment is well sorted, but where there is a wide range in sizes of components, the composition thus determined may bear little resemblance to one which takes into account volume or weight occurrence of constituents. In most sediments having a wide range of particle sizes it is impractical to separate completely the components as must be done to determine weight or volume percentage occurrence. In samples of this type a double scale must be used for adequate description, one part of which represents the composition in terms of the relative frequency of the components and the other part representing the mechanical composition of the deposit. Use of a double scale showing both constituent and size analyses is considered to be essential in describing the sediments which occur in the Near Islands area. This is a difficulty which always attends the study of deposits of this nature, since both weight-or-volume and frequency of occurrence of components are important in describing the character of the sediment.

Size analyses of the samples were made using sieves for separation of grade sizes coarser than 1 mm. and the Emery settling tube for sizes smaller than 1 mm. (Emery, 1938). Only two samples contained material which could not be analyzed by these methods; in these the hydrometer method of analysing fine grained materials was used. The results of size analyses are expressed using the graphic phi system described by Inman (1952). This method utilizes the phi notation introduced by Krumbein (1936) and develops a series of five parameters to express the size distribution of a sediment. These parameters are the median diameter (Md_ϕ), phi deviation measure (σ_ϕ) for sorting, phi kurtosis measure (β_ϕ), and two measures of skewness (α_ϕ, $\alpha_{2\phi}$) and are computed from the 5, 16, 50, 84, and 95 percentile phi diameters obtained from the cumulative size-frequency curve of the sediment. Expressions for these parameters are:

$$Md_\phi = \phi_{50}$$

$$\sigma_\phi = 1/2(\phi_{84} - \phi_{16})$$

$$\alpha_\phi = \frac{M_\phi - Md_\phi}{\sigma_\phi} \quad \text{(where } M\phi = 1/2\ (\phi_{16} + \phi_{84})\text{)}$$

$$\alpha_{2\phi} = \frac{1/2(\phi_5 + \phi_{95}) - Md_\phi}{\sigma_\phi}$$

$$\beta_\phi = \frac{1/2(\phi_{95} - \phi_5) - \sigma_\phi}{\sigma_\phi}$$

The phi skewness measures are zero for a normal distribution, negative if the curve is skewed toward coarser diameters, and positive if skewed toward finer diameters. For a normal distribution the phi kurtosis measure has a value of 0.65. If the distribution is less peaked than the normal, values of β_ϕ will be greater than 0.65 and conversely, if the distribution is more peaked, the values will be less than 0.65. From these statistical constants the five percentile diameters of the cumulative size-frequency curve can be computed. For a more complete discussion and a theoretical treatment reference should be made to Inman (1952, pp. 125-45).

Marine sediments of the Near Islands may be subdivided into environmental groups for purposes of discussion. These environments are: 1) the bays, 2) the adjacent open shelf (exclusive of the outer portion of the shelf south of the islands, 3) shelf-basins, and 4) the outer shelf and upper insular slope. Such a classification is principally one of geographic (or topographic) environments and places arbitrary lines of distinction between adjacent areas. Type examples of sediments from the different Near Islands environments can be established, but between two adjacent types it is probable that all gradations can be found.

This concept of component variation was taken into consideration in the construction of the chart of bottom sediments (fig. 4, in pocket). Lines separating sediment types are avoided; instead, the gradual variation of sediment character is indicated by blending of symbols showing the sediment components. Thus, along the southern margin of the insular shelf the sediment pattern is composed of the symbols for rock and shell-sand, diatoms, Foraminifera, sponge spicules, and pebbles and granules. This shows, in a qualitative way, that the sediment in the southern area is made up of these three components. The pattern is different to the north and does not include the symbol for pebbles and granules indicating this component is about in the shelf-basins. Such a method of representation seems to be a realistic one in an area where the data do not indicate sharp lateral changes in sediment and environment, and is, in effect, a graphic and qualitative method of contouring several components on one chart.

Bay Sediments.

Sediments of the bay environment (Plate V) generally occur as aprons lying seaward of the rivers which empty into the bays. The aprons normally are restricted to the axes of the bays and extend onto the open shelf as more or less discontinuous bodies. On the landward side the deposits usually merge with post-glacial beach, stream, or lake deposits. Toward the open sea the bay sediments thin and are replaced by rock in most places, but in some instances appear to extend outward to the shelf margin and grade into open shelf sediments.

Bay sediments generally are more continuous and seem to be of maximum thickness inshore where they merge with beach and relatively thick valley floor deposits. Actual thicknesses at these points are not known and undoubtedly vary depending to a large extent on the configuration of the valley floors left by the retreating glaciers. In some of the exposed southern bays on Attu no beach or stream deposits exist, and the bay sediments are not present in the inner shallow bay heads. Bay sediments probably are quite thin in most places. This estimate of the thickness is based on the usual valley gradients which are relatively regular, passing from rock offshore into sand inshore with no major change.

Composition and texture of bay sediments is given in table V and figure 6 which also includes the open shelf sediments. Rock sand is the dominant component in all but one of the samples and in most constitutes more than 94 per cent of the sediment. Shell fragments make up most of the sediment in one sample, are abundant in three others, but for the most part are relatively insignificant. Diatoms, Foraminifera, and sponge spicules are minor accessories and pebbles occur too rarely to figure. Bay sediments exhibit a great range of median diameters, varying from coarse sand to silt. For the most part they are well sorted, although some poorly sorted material occurs, and may be showed toward either the coarse or fine sizes.

Bay sediments are primarily the product of deposition near the mouths of rivers. The rock sand introduced by the rivers is augmented to some extent by similar material produced by wave action on the shoreline. Despite the fact that the sea cliffs are out of adjustment with present sea level, this may be an important source in some

Table V. Composition of Bay Sediments

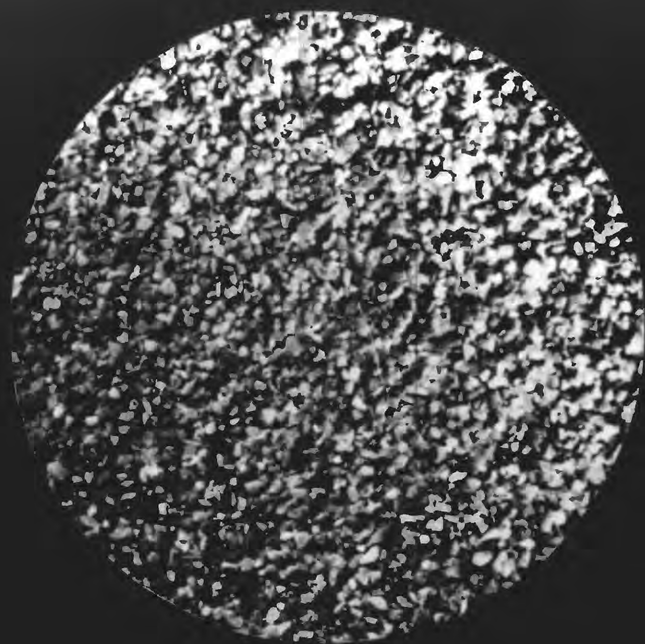
A. Components by grain count.

Sample Number	Per Cent Pebbles, etc.	Per Cent Rock and mineral Sand	Per Cent Shell Fragments	Per Cent Diatoms, etc.
33	0	94	4	2
63	0	94	4	2
69	0	93	7	0.4
71	0	78	22	0.2
74	0	38	62	0
75	0	68	32	0
112	0	99	1	0
130	0	98	1	1
131	0	98	1	1
143	0	99	0.7	0.3
148	0	99	1	0.3

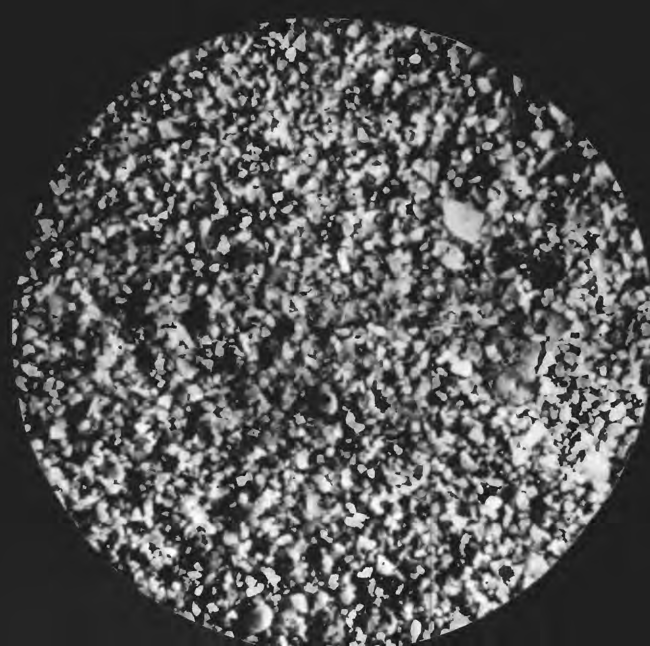
B. Size Composition by weight (notations after Inman 1952).

Sample Number	Depth (Fathoms)	Md_{mm}	Md_{ϕ}	σ_{ϕ}	α_{ϕ}	$\alpha_{2\phi}$	β_{ϕ}
33	37	0.14	2.81	.20	-.15	-.20	1.0
63	74	.17	2.57	.37	-.05	.054	1.38
69	38	.25	2.03	.31	-.32	-.58	2.45
71	12	.48	1.07	.57	-.123	.23	0.86
74	1/2	.53	0.92	.63	.07	.094	0.81
75	6.6	.27	1.92	.35	-.142	-.60	0.89
112	12.5	.14	2.82	.36	-.34	-1.30	1.58
130	6.6	.095	3.40	.38	-.131	-.45	0.95
132	10.0	.057	4.13	1.65	.042	--	--
143	4.5	.13	2.22	.30	-.23	-.47	0.70
148	6.0	.12	3.06	.50	-.02	-.56	0.98

[illegible]te [illegible]. [illegible] Sediments.



E 148 (X 7.5)



E 112 (X 7.5)

localities. Headlands which separate the major bays are the loci of intensive wave action as evidenced by the wide wave-cut benches which surround them. Some of the sand formed by the waves cutting benches and moving cobbles and gravel on the rocky beaches undoubtedly is introduced to the bays by the action of longshore currents produced as the waves enter the bays. These currents would tend to sweep the sand toward the bay heads and deposit it with river-derived material.

Shell fragments constitute a large proportion of bay sediments only where conditions are such that rock sand is not introduced in quantity. The samples with a high percentage of shells lie in bays and coves east and south of Agattu or on the border between the bay and open shelf environments. The small streams of Agattu probably bring in a relatively small amount of detritus to mark shell remains. In addition, the shore configurations do not promote pronounced funneling of wave-produced detritus to a central location.

Pebbles occasionally occur in the bay deposits, although they are not abundant. This is an interesting fact which suggests that ice rafting of pebbles is occurring on a small scale at the present time. It seems likely that stream ice containing some pebbles is released by spring thaws and drifts out into the bays where the pebbles are freed and deposited by melting of the ice.

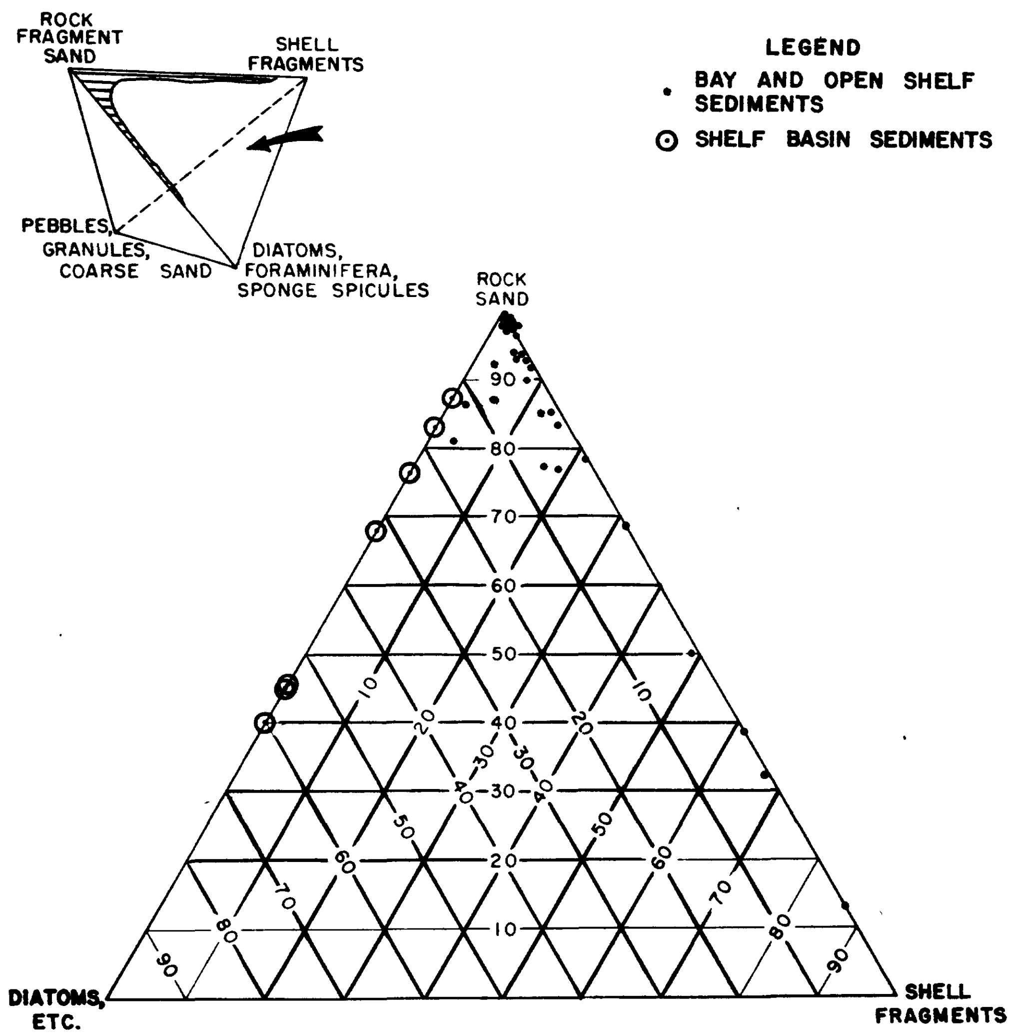
Open Shelf Sediments.

Sediments of the open shelf (Plate VI) frequently are difficult to separate from those of the bay on a purely lithologic basis; therefore the two types of deposits are shown together on the

FIGURE 6

NEAR ISLANDS

COMPOSITION OF BAY-OPEN SHELF AND SHELF BASIN SEDIMENTS



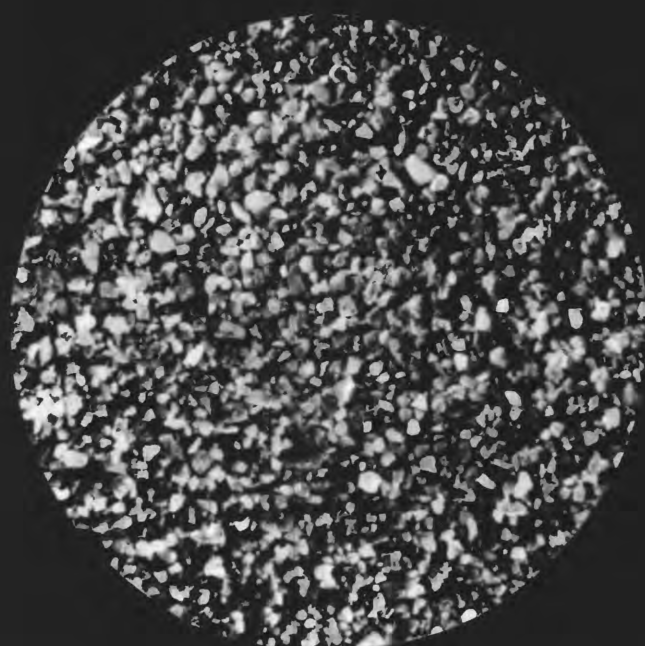
composition diagram (fig. 6). Open shelf deposits are of sand size and generally occur as small isolated patches of detritus which appear to be very thin and discontinuous. Those patches which were found are indicated on the chart, but others undoubtedly exist. Shelf sands also border shelf-basins and grade into the characteristic sediments of that environment. Open shelf sediments occurring adjacent to a basin probably are more persistent in areal distribution than the patches which are found on more exposed areas.

The composition of open shelf deposits is shown in table VI and figure 6. As in bay deposits, rock sand is the chief component; however, shell fragments are of greater significance and in several samples are dominant. Diatoms, Foraminifera, and sponge spicules, although of minor importance, also occur in greater quantities. Open shelf sands show a larger range of median diameters than bay sediments, are well sorted, and are skewed toward coarser diameters in most samples. In addition, the size frequency curve usually is more peaked than that of the bay sediments (cf. ϕ values in tables V and VI).

Open shelf sediments are derived largely from erosion of the land either by streams or wave action and from shells produced principally in shallow nearshore water. Composition of the sediment seems to be related to its position with respect to an abundant source of terrigenous material. Most samples collected near the mouths of bays or portions of the coast where waves are most effective have a high percentage of rock sand, whereas those collected in areas where wave action is reduced or which are somewhat farther from

Plate VI. Open Shelf Sediments.

E 119 (X 7.5)



E 28 (X 7.5)

Table VI. Composition of fine-grained Open-Shelf Sediments

A. Components by grain count

Sample Number	Per Cent Pebbles, etc.	Per Cent Rock and mineral Sand	Per Cent Shell Fragments	Per Cent Diatoms, etc.
28	0	92	7	1
29	0	77	17	6
30	0	86	13	1
35	0	92	3	5
36	0	13	87	0
62	0	94	6	1
93	0	86	2	12
99	0	88	4	8
119	0	99	1	0
121	0	99	1	0
125	0	97	3	0
155	0	32	67	1
158	0	50	49	1
162	0	81	16	3
171	0	90	8	2
172	0	83	16	1
183	0	77	18	5
184	0	85	13	2
185	0	99	0	1
186	0	99	0	1
187	0	99.3	0	0.5
204	0	99	0	1

B. Size Composition by weight (notations after Inman 1952).

Sample Number	Depth (Fathoms)	Md_{mm}	Md_{ϕ}	σ_{ϕ}	α_{ϕ}	$\alpha_{2\phi}$	β_{ϕ}
28	52	0.18	2.50	.38	-.24	-.37	.60
29	58	0.175	2.52	.24	-.54	-.082	1.58
35	50	0.12	3.10	.34	-.15	-.32	.62
62	54	0.73	0.55	.44	-.091	-.34	.82
93	51	0.19	2.42	.49	.061	.122	.65
99	52	1.00	0.0	.25	.08	.12	1.64
103	51	1.45	-0.53	.44	-.045	-.114	.70
119	24	0.70	0.51	.48	-.083	.165	.67
125	46	0.41	1.27	.60	-.183	-.52	2.37
171	40	0.16	2.68	.38	-.236	-.315	.69
186	57	0.18	2.49	.24	-.29	-.63	.87
204	43	0.14	2.81	.21	-.24	-.47	1.10

bay mouths have higher percentages of shell fragments. Occasional small fragments of Halinsia, Mytilus, and Strongylocentrotus, all shallow water forms, were found at depths greater than 50 fathoms and at considerable distances from shore, suggesting that seaward transport from nearshore areas is taking place.

The extent to which reworking of submarine glacial drift has furnished terrigenous sediment is difficult to determine. Depth of winnowing of glacial deposits and the volume and permanence of open shelf sediments are unknown. Open shelf sands mean to be in a precarious state of balance and are probably being reworked continuously. Menard (1952, p. 6) describes photographs taken at a depth of 50 fathoms south of Unimak Pass in the Aleutian Islands (see Plate VII) showing sand ripples which he feels have moved rapidly enough on the bottom to partially bury living brittle stars. An environment such as shown in this photograph is probably similar to the open shelf of the Near Islands and is one conducive to the formation of winnowed sedimentary deposits. Skewness of the size-frequency curve toward coarse diameters also seems to confirm this view. This characteristic of the curve suggests that finer material is either never deposited or is removed quickly, leaving behind coarser fractions which are more difficult to transport.

The sources of detritus may have changed somewhat in relative importance since glacial times. Originally, reworking of moraines must have been important in areas where these exist so that deposits of shelf sand may have been more extensive. With the passage of time, however, equilibrium with more constant sources would be set

Plate VII

Bottom Photograph Near Unimak Pass, Aleutian Islands

54° 17.5' N; 164° 32.2' W; 50 Fathoms

Official U.S. Navy Photograph

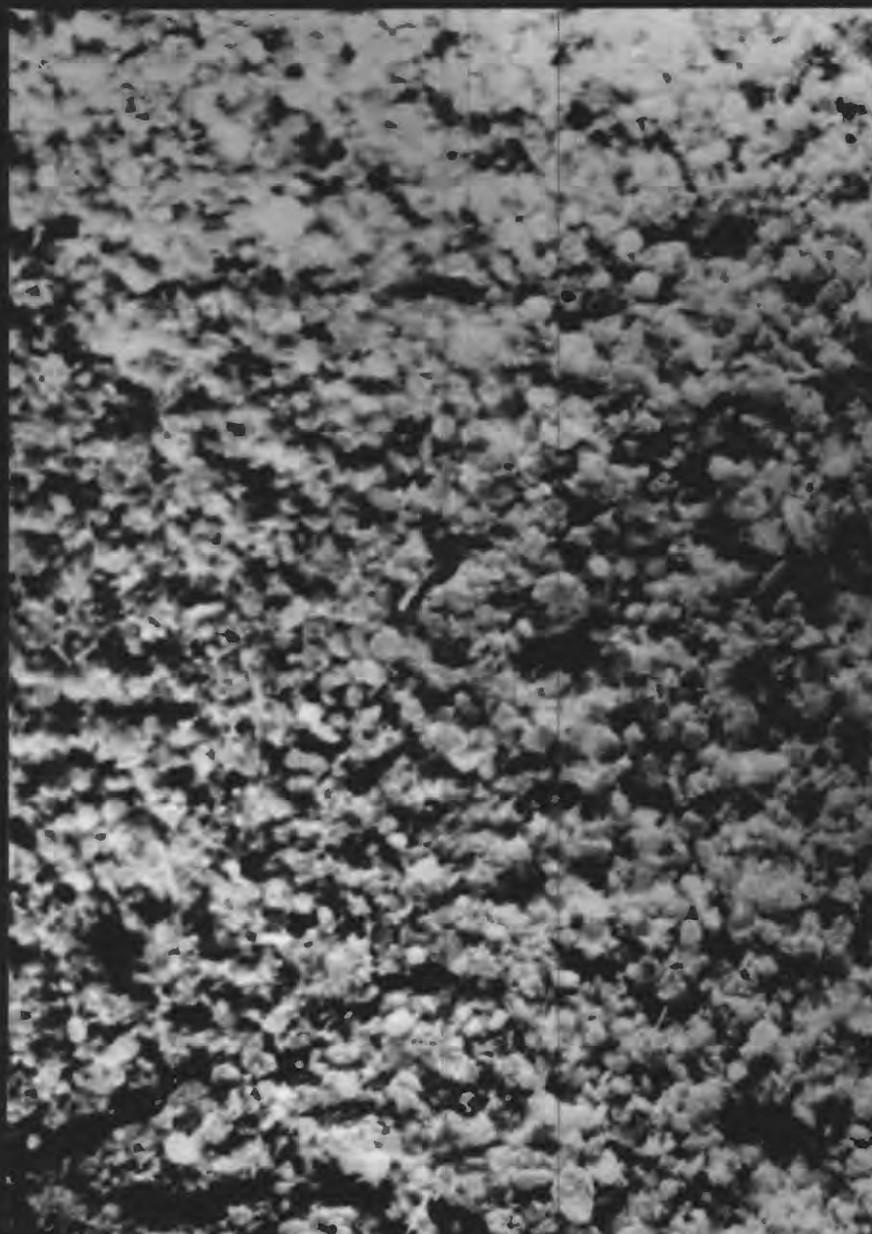
up and land and nearshore detritus would become of greater significance. If glacial deposits were once of major significance, a change of source seems almost certain. Glacial deposits on the sea floor have been effectively exhausted of fine material, and distribution of the more important occurrences of open shelf sand seem to be related to insular sources. These considerations suggest that glacial moraine on the sea floor is of little importance as a source of sand to modern surface deposits, whether these deposits are thick or thin. If the deposits are thin, equilibrium conditions would have removed most of the original glacial sand, and if they are thick, this sand would have been buried beneath later debris of insular origin.

Shelf-Basin Sediments.

Deposits of rock sand with a high proportion of diatoms, Foraminifera, and sponge spicules and occasional radiolarians are associated with the five largest basins on the insular shelf (Plates VIII, IX). Table VII and figures 6 and 7 give the composition of this sediment. Detrital particles of terrigenous origin constitute an important part of the sediment and in most samples are predominant. All the samples have median diameters in the sand range, are well sorted, and tend to be skewed toward finer diameters. The abundance of diatoms, Foraminifera, and sponge spicules gives the samples a distinctive appearance and differentiates them from the bay and open shelf sediments.

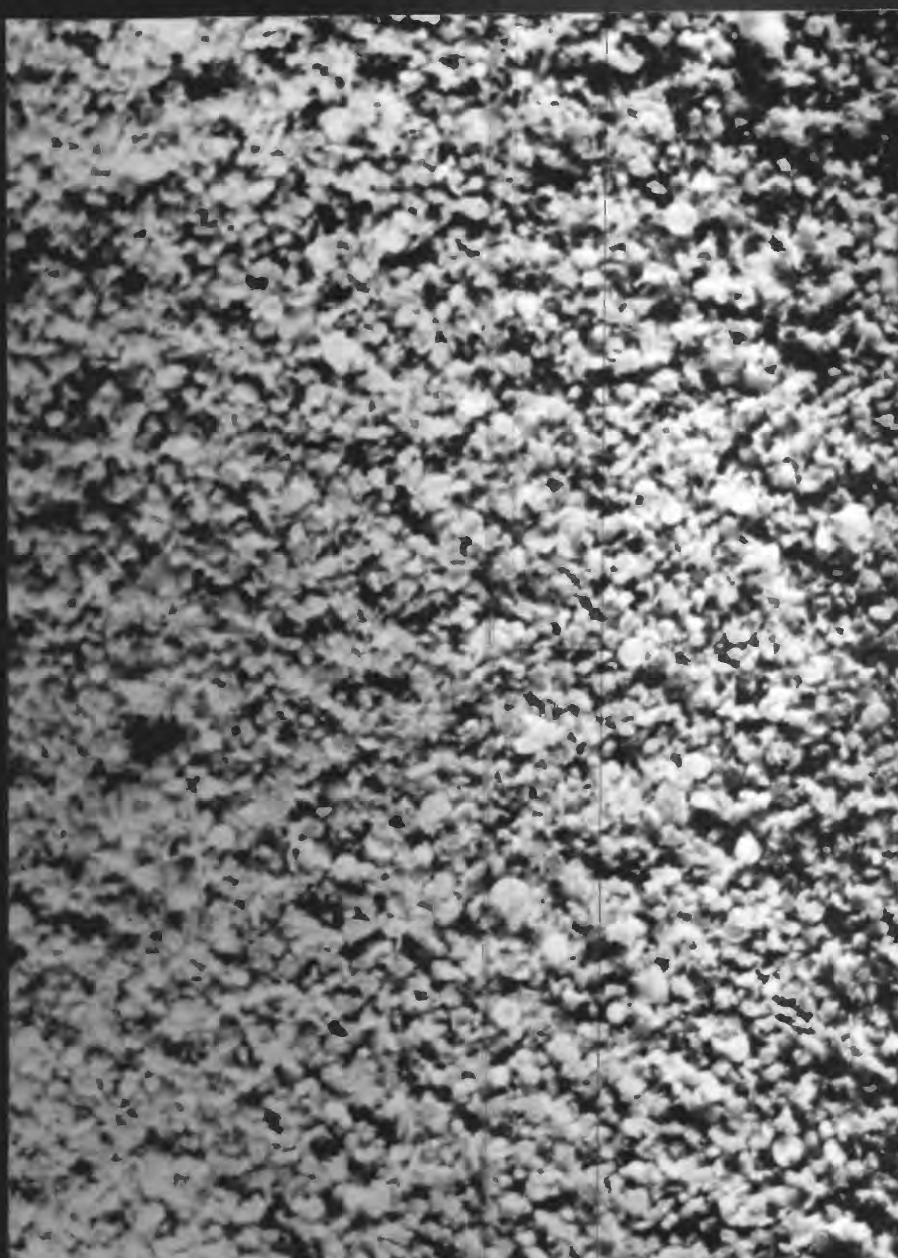
Classification and naming of material of such mixed origin

Plate VIII. Shelf-Basin Sediments.



E 78 (X 15.9)

Plate IX. Shelf-Basin Sediments.



E 201 (X 15.9)

Table VII. Composition of Shelf-Basin Sediments

A. Components by grain count.

Sample Number	Per Cent Pebbles, etc.	Per Cent Rock Sand	Per Cent Shell Fragments	Per Cent Diatoms, etc.
16	0	77	0	23
51	0	83	0	17
57	0	87	0	13
76	0	45	0	55
198	0	46	0	54
199	0	40	0	60
201	0	68	0	32

B. Composition by weight (notations after Inman, 1952).

Sample Number	Depth (Fathoms)	Md_{mm}	Md_{ϕ}	σ_{ϕ}	α_{ϕ}	$\alpha_{2\phi}$	β_{ϕ}
16	57	0.13	2.95	.45	-.15	-.13	1.05
51	67	0.11	3.22	.43	.07	.14	.91
57	72	0.095	3.39	.37	-.13	.135	.79
78	81	0.12	3.07	.44	.205	.635	.85
201	75	0.182	3.68	.50	.22	.46	1.12

presents some problems. Neaverson (1934) experienced those same difficulties in classifying some of the bottom samples collected by the Willis Georeshy in Drake Strait. He differentiated between deposits of diatomaceous ooze and diatomaceous mud, defining the latter as diatom-rich sediments with an appreciable contest of terrigenous material (p. 303). His samples of diatomaceous mud contained Foraminifera, sponge spicules, some radiolarians, and mineral grains up to 0.5 mm. in diameter in addition to diatoms; judging by the descriptions, his samples were rather poorly sorted and skewed toward the finer diameters. In describing sample W5 403 from Drake Strait, Neaverson noted (1934, p. 335): "This sample is not easy to classify. The coarse washings might almost be a Olobigering ooze, but the proportion of mineral grains is too large. The finer material, which force the greater proportion of the deposit, has the typical constitution of diatomaceous mud. The deposit is therefore classified as such, despite the unusual abundance of Foraminifera." From this description there is little doubt that this material is similar to that found off the Near Islands. Revelle (1944, p. 16) proposed a classification of deep sea sediments in which he also suggested the use of the term mud and several descriptive adjectives for fine grained terrigenous sediments of this general character. Use of the term mud is not warranted in the case of the Near Islands material, however, because of the relatively large grain size and good sorting of these sediments. The Near Islands diatom-rich sediments do not fit precisely into either the classification of Revelle or Neaverson, but the similarities are so close as to suggest the term diatomaceous sand for this material.

Diatomaceous sand is found only in the large, irregularly ovoid, or elongated basins of the shelf. The basins (see fig. 3) occur spaced at random and usually well out on the exposed shelf at considerable distances from abundant sources of clastic sediments. They vary in depth from 5 to 30 fathoms and the larger ones are filled to an unknown extent with diatomaceous sand. The deposits were penetrated only on the ridge between the two elongated basins west of Agattu, at station S 200. Here the material was found to be approximately three inches thick. This suggests that the diatomaceous sand thins and pinches out away from the deeper parts of the basins.

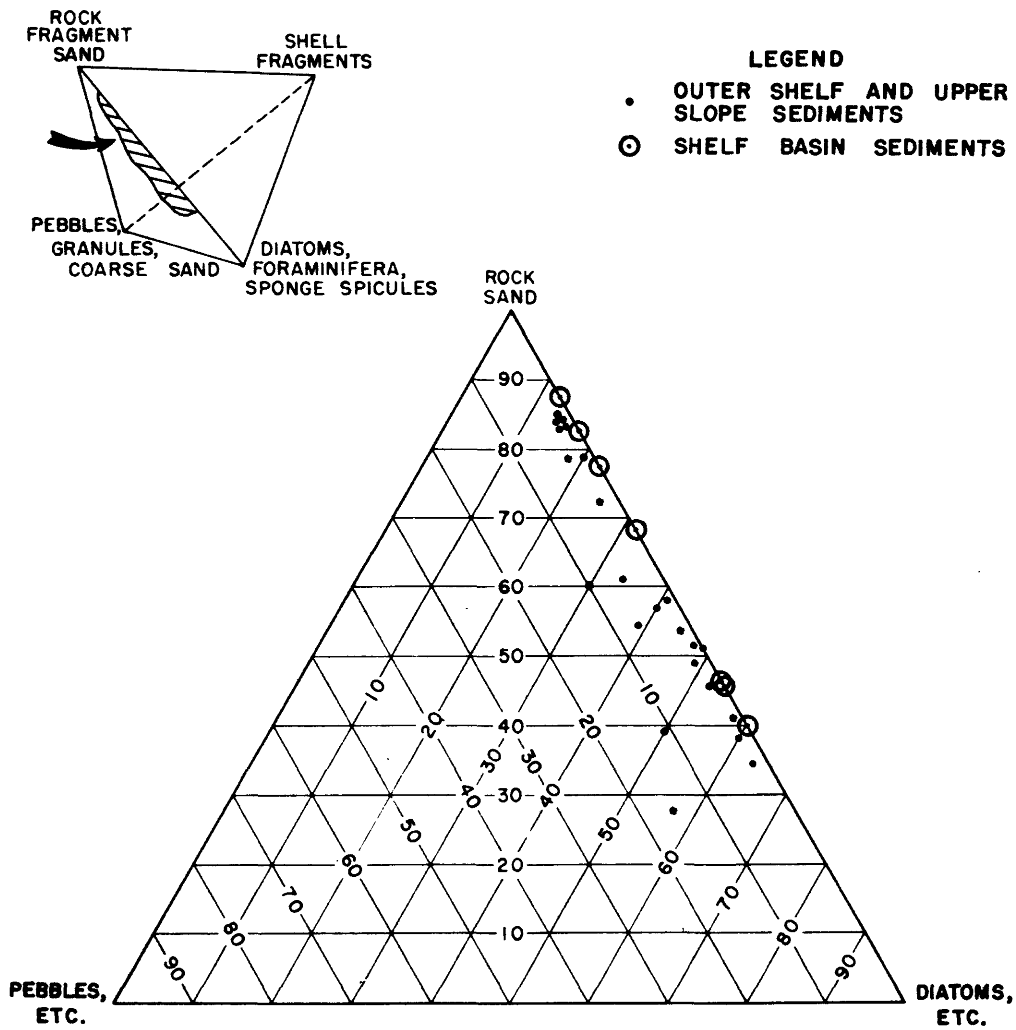
Sediments of this type are a combination of terrigenous materials and of the remains of marine organisms largely of planktonic origin. Terrigenous components may be derived from the islands by erosion or from reworking of submarine glacial deposits. Submarine glacial drift, as in open shelf sands, is probably of little quantitative significance at present.

Absence from samples of shelf-basin sediments of particles which could be identified as shell fragments is puzzling as organisms capable of furnishing this material live on the shelf. The presence of calcium carbonate in the tests of Foraminifera, many of which are thin and delicate, indicates that shell fragments are not removed from the deposits by solution. Selective mechanical destruction after deposition seems equally unlikely. The best explanation may be that shell fragments are not supplied to the basin, or if present,

FIGURE 7

NEAR ISLANDS

COMPOSITION OF OUTER SHELF-UPPER SLOPE AND SHELF BASIN SEDIMENTS



were too altered to be recognized. Of these possibilities the most plausible suggestion seems to be that the shell fragments are considerably larger than the fine debris which reaches the depths of the basins and are trapped near the margins where they were not sampled. However, it is possible that the physical characteristics of the shells permit rapid mechanical comminution during transportation; extremely small particles of calcium carbonate probably would not have been recognized as being derived from shell material.

Abundance of the remains of planktonic organisms in shelf-basin deposits, as contrasted with those of the open shelf, accounts in part for the size distribution characteristics of the shelf-basin deposits and in part for their thickness. Presumably, remains of planktonic organisms are supplied to the bottom sediment more or less uniformly over the entire shelf area. Therefore their concentration in some places and absence in others suggests that considerable lateral movement takes place after initial deposition, and that the tests and frustales are trapped in the relatively quiet basins. This lateral transport is also indicated by the large expanses of bare rock on the shelf. Sand grains somewhat finer than the organic remains would behave in the same manner because of the differences in specific gravity, so that the resulting sediments should be relatively fine grained and tend to have size-frequency curves skewed toward finer diameters. As was noted in discussion of open shelf sands, the skewness values suggest they are being denied finer grained materials.

The presence of fine grained sediments of these characteristics flooring the basins furnishes some evidence as to the origin of the basins. Occurrence of such basins on a shelf generally composed of rock can be explained as due to 1) tectonic activity, 2) tidal scour, or 3) glacial erosion. The irregular and variable shapes and depths of the basins and the lack of alignment with major topographic irregularities, together with an absence of such features on the islands explainable by tectonic movements east doubt on tectonic activity as a principal cause. The irregular shapes, the locations of some of the basins removed from conceivable loci of strong and effective tidal scour, and the fine grained sediments flooring the bottoms oppose tidal action as a cause of the basins. Glacial erosion, perhaps made more effective by localized faulting or jointing, is the only mechanism known to have worked on the shelf in recent times that is capable of having formed the basins. This is a reasonable interpretation when the characteristics of glaciated regions of low relief are considered. An abundance of irregularly shaped lakes of variable depths in regions of plentiful exposures of bed rock is one of the criteria by which past glaciation is deduced. Interpretation of these basins as being of glacial origin somewhat extends the area of the insular shelf which must have been buried beneath Pleistocene ice beyond that indicated by the distribution of cobbles and gravel and other topographic features. The long narrow basin north of central Attu, however, appears to be of different origin. The known intensive faulting (O. Gates, personal communication) and the topographic offsetting in this area suggest this basin is of primary tectonic origin, perhaps enlarged by glaciation.

Outer Shelf and Upper Slope Sediments.

Sediments similar in character to shelf-basin deposits but containing in addition an admixture of pebbles and granules were found to be almost continuous along the deep southern margin of the insular shelf and to extend to unknown depths down the insular slope (plate X). These deposits either pass beneath shelf-basin sediments or pinch out against areas of rock or cobbles. They were found deeper than approximately 65 fathoms. These deposits were penetrated by several cores along the upper margin of the insular slope and were found to be quite thin, varying from 3 to 10 inches in thickness. At greater depths the deposits were not penetrated and the thickness is greater but unknown. Cores on the outer edge of the shelf are quite short which suggests that the outer shelf deposits are thin and overlie directly rock or cobbles. Frequently the core nose was bent while sampling this material. This evidence on the thickness of the deposits is inconclusive, however, because the pebbles contained in the sediment conceivably are capable of producing the same effect as striking bed rock beneath.

Composition of these sediments is shown in figures 7 and 8. Table VIII gives the frequency of occurrence of the components and statistical constants computed from the mode composed of the finer constituents. Figure 8 shows size-frequency curves of the total sediment and indicates the mode from which statistical constants were computed. The composition of the shelf and slope sediments compared with shelf-basin deposits, shown in figure 7, indicates that the two deposits are similar, the difference in composition

Plate X. Upper Slope and Outer Shelf Sediments.

E 19

E 21

Table VIII. Composition of Deposits of Southern edge of Shelf and Upper Slope

A. Components by grain count.

Sample Number	Per Cent Pebbles, etc.	Per Cent Rock Sand	Per Cent Shell Fragments	Per Cent Diatoms, etc.
19	2	53	0	45
20	1	45	0	53
21	1	52	0	47
22	15	27	0	57
23	2	83	0	15
46	0	52	0	48
47	1	41	0	58
48	1	39	0	60
49	2	49	0	49
60	5	61	0	34
61	2	34	0	64
65	3	57	0	40
66	10	60	0	30
94	3	79	0	18
101	7	54	0	39
102	1	83	0	16
103	3	72	0	25
108	1	85	0	14
113	1	86	0	13
115	11	39	0	50
116	1	84	0	15
175	1	79	0	20
180	1	58	0	41

B. Size Composition by weight (notations after Inman, 1952)1/

Sample Number	Depth (Fathoms)	$Md_{mm.}$	Md_{ϕ}	σ_{ϕ}	α_{ϕ}	α_{ϕ}	β_{ϕ}
21	85	0.11	3.17	.74	-.175	-.62	.90
23	76	0.14	2.82	.78	-.039	-.115	.57
94	181	0.15	2.70	.50	.12	.22	.98
113	122	0.13	2.95	.37	.054	.30	1.08
116	110	0.16	2.64	.35	.086	.31	.80

1/ Statistical constants computed on the small diameter mode in figure 8.

being the presence or lack of pebbles and granules. Comparison of statistical constants further indicates the similarity. The frequency curves, however, show the great range in diameters present in the outer shelf and upper slope deposits and also the polymodal nature of the size-frequency distribution. It seems impossible that only one agent could be responsible for the transportation of the sediments, they must be in part the result of deposition of particles frozen into ice which drifted outward from the island masses and melted. Deposits similar to these have been described by, among others, Bramlette and Bradley (1940) from the North Atlantic, Statson and Upson (1937) from the Ross Sea, and Hough (1950) from the Antarctic Ocean and similar conclusions as to the origin were reached. Sizes of particles thus supplied must have varied from the finest available to the coarsest material which could be floated by the drifting ice. The slightly greater median diameters and poorer sorting and the tendency toward coarser diameter skewnesses of outer shelf and upper slope sediments when compared to shelf-basin sediments suggests the fine-size mode is composed in part of ice-rafted material. These considerations, together with the character of the frequency curves, suggest that all terrigenous material occurring in these deposits greater than approximately 0.5 mm. in diameter has been ice-rafted.

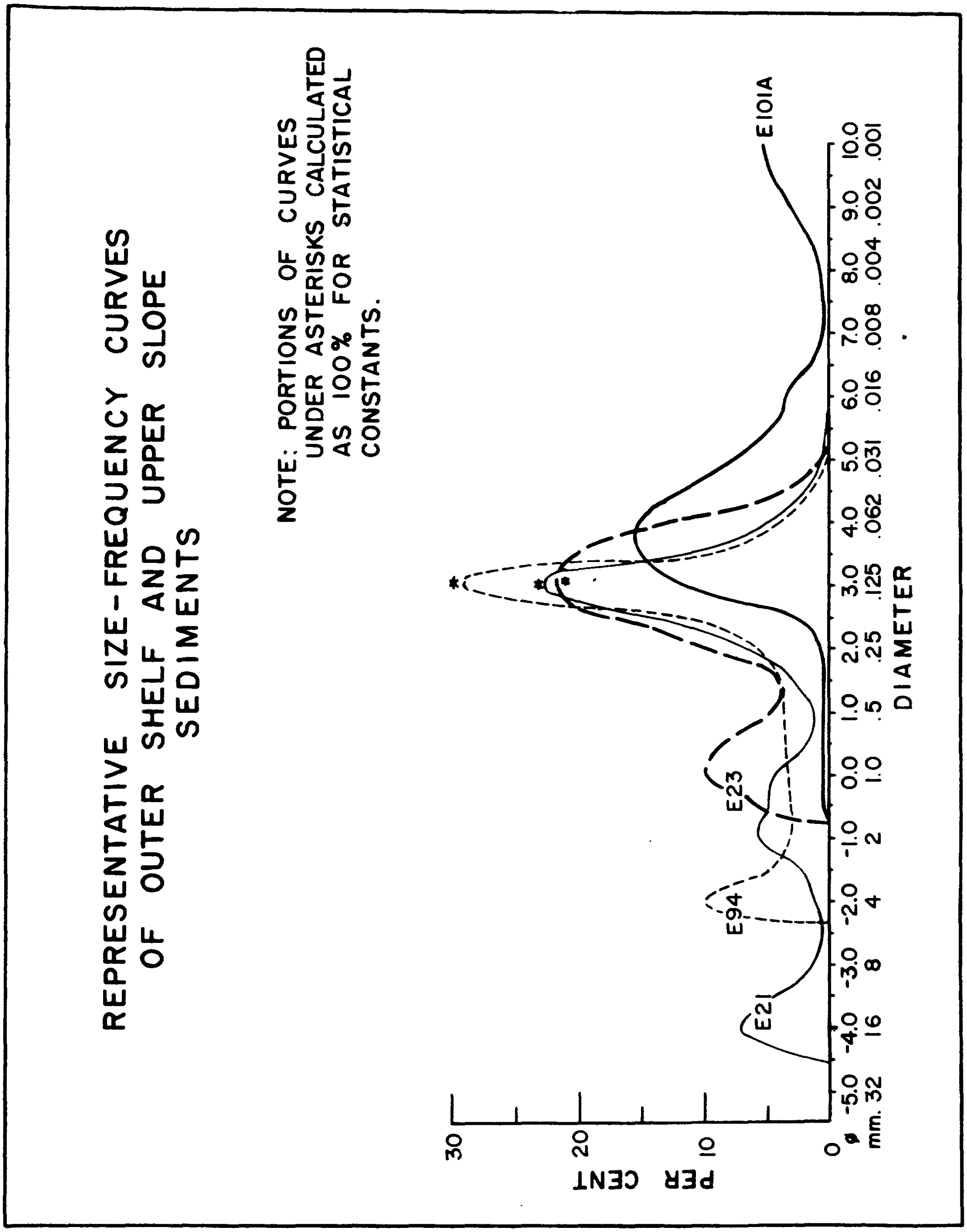
The southern limit of Bering Sea ice is along a line which extends northwest-southeast from a point just south of St. George Island in the Pribilof group, so that the southeastern part of the

Bering Sea is ice-free at all times (U.S. Coast Pilot, Alaska, Pt. II, 1947 ed., pp. 501-03). The position of the southern limit of the pack ice which contains no sediment, the lack of ice-rafted materials in shelf-basin sediments, and the similarity of the ice-rafted pebbles to rocks of the islands show that ice rafting is a process which is not quantitatively effective in the Near Islands area at present.

Lying beneath the surface deposits and usually below the southern margin of the insular shelf are poorly sorted deposits of sandy mud which also contain the components of the surface deposits. Material of these muds is predominantly fine, unweathered, rock sand and gray silty clay with a small amount of granules and coarse sand. Diatoms, Foraminifera, and sponge spicules are present in minor quantities. Figure 9 shows representative cores which penetrated this material and figure 8 gives a size-frequency curve of the mud from the base of core E 101 (labeled E101A). The size distribution is markedly bimodal with a pronounced "tail" of coarser diameters; slightly more than 19 percent of the sample was finer than one micron in diameter. Thickness of sandy mud of this character is unknown, and its distribution is confined to depths greater than the edge of the shelf.

The Foraminifera fauna of this material was analyzed in order to determine the probable depth of water in which the sandy mud was deposited. This fauna differs in no way from that of the overlying surface deposits, so that the beds appear to have been deposited at

FIGURE 8


REPRESENTATIVE SIZE-FREQUENCY CURVES
OF OUTER SHELF AND UPPER SLOPE
SEDIMENTS
NOTE: PORTIONS OF CURVES
UNDER ASTERISKS CALCULATED
AS 100% FOR STATISTICAL
CONSTANTS.
E101A
E23
E94
E21
PER CENT
0
10
20
30
ø -5.0 -4.0 -3.0 -2.0 -1.0 0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
mm. 32 16 8 4 2 1.0 .5 .25 .125 .062 .031 .016 .008 .004 .002 .001
DIAMETER

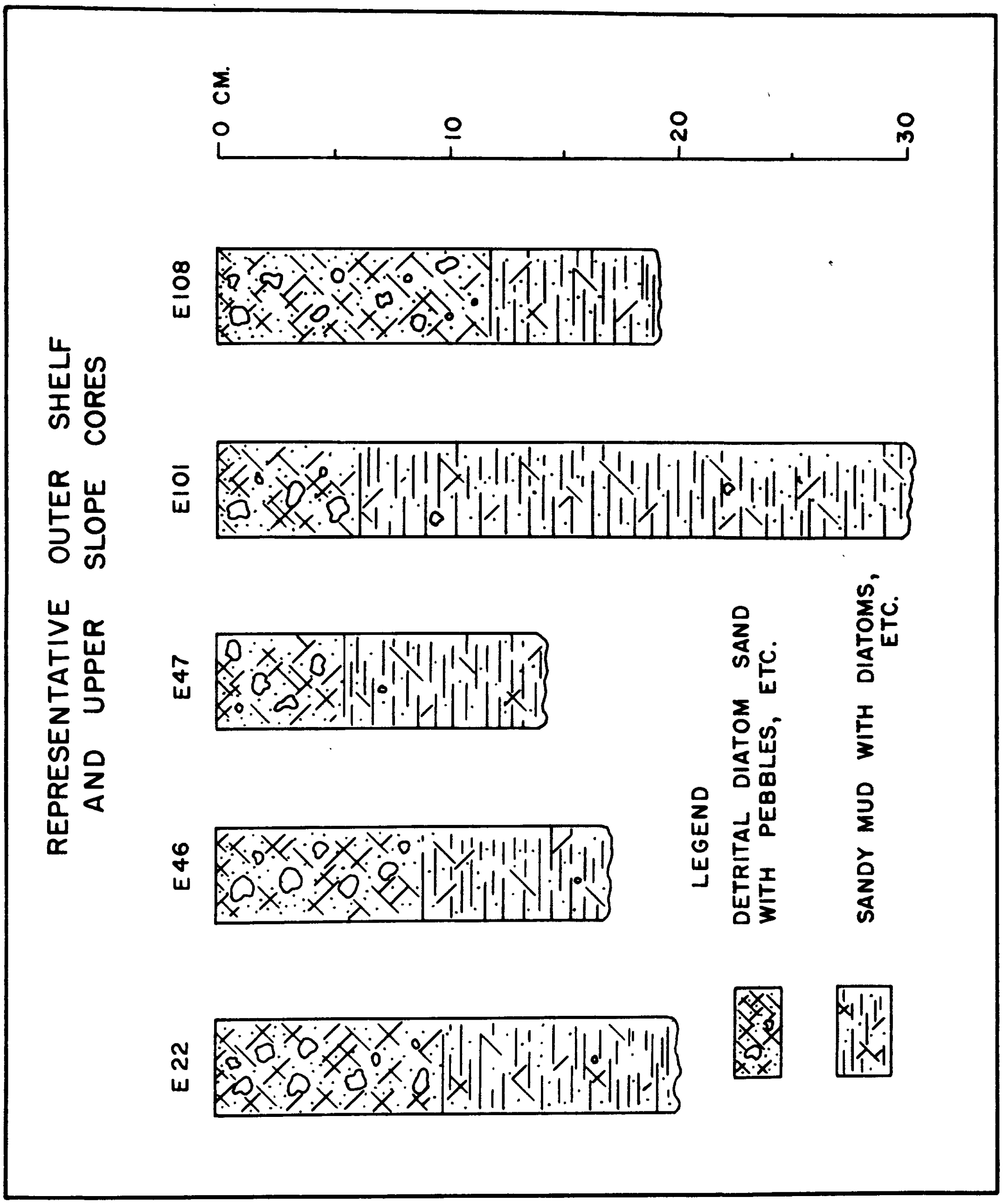
much the same depths at which they now occur.

The sandy mud is similar to coarse glacial flour. The source of this material, however, is not necessarily of direct glacial origin. Winnowing of shelf glacial deposits would begin immediately once they were exposed to the sea by the melting of glaciers and could be expected to supply sediment in diminishing quantities until exhausted. The sandy mud is composed of the general type and size range of particles which are absent from the winnowed shelf glacial deposits.

Since ice-rafted pebbles persist in the deposits virtually to the surface in most of the cores and occur above the sandy mud, some drift ice was still present after the winnowing of shelf glacial deposits. There is no reason to doubt that both the sandy mud and the diatomaceous sand with pebbles and granules underlie the diatomaceous sand of the shelf-basins in the same sequence but have been buried by relatively rapid basin deposition.

It is not known definitely whether the few millimeters of diatomaceous sand which lie above pebbles in some places on the outer shelf or upper slope represent the total of normal deposition in these areas since ice-rafting ceased or whether bypassing of the region now is taking place. This material, together with the fine yellowish green flocculent, may be matrix material which was thrown into suspension on coring. Presence of the pebbles at or practically at the surface of the sediment shows either that deposition on the outer shelf and upper slope has been very slow after the complete melting of the ice or that a comparatively short period of time has

FIGURE 9


REPRESENTATIVE OUTER SHELF
AND UPPER SLOPE CORES
0 CM.
10
20
30
E108
E101
E47
E46
E22
LEGEND
DETRITAL DIATOM SAND
WITH PEBBLES, ETC.
SANDY MUD WITH DIATOMS,
ETC.

elapsed since the ice disappeared. Topographic evidence from the islands in the form of eroded canyons and sea cliffs and stabilized valleys indicates a considerable lapse of time since the disappearence of the tidal glaciers. This suggests that deposition has been very slow since ice-rafting and deposition of pebbles and granules ceased. Coarse sands are found commonly along shelf margins and may indicate the relatively rigorous conditions on shelf margins caused by general increase in tidal current velocity near the break in slope suggested by Fleming (1938) and Fleming and Revelle (1939, pp. 134-135). On the other hand, the yellowish green, very fine grained, siliceous material, if it is on the surface with diatom-rich sediments, suggests current action cannot be severe. The evidence seems to suggest bypassing is occurring, but it is not completely conclusive. In either event the effectiveness of shelf-basins as sediment traps is demonstrated. Although bypassing in shelf margin environments may be occurring at present, deposition in this area during the period of ice-rafting could have been more stable and at a greater rate. Transportation of detritus by floating ice would not only augment the supply of terrigenous debris, but the presence of pebbles and granules would establish current shadows and small holes and pockets on the bottom within which fine materials could collect. An illustration which suggests this phenomenon is found in a recent paper by Menard (1952, Pl. 2) where he gives bottom photographs of Globigerina ooze collecting in current shadows and between large manganese nodules on the top of a seamount in the Pacific Ocean. Since the surface deposits of the outer shelf and upper slope are thin, even where pebbles are present, the most reasonable interpretation seems to be that deposition was more rapid while pebbles were being added than after the termination of ice-rafting. Termination of ice-rafting slowed deposition in part because pebbles and granules were no longer being supplied and in part because the current shadows and small holes and pockets, created by the addition of pebbles and granules and into which fine grained material could filter, were not present.

The occurrence of very fine grained material of unknown but considerable thickness deposited in an environment apparently being bypassed at present shows the importance of factors other than those of the immediate environment in controlling sediment character. A relatively abundant supply of terrigenous detritus existed during the deposition of the sandy nuds. The result is a fine grained polymodal sediment with occasional remains of organisms. Failure of the abundant supply of terrigenous material accented the components still being supplied with the result that the sediment became much coarser and the remains of organisms more abundant. Still later, failure of the supply of pebbles and granules resulted in virtual cessation of permanent deposition of all other components as well.

Age of Shelf Deposits

The shelf deposits are probably of latest Glacial and Post-Glacial age. Cobbles and gravel along the shelf margin are the oldest deposits encountered. The extensive moraine southeast of Attu and the uppermost beds of sandy mud on the upper insular slope are next oldest and are approximately correlative. Deposits of diatomaceous sand with ice-rafted pebbles and granules occurring on the insular slope and outer shelf are somewhat younger. The latest beds to have been deposited are the shelf-basin diatomaceous sands and the open shelf and bay sands which are correlative in age.

Summary of Fine Grained Marine Sediments

Fine grained marine sediments of the Near Islands are composed of material of both terrigenous and biological origin. The terrigenous components are principally the product of mechanical disintegration of the rocks of the islands. Sediment of biological origin is made up of the skeletons of marine organisms of which a few types are dominant. These dominant types are deep or cold water forms and forms which have a wide range of temperature tolerances. In addition, the number of species of any given type is small. Composition of the sediment is a function of the relative availabilities of terrigenous detritus and biological detritus of marine origin. Where terrigenous material has been supplied rapidly relative to the remains of the organisms living in the area the sediment has the composition of most bay and some open shelf deposits, and where biological remains have been in relatively rapid supply the sediment has the composition of shelf-basin deposits or shell sands. In general, therefore, components of marine origin become more abundant in the sediment seaward from the islands.

Most of the shelf bottom is bed rock, boulders, or deposits of cobbles and gravel. Of the fine grained marine sediments, the finest are found in the most protected bays near the mouths of rivers and in the deep shelf-basins. In general sediment in well sorted and negatively skewed and in places relatively coarse where found on the open shelf, but is poorly sorted and contains ice-rafted pebbles on the outer shelf and upper slope. Composition of the terrigenous sands suggests use of the term "graywacke" to characterize them. Sorting generally is good, however, with the clayey matrix considered important as a component of graywacke type sands (Pettijohn, 1949, pp. 243-44) occurring only in most protected areas.

Marked changes occur in the stratigraphic section deposited on the outer shelf and upper slope in post-glacial time. These changes seem to be due to: (a) the melting of glaciers and the removal of an abundant source of very fine material and (b) later removal of drift ice and therefore the means of transporting pebbles and granules. It is believed that similar stratigraphic details are present in the shelf-basins but have been more deeply buried.

ENVIRONMENTAL CHARACTERISTICS OF THE NEAR ISLANDS REGION AND THEIR EFFECTS ON MARINE SEDIMENTATION

Interpretation of the shelf deposits of the Near Islands requires an understanding of the environmental factors which contribute to the formation and distribution of sediments. In the subaerial environment these factors are climate, vegetation, nature of weathering and erosion, and agents of sediment transportation. In the marine environment the factors are temperature, large scale currents and history of the water mass, chemical characteristics of the water, waves, and tidal currents. These factors of the subaerial and marine environments and their relationships to the sediments will be discussed at such length as the available data permit.

Subaerial Environment

Climate.

The climate of a region is the average weather and is made up largely of the factors of temperature, precipitation, and winds. The Atlas of Climatic Charts of the Oceans (1938) has been relied on almost entirely for numerical climatic data. Because this information is based on ships' observations at sea it must be modified when the islands are concerned. Various works of the Department of Agriculture (Dept. of Agriculture, 1949; Dellogg and Nygard, 1951) contributed to such modification as has the Coast Pilot (Alaska, Pt. II, 1947). Meteorological personnel of the U. S. Navy stationed on Attu furnished some additional information.

The basic climatic information on the area is given in table IX. These data show average absolute values of the principal climatic factors for any month and also the annual cycle of these factors.

The average winds blow with minimum velocity during the summer months, rapidly increase in intensity reaching a maximum in November and December, decrease somewhat and remain approximately constant until May when they begin to moderate. During June, July, and August the winds are relatively light and variable in direction, but blow predominantly from the southwest off the North Pacific Ocean. During the remainder of the year (September through May) wind force is much greater and the predominant direction is from west to northwest, off the Asiatic mainland. This annual pattern of wind direction seems to be of great significance in its effect on the heat budget of the area. Warm moist air from the southwest cannot take up heat from the relatively cold sea; however, heat can be taken up from the relatively warm sea by the cold, dry air from the Asiatic mainland during the winter months. Atmospheric phenomena accompanying the heat exchange in winter result in extreme instability of the air mass and large scale vertical mixing and winds (Burke, 1945, p. 98). In the summer the air is cooled from beneath, stabilization and condensation take place, and the thick fog blanket often seen in the Aleutians is produced. The pattern of winds also seems to be important as a factor affecting general marine circulation of the area.

Fluctuation in the precipitation pattern is not marked. The average annual rainfall of approximately 75 inches is well distributed throughout the year with November showing the maximum of around

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Table I[illegible]

AVERAGE [illegible] CONDITIONS, NEAR ISLANDS AREA

(From Atlas of Climatic Charts of the Oceans, 1938, Charts 1-130, Table 3)

Month	Ave. wind velocity (by seasons)	% of winds Beaufort 7[1] or greater (Beau. 8)	Fog[2,3]	Cloud Cover (in 10ths)	Ave. Air Temp.[4]	Ave. Sea Surf. Temp.[4]	Relative Humidity	Rain in any Form[5]
January	18	20 (15)	few	7	33.0	36.7	80	10
February	18	18 (15)	few	7	33.0	36.1	80	10
March	16	20-25 (5-10)	1-5	6	34.7	36.1	81.5	12
April	16	20 (5-10)	1-5	6	35.8	37.0	82	12
May	16	10-15 (5-10)	1-5	8	37.9	38.3	83	12
June	10	5 (1)	20	8	42.3	42.1	92	14
July	10	1-5 (1)	20	8	46.3	45.7	93	15
August	10	10 (1)	20	8	50.4	49.8	93	16
September	17	15 (10-15)	1-5	7	48.8	[illegible]	86	20
October	17	15-20 (10-15)	1-5	7	44.2	45.4	85	20
November	17	25 (10-15)	1-5	7	38.6	41.5	83	20
December	18	25 (15)	few	7	35.4	38.4	82	10

[1] Percentage of Greenwich mean noon observations showing wind indicated.

[2] Percentage of Greenwich mean noon observations showing light or dense fog.

[3] Mist and haze follow same pattern.

[4] In degrees Fahrenheit.

[5] Percentage of Greenwich mean noon observations showing rain in any form.

Wind direction, while highly variable, tends to be from the west to north quadrant from September through May and from the southeast (off the North Pacific) from June through August.

nine inches. Snow covers much of the higher regions of the islands for a considerable portion of the year to depths of six to eight feet. No figures are available for Attu, but the blanket at high elevations must persist for a longer time than on the low island of Shamya in the Samichis where snow is present an average of 120 days from October to early April (Coast Pilot, 1947, p. 357). The effect of this snow blanket is to increase the fluctuation in runoff which otherwise might be quite uniform in response to the uniform precipitation. The melting of the snow blanket in spring can be expected to produce freshets and floods capable of transporting relatively large quantities of sediment from the higher regions of the islands.

The annual range of average sea surface temperatures and the range of average air temperatures immediately above the sea are shown in table IX. Both air and sea temperatures reach their maxima in August and steadily decline to minima in February or early March. The data in table IX must be modified when considering the islands, particularly the higher portions. The Navy weather station maintained on Attu noted a maximum range in temperature of 10° to 70°F. This station is located near the shore so that this range in extreme temperatures is intermediate between that found at sea and in the higher portions of the islands. The maximum temperature in higher parts of the islands probably does not increase greatly, if at all, but the minimum may be somewhat lower. A mean monthly temperature range of somewhat over 50°F. to a minimum of something like 20°F. is a reasonable estimate for the higher portions of the islands.

It is possible to classify the climates of the region in the

Hoppen system using this information (James, 1935, pp. 371-79). The marine climate of the area can be classified as a Cfca's[1/] climate, whereas the higher regions of the islands appear to have a Dfc[2/] climate.

Native Vegetation.

The native vegetation of the Near Islands is a tundra association. A thick green carpet of vegetation covers much of the lands at lower elevations. This vegetation consists primarily of dwarf Arctic shrubs including crowberry, dwarf willow, dwarf birch, mosses, lichens, and various flowering plants. Some sedges and grasses are found nearly everywhere, and in a few places they are dominant in the flora (Kellogg and Nygard, 1951, p. 16, fig. 12; Dept. of Agriculture, 1949, p. 68). This carpet in general is thickest on low slopes near sea level and becomes more sparse with increasing elevation and land slope. Much of the highest area of the islands, the higher peaks, and the steeper slopes are practically devoid of a cover of vegetation.

Soils.

In the development of soils climate is important in its effect on the character and rate of weathering and on the vegetation. Climate controls the total amount of water which may be present and

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1/ Temperature of coldest month below 18°C but above -3°C; temperature of warmest month over 10°C. No dry season. Cool short summers, maximum rainfall in autumn. Frequent fogs.

2/ Temperature of coldest month below -3°C; temperature of warmest month above 10°C. No dry season. Cool short summers.

thus affects drainage. The precise nature of the relationships between soils and climate is not understood, but their existence is indicated by the close correlation between soil types and climate belts (Kellogg and Nygard, 1951, p. 22; Jenny, 1950; Reiche, 1950).

Two types of relief conditions affecting runoff and soil drainage exist in the Near Islands (cf. Kellogg and Nygard, 1951, pp. 24-25). The first of these is a steeply sloping or excessively drained surface on which plants have less water than do those on adjacent more gentle slopes. The soil profile under these conditions is thin if present at all, and rapid erosion of the surface takes place. The other extreme is a nearly flat or depressed area with poor drainage. The water table is even with or near the surface of the ground at all times. In these cool humid regions organic matter forms more rapidly than it is destroyed and under such conditions may accumulate in thick deposits. There is no erosion from such an area. These two types of conditions represent extremes between which intermediate sub-types occur.

In general, time has been short for soil formation in the Near Islands. This is a function of both the relative youth of the topography and the cool climate. The climate and the agents which have caused the physiographic development have been of greater significance in the higher reaches of the islands, so that time for soil formation has been shortest in these areas.

Kellogg and Nygard published a map of Alaska showing the distribution of soil associations (1951, cover page 3). In the legend accompanying the map the types of soils in each association and the relative proportions of these types are given. Soil types of the Near Islands, their proportion of the whole, and short definitions of each are listed below.

1. Lithosol (40-50 percent) Azonal soils that consist mainly of rock with or without thin irregular coverings of true soil material. Generally found above 1000 feet.
2. Tundra (without permafrost) (30-40 per cent) Soils with a tough fibrous brown mat of vegetation on the surface underlain by a few inches of dark colored humus-rich soil which fades to a lighter colored gray or mottled soil beneath. Soils nearly always wet but because of low temperature, physical processes of weathering predominate. Found in lower stabilized valleys and on smooth uplands.
3. Alpine Meadow (5-10 per cent) Soils have a mat-like covering of vegetation which has less mosses and lichens than does the tundra. Similar to tundra but has less well-defined horizons.
4. Bog (5-10 per cent) These soils consist chiefly of organic matter, more or less decomposed. In lower stabilized valleys and on smooth uplands.
5. Alluvial (5-10 percent) Soils which are derived from alluvium so freshly deposited that few, if any, of the effects of vegetation and climate can be seen.
6. Regosol (5-10 percent) Soils which consist mainly of soft or unconsolidated rock with or without thin irregular coverings of soil material. Are not stony like lithosols

and roots can more easily find a foothold. Include relatively fresh morainic debris left by glaciers and beach sands and dunes.

Thus within the relatively small area of the Near Islands a number of different types of soil develop in response to the differing interactions of the agents producing soils from the parent material. From the nature and distribution of these soils, however, it is apparent that some are more subject to erosion than are others. Soils of the high areas, the steep slopes, and the nearshore environments, poorly protected by vegetation, erode much more easily and rapidly than do the stabilized soils of the bogs and the smooth valleys and uplands. Soils of the areas most subject to erosion are the lithosol, regosol, alluvial, and to some extent, the upland meadow. Although these soils may cover no more than 65 per cent of the island area, the proportion of clastic material for sediment which they yield must be 90 percent or more. Sedimentary materials furnished by these soils is similar to the original rock in nature. It has been derived from the fine-grained parent rocks by mechanical processes of weathering with little alteration by chemical processes, and as rock fragment sand, is found to constitute the largest proportion of the marine bottom deposits. Clay-sized particles, which also must be formed, were found in surface deposits only at the inner end of the most protected bay close by the mouth of a river (E 132).

Agents of Erosion and Transportation.

Agents of subaerial erosion in the Near Islands are primarily wind, streams, and glaciers. These agents also are active in supplying terrigenous detritus to the sea.

Winds of the Aleutian Islands blow with high velocities at some seasons of the year (see table IX). Speeds approaching 100 miles per hour have been recorded and winds of somewhat lower speed are relatively common during the stormy seasons of the year. Winds of this force can transport large quantities of sediment if all other conditions are proper, but a cover of vegetation and a wet or moist soil combine to make the work of the wind less effective. Winds of these high speeds are largely the result of concentration and funneling of air in the larger valleys, so that much of their force is dissipated in areas where the thick moist mat of vegetation does not favor such transportation. For this reason it does not seem likely that much sediment is carried into the sea by wind.

The high rainfall on the islands insures a constant flow of streams to the sea, and they are capable of transporting large quantities of sediment. In the summer the streams are clear, but in spring under the influence of melting snow they are more capable of removing material.

Streams are aided in transporting sediment by processes of earth slumpage which occur in the islands. Solifluction is a common process because of the climate and topography. In addition, the steep valley walls left as a result of glaciation and the intensely faulted nature of much of the bed rock suggest that large scale land slides must occur occasionally.

Despite the effectiveness of erosion at higher elevations and the capacity of the streams, terrigenous sediment is not delivered to the sea at a high rate because of the small size of the source areas.

Glaciers appear to have been the most effective agents of sediment transport to the sea within relatively recent times, although they are no longer present on a large scale. All of the large valleys have been heavily glaciated and exhibit typical U-shaped, over-flattened, valley floors. Large volumes of rock have been removed to develop these land forms. Glaciers have been of further significance in their effect on subsequent rock weathering and stream transportation. They are responsible for the steepened valley walls which afford poor sites for the development of deep mature soils, and the flat valley floors which are of such low gradient that the erosive efficiency of running water is reduced.

Marine Environment

Water Mass of the Western Aleutians.

The water mass which is found in the region of the western Aleutian Islands is a subarctic type. Sverdrup (1942, p. 712) has termed the water north of about 45 E the North Pacific Subarctic Water Mass. Uda (1935, p. 127) considers the water with temperatures below 15° and salinities below 34°/oo to be Oyashio Water (- Subarctic Water of Svardrup in part). The temperature of this water around the Near Islands varies from about 11.5°C in the surface layers to 2°C at 1000 meters in the summer. Salinities vary through the same depth range from about 31°/oo to 34.5°/oo (Sverdrup, 1942, pp. 712-13, figs. 199, 200; Uda, 1935, 1938; Zeusler, 1934, p. 49). The temperature and salinity of the upper 100 meters is variable, being affected by seasonal changes due to heating, precipitation, and mixing, but below this depth the water is reasonably uniform in characteristics. From 100 to 1000 meters the temperature changes from 3° or 4° to 2°C, and the salinity increases from 33.3°/oo to 34.5 °/oo. In general it may be said that the surface water around the Near Islands is cold, south-flowing, Oyashio Water of relatively low salinity, the characteristics of which are developed in the Bering Sea.

Water Temperature.

Study of water temperature is important because it constitutes one of the important environmental features of the Near Islands Shelf. In addition, this information can be used to indicate some of the features accompanying flow of water. The EIDER, during August of 1950, made observations of surface water temperature at all stations and collected a large amount of vertical temperature data with the bathythermograph. These observations were distributed on a relatively close grid. The period within which this information was collected is of sufficiently short duration to permit evaluation of the maximum temperature achieved. This is of particular significance, because it is only during the period of maximum water temperature that the potential extent of variability can be assessed. Moreover, details of temperature distribution which would be obscure under conditions of small range can be studied.

Naval vessels, operating in the Aleutians during World War II, also made many bathythermograph observations distributed throughout the year. These records are on file at the Scripps Institution of Oceanography and were studied. Thus, quite detailed information is available during the short critical period of the year, and sufficient material during the remainder exists to permit evaluation of the changes in temperature and its distribution, areally and with depth, which occur on an annual basis.

Bathythermograph records are expressed in degrees Fahrenheit and feet. These units have been retained in some of the diagrams, but the more conventional fathoms are used in the discussion to indicate depth.

Distribution of surface temperature in August is shown in figure 10. When seen in detail the distribution is complex, but viewing the area generally it is apparent that temperatures tend to be high offshore and low over the insular shelf. Within the area of detailed study the temperatures are higher in the Bering than in the Pacific, and these higher temperatures are closer to shore. Topographic highs in general have associated with them colder surface water than do the depressions. Warmer surface water tends to lie along the eastern margins of the main north-south pass in large isolated patches. The coldest surface water of the area also is found in the main pass and overlies an area of relatively shallow bottom which is highly irregular in contour. Although the islands are surrounded in general by colder surface water (see especially Agattu), the heads of the deep bays on Attu contain water which is somewhat warmer than in adjacent more exposed areas. Two large cold areas are indicated off the northwest coast of Attu. The observations which established these latter features were made during one period of flood tide and can be considered synoptic.

The cross sections of temperature distribution (figs. 11, 12, 19) show much of the same complexity. They serve to indicate further the correlation between irregularity in the bottom topography and in the temperature structure of the overlying waters. Another feature brought out by these figures is the tendency of the isotherms to diverge over the insular shelf. This is seen on the surface chart as a decrease in temperature toward the islands. The vertical temperature sections showthat there is an accompanying increase in temperature of the bottom layers. This probably is the result of vertical mixing induced by flow over the bottom and results in a water column which is more homogeneous in temperature throughout a particular depth range in the shallower water than would be found in a comparable depth range farther to sea.

Before it is possible to discuss the temperature distribution at other seasons of the year, the amount of the annual change and the depth to which it is effective must be known. Adequate data are not available for this development within the immediate area of the Near Islands. However, by using information from areas closely adjacent, a reliable cycle can be portrayed. Figure 14 shows this cycle in the form of actual bathythermograms. Three records which are representative of each month have been selected for this figure from those studied. Table X gives the positions where these records

Page 128 - Figure 10

FIGURE 11

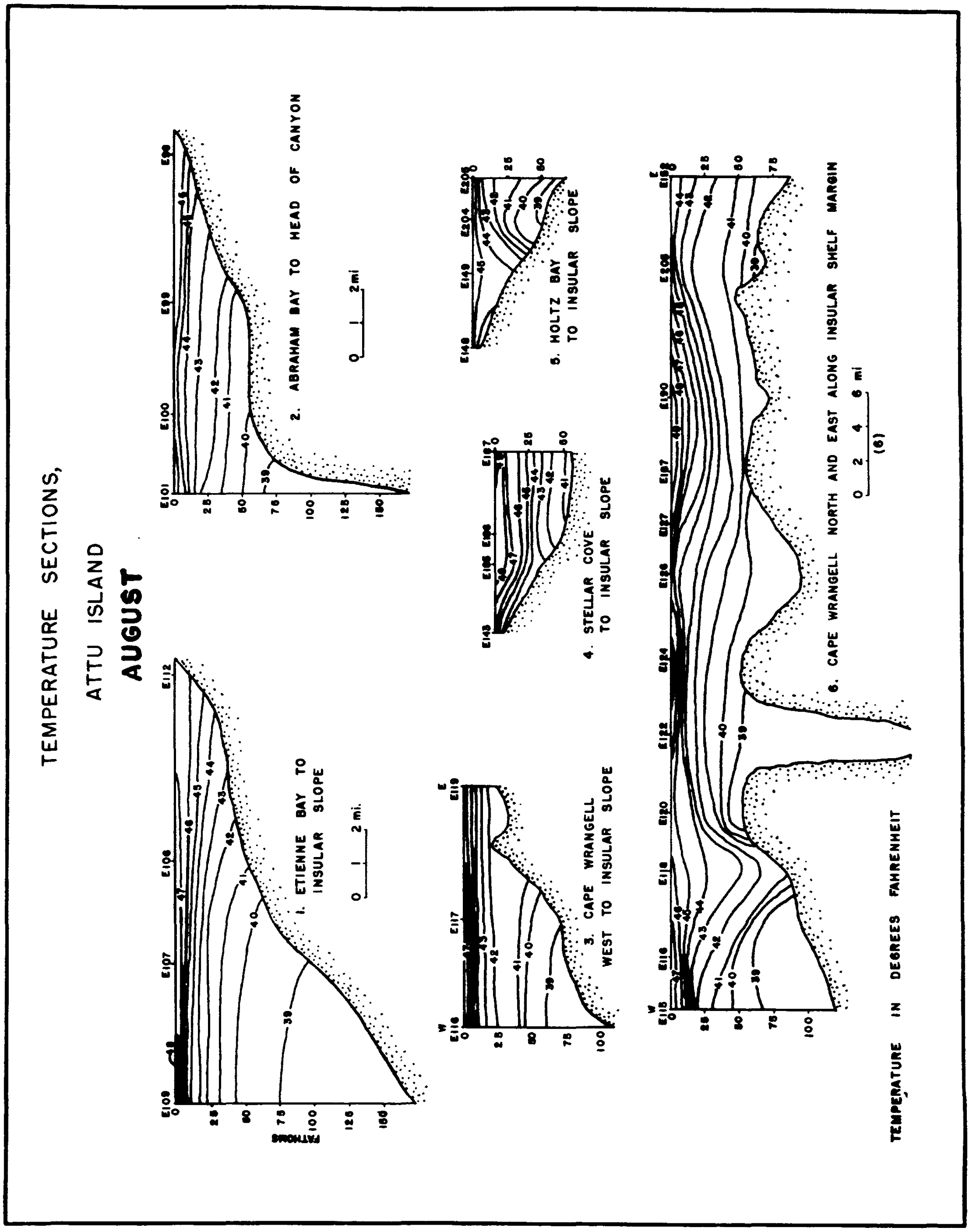

TEMPERATURE SECTIONS,
ATTU ISLAND
AUGUST
1. ETIENNE BAY TO INSULAR SLOPE
2. ABRAHAM BAY TO HEAD OF CANYON
3. CAPE WRANGELL WEST TO INSULAR SLOPE
4. STELLAR COVE TO INSULAR SLOPE
5. HOLTZ BAY TO INSULAR SLOPE
6. CAPE WRANGELL NORTH AND EAST ALONG INSULAR SHELF MARGIN
FATHOMS
TEMPERATURE IN DEGREES FAHRENHEIT

FIGURE 12

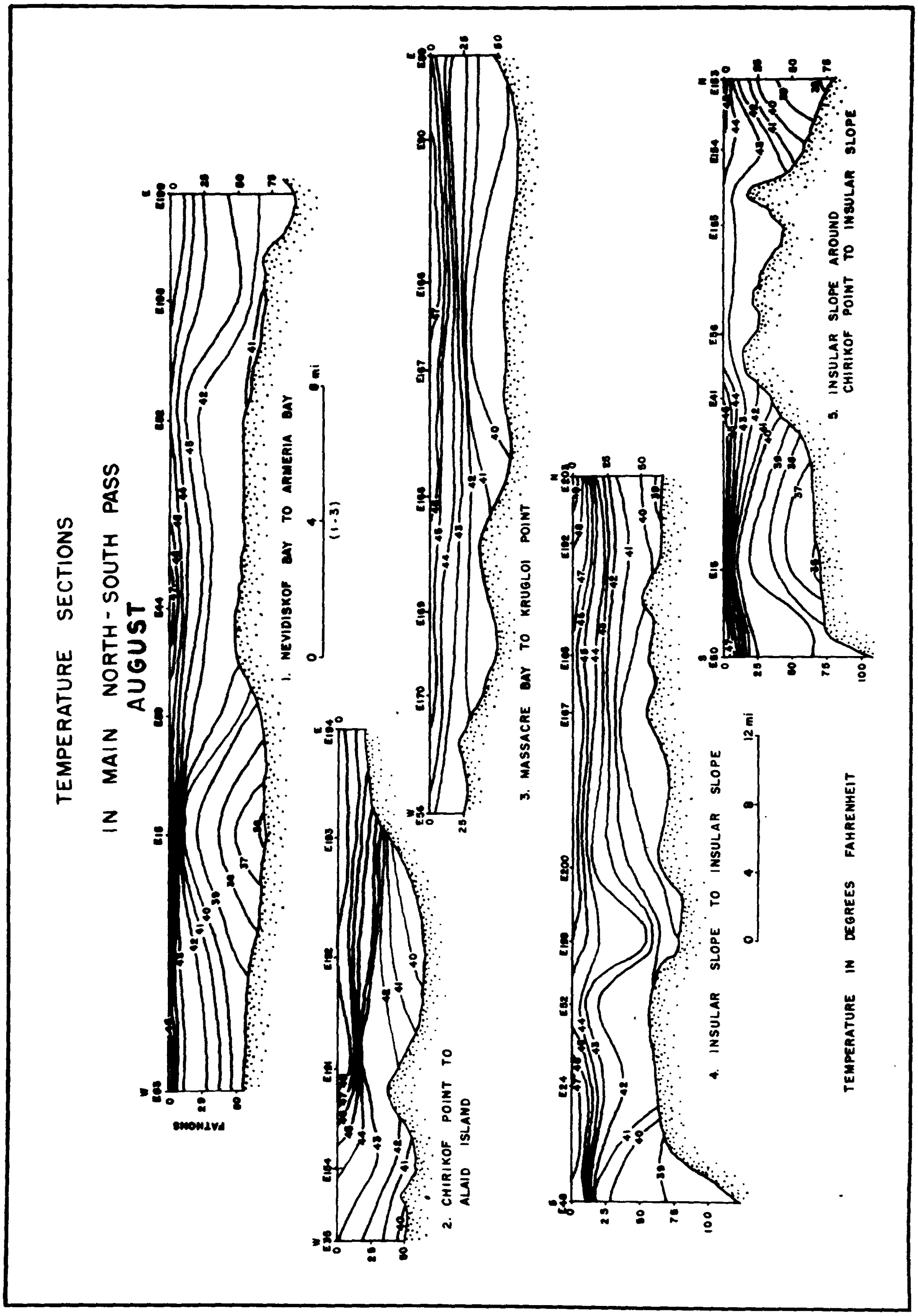

TEMPERATURE SECTIONS
IN MAIN NORTH-SOUTH PASS
AUGUST
1. NEVIDISKOF BAY TO ARMERIA BAY
2. CHIRIKOF POINT TO ALAID ISLAND
3. MASSACRE BAY TO KRUGLOI POINT
4. INSULAR SLOPE TO INSULAR SLOPE
5. INSULAR SLOPE AROUND CHIRIKOF POINT TO INSULAR SLOPE
TEMPERATURE IN DEGREES FAHRENHEIT
FATHOMS

FIGURE 13

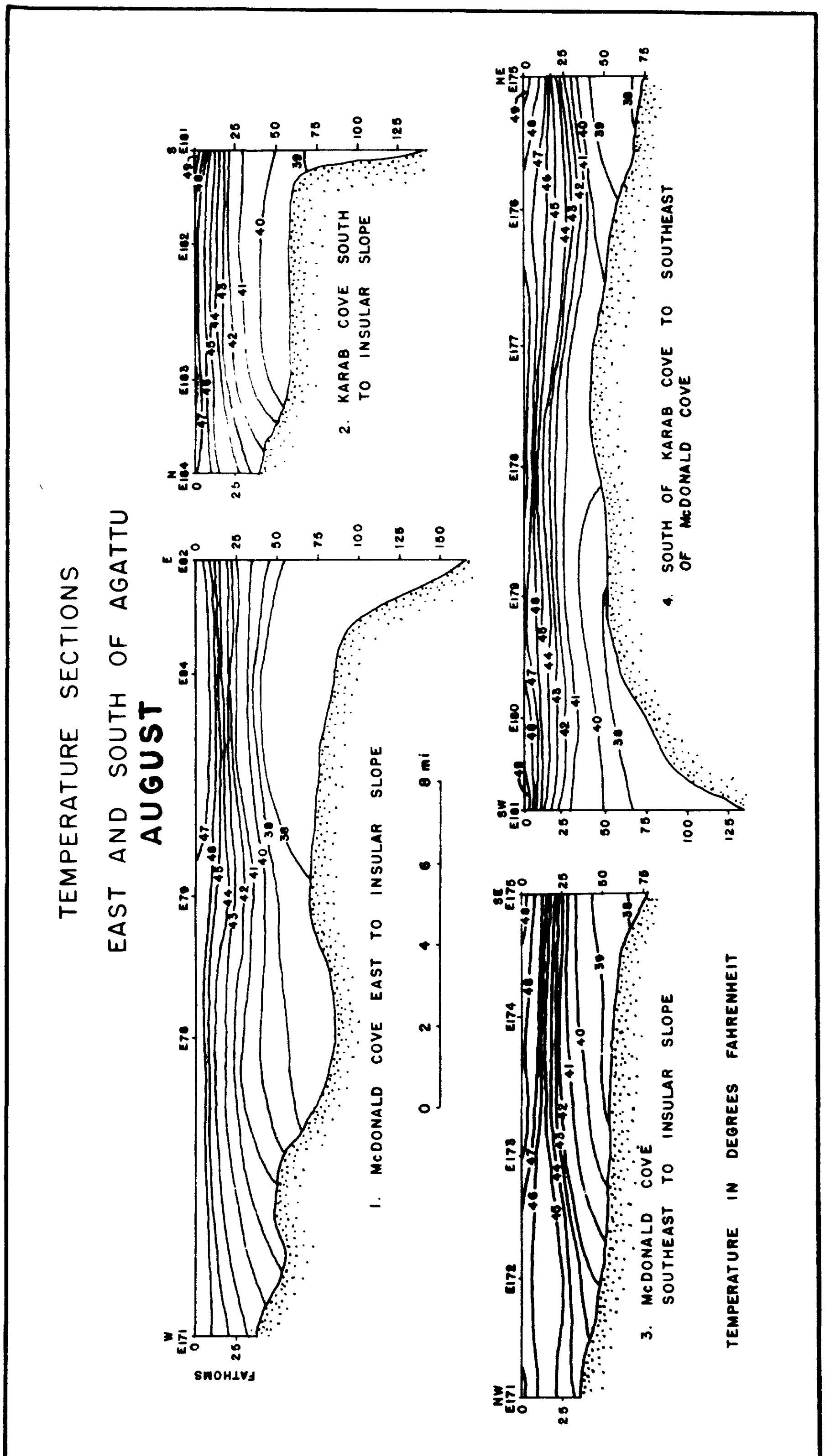
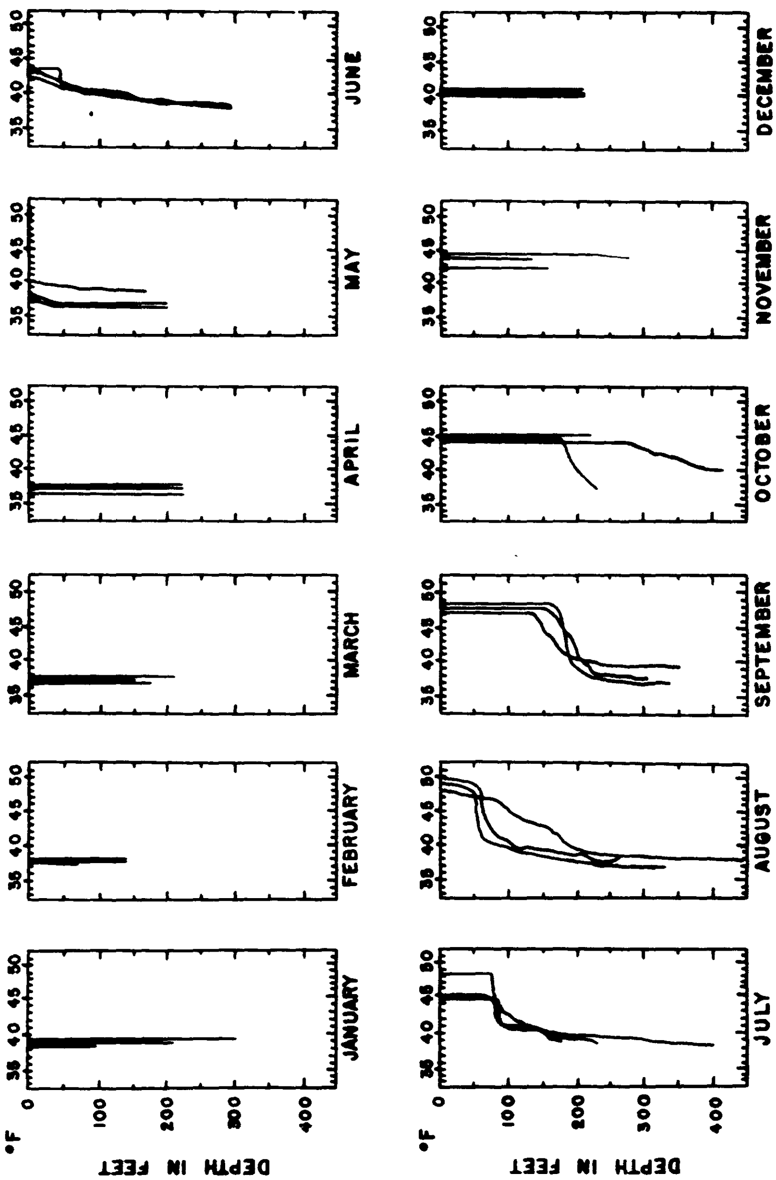

TEMPERATURE SECTIONS
EAST AND SOUTH OF AGATTU
AUGUST
1. McDONALD COVE EAST TO INSULAR SLOPE
2. KARAB COVE SOUTH TO INSULAR SLOPE
3. McDONALD COVE SOUTHEAST TO INSULAR SLOPE
4. SOUTH OF KARAB COVE TO SOUTHEAST OF McDONALD COVE
TEMPERATURE IN DEGREES FAHRENHEIT
FATHOMS
0 2 4 6 8 mi

FIGURE 14



THE ANNUAL CYCLE
OF VERTICAL THERMAL STRUCTURE
IN THE NEAR ISLANDS REGION
(FROM BATHYTHERMOGRAMS, 1943-50)

Table X

DISTRIBUTION OF BATHYTHERMOGRAMS

SHOWN IN FIGURE 14

Month	BT Number		Date Taken	Lat. (N)	Long. (N)	Surf. Temp. (°F)	Water Depth (Fath.)	BT Depth (Feet)
January	V-61-1	1	1-4-44	52-56	173-15	38	50	90
	V-21-3	8	1-25-44	51-51	172-42	39	--	303
	V-112-4	3	1- 7-44	52-28	172-00	37.5	1200	210
February	V-66-1	92	2-17-44	52-50	175-05	38	2000	70
	V-66-1	94	2-21-44	53-00	174-00	38	--	140
	V-66-1	93	2-18-44	52-52	173-40	38.2	380	140
March	V-66-2	3	3-11-44	52-42	174-04	36.5	0	175
	V-61-2	9	3-18-44	52-51	174-30	37.0	1900	150
	V-61-2	10	3-18-44	52-54	174-00	37.5	1200	210
April	V-19-5	13	4-6- 44	52-48	173-50	36.5	63	225
	V-19-5	14	4-6- 44	52-50	174-00	37.1	1050	225
	V-19-5	15	4-6- 44	52-50	174-11	37.5	--	225
May	V-60-2	2	5-16-44	52-35	173-52	38.0	83	200
	V-60-2	3	5-16-44	52-39	173-58	38.0	79	200
	V-23-1	1	5-19-43	52-40	174-35	40.0	500	170
June	V-16-3	67	6-26-43	52-50	173-38	42.2	500	290
	V-16-3	69	6-27-43	52-55	174-36	43.0	1500	290
	V-15-3	65	6-19-44	52-55	174-16	43.5	2130	175
July	V-19-6	8	7- 4-44	52-59	174-31	44.5	2150	190
	V-19-8	7	7- 4-44	52-54	173-58	45.0	1560	225
	V-66-4	7	7-31-44	52-40	171-50	48.2	1200	400
August	GS-1 E175		8-17-50	52-19	174-00	48.2	75	440
	V-19-3	61	8-18-43	52-59	173-50	49.0	--	130
	V-19-2	169	8-10-43	52-58	174-22	50.0	--	270
September	V-174-1	18	9- 3-45	52-45	174-16	47.4	2200	350
	V-19-4	67	9- 3-43	52-59	174-59	47.9	--	310
	V-19-4	70	9- 3-43	52-53	174-53	48.5	--	330
October	V-19-7	22	10-31-44	52-51	174-05	44.3	700	420
	V-19-4	26	10-12-43	52-57	174-02	44.7	--	230
	V-21-2	18	10-25-43	52-30	174-40	45.1	--	220
November	V-66-1	50	11-25-43	52-35	173-50	42.4	--	160
	V-27-3	2	11-10-44	52-48	173-49	44.0	58	130
	V-19-7	1	11- 3-44	52-48	173-55	44.5	160	275
December	V-66-1	58	12- 1-43	52-35	175-11	40.0	--	210
	V-66-1	60	12- 2-43	52-40	174---	40.5	--	210
	V-66-1	65	12- 8-43	52-48	173-32	40.9	50	210

were obtained together with the times at which they were taken and other appropriate information.

Figure 1 shows that the temperature reaches a minimum in February to March and warms in the following months to a maximum at the surface in August. From the maximum, the temperature drops until the following February or March. These observations agree with average values in table IX. The response by the water column to the agents causing changes in temperature is also well brought out by the figure. The cold, isothermal water column in April is warmed gradually from above in the ensuing warmer months. A small thermocline develops at the surface in May as winds decrease in speed and becomes steadily deeper and more pronounced with the passage of time until August. The month of August shows a slightly anomalous picture. In September, however, the thermocline is still deepening but beginning to be less pronounced. Increase in wind velocity and evaporation, decrease in air temperature and absorbed radiation, and deepening of the mixed layer with a diminished thermocline development continue until probably January when the water column in the upper layers again is isothermal to considerable depths. The temperature of the water continues to diminish until the minimum is reached, when the trend is reversed. The precise depth to which the annual change is effective cannot be determined from the available information. The fact that the temperature in the surface layer reaches a minimum of about 36°F and the water column is isothermal vertically, however, suggests the change must extend to depths of 100 to 200 fathoms. Below this depth of change a temperature inversion appears to be likely during a short period of the year, as a temperature of 36°F is not found at deep stations in the area above approximately 1000 fathoms. Regardless of the absolute depth to which the annual change is effective, all of the shelf area is subject to the cycle.

Knowledge of annual changes permits evaluation of temperature distribution, both vertical and horizontal, in the water on the Near Islands Shelf during other periods of the year. Figures 10, 11, 12, 13, and 14 show that in August temperatures may be found at the surface in some places which are characteristic of depths as great as 25 fathoms in the normal vertical temperature distribution over most of the shelf. This condition leads to surface temperature variations of as much as 8°F within the area. Variation of surface temperatures at other seasons is less, as the vertical distribution of temperatures becomes more uniform. Surface temperatures probably are nearly uniform over the shelf when the isothermal layer extends below the general level of pronounced roughness elements.

Figure 15 shows the distribution of temperature at the bottom during August as indicated by EIDER bathythermograms and also can be used to give the extent of annual bottom temperature variations. This variation can be arrived at by subtracting the minimum temperature reached in the area (about 36°F) from the temperature shown on the figure at the desired location. The value derived in this manner will not be precise for all locations because of the nature of the annual temperature cycle. Figure 14 shows that temperatures may be higher at depths from about 50 feet to 50 fathoms during

September, October, and November than in August. Thus, for depths between 50 feet and 50 fathoms the maximum range of temperature averages approximately 2°F greater than is indicated by figure 15.

The annual temperature cycle of the Near Islands is a product of changes due to local absorption of radiation and climate and changes resulting from currents flowing from other regions. The relationship of the benthonic Foraminifera fauna to temperature conditions in the Near Islands has been discussed. This fauna consists of species whose distribution apparently is controlled more or less by the temperature regimen and therefore reflects this regimen in the bottom sediments. The diatom flora of local origin appears to illustrate this same control. Insofar as temperature is the product of local conditions, these organisms reflect those conditions. Planktonic Foraminifera and diatoms, however, are distributed by currents and are characteristic of water masses with properties developed over wider areas. The relationship of these organisms to the environment can be understood only through an understanding of these larger scale phenomena.

Salinity.

The distribution of salinity around the Near Islands is less well known than the temperature distribution. The little information available has been cited in the treatment of the water mass of the area. All that can be added is on the probable nature of the vertical and horizontal distributions and the annual cycle.

The climate, currents, and effects of bottom topography and the

Page 137 - Figure 15

islands probably exercise primary control on the magnitude and distribution of salinity, as with temperature. Zeusler (1934, p. 49) gives the results of salinity determinations made in August near Attu, and from these something of the magnitude of the variations can be predicted. The surface salinity at the Chalga station was 31.00°/oo and at 25 fathoms it was 31.85 °/oo. If this represents the greatest range of salinity between these depths in the area, the surface salinities can be expected to vary within these limits over the area in a manner analogous to the temperature variation.

The strong winds and cooling of fall and winter produce a mixed layer through which salinity is distributed equally. Salinities can be expected to increase during this period of the year, despite the somewhat greater rainfall, because of the increase in evaporation (Jacobs, 1951, p. 85). If the salinity at 160 fathoms in August furnishes an indication of the amount of this increase, as does the temperature at that depth and time, surface salinities reach a maximum in the spring of about 32.7 °/oo. In general salinities probably vary between 30 and 33 °/oo.

Land masses may have pronounced effect on salinities of adjacent marine water because of dilution by large streams. The Near Islands are not large enough, however, despite the heavy rainfall, to contribute large volumes of fresh water. The effects of rainfall are lessened further because fresh water drainage is well distributed to the sea by a number of streams entering at widely scattered points. Surface waters at the heads of deep embayments where these streams enter must be somewhat less saline than the average surface water, but free connection with the open sea and strong currents insure rapid mixing so that the influence probably is not pronounced.

Minor Chemical Constituents.

Even less is known about the distribution of the minor constituents than is known about the salinity. Barnes and Thompson (1938, table 16, pp. 79-80) give the results of measurements of phosphate and silicate north of Adak in the Bering Sea; these measurements being the closest to the area that are available. The range of values at the surface and at 160 fathoms is given in the following table together with pH values at the same depths.

Table XI

Depth Distribution of Minor Chemical Constituents

North of Adak Island

(from Barnes and Thompson, 1938, Table 16)

Depth	P (acg at./L)	Si (mcg at./L)	pH
Surface	1.25-1.3	40-50	8.15-8.2
160 feet	2.2- 2.3	80-90	7.9

The values for phosphate and silicate agree quite closely with those found in the extreme South Atlantic and South Pacific oceans. They are higher than those found south of the Aleutian Ridge near Adak, a condition which is explained by Barnes and Thompson (1938, p. 60) as the result of turbulence and vertical mixing induced as the waters cross this ridge.

Semi-Permanent Currents of the Western Aleutians.

The current pattern in the western Aleutians is not well understood. This lack of understanding is in part a function of geographic isolation and the weather conditions of the area. The region also is one which lies on the border of American and Russian spheres of control. A number of oceanographic expeditions to the Bering Sea have been conducted, but because of international complications, investigations largely have avoided the border zone. Thus, while much information has been obtained on surrounding areas, political and security considerations govern acquisition and publication of results on the margins, and the older literature must still remain the primary source for the Western Aleutians.

The lack of understanding is not entirely due to a lack of study. The region is extremely complicated in its current pattern. The work of Japanese oceanographers (Uda, 1935, fig. 49b, p. 91, pp. 126-130; Uda, 1938, figs. 4a, b, c, pp. 16-18, pp. 64-66; also Sverdrup, 1942, p. 721) has indicated the nature of the complexity in the region of mixing of the Kuroshio and Oyashio currents south and southeast of the Kamchatka Peninsula. Their studies show a zone of large eddies where these two currents meet. Seasonal or long-period variation in the volumes of water transported by these currents probably also contribute to the uncertainty (Sverdrup, 1942, p. 721; Wüst, 1929, p. 49). Any variation in the velocity, the volume of transport, or the locus of movement of any one of the major currents in the area must affect all others in some measure since they are later-related in time and space. Some idea of the extent of the complication can be gained from the observations made on Bering's voyage of discovery to the American continent. Assistant Navigator Kharlan Kushia, of Bering's vessel St. Peter, notes, after almost a year (November, 1741 to August, 1742) on Bering Island of the Koundorskis, the following current observations (Golder, 1922, Vol. I, p. 237): "When the west wind blew, it brought from Kamchatka to this island building timber which has been in use, (such as) smashed boats and Koriak deer sleds. When the east wind blew it brought from America big pine trees, oars, and weapons such as are used by the natives of America but not by those of Kamchatka." These remarks represent the first attempt to analyze the currents of the region.

Prior to 1933 most of the knowledge of the currents in the western Aleutians was derived from ships' records. The 1931 edition of the Coast Pilot (Alaska, Pt. II) gives a summary of conditions based on these observations; one which has been quoted in most reports on the area since its appearance. This report (p. 43) observes:

> "As far west as Attu Idland, water flows through the passes of the Aleutian Islands from the Pacific to the Bering. A rising tide increases the current to the north. A failing tide reverses it to the south, but this flow is of smaller velocity. Immediately north of the Aleutian Islands from Attu Island to Unalaska Island, the currents set toward the east and are not affected by tides."

Shortly after this statement was published a number of expeditions visited the Bering Sea. Some of these did a limited amount of work along the Aleutian Islands, furnishing most of the oceanographic observations which are available. Unfortunately, the results of these investigations do not entirely agree.

In 1932 and 1933 two Russian vessels made observations along the Siberian coast and the southern margin of the Bering Sea almost to Bristol Bay on the Alaskan coast. Principally on the basis of these observations, Ratmanoff published a review of the current patterns of the Bering Sea and North Pacific Ocean immediately south of the Komandorski Islands (Ratmanoff, 1937, portions translated from the Russian by Mr. Warren S. Wooster; also English summary, p. 117; cited by Goodman, et al, 1942, pp. 116-118). His chart of current patterns of the Bering Sea and the North Pacific Ocean, computed from the distribution of density from 0 to 100 meters, shows a large counterclockwise eddy lying to the west of the Near Islands. The water in this eddy moves south along the east coast of Siberia to a point south of the Komandorski Group where it turns east and finally northeast. The northeast flow of this current is shown moving past the northwest coast of Attu and into the Bering Sea. The part of this current chart in the region between the Fox and Komandorski islands is based on only five oceanographic stations which are not well distributed (see Ratmanoff, 1937, esp. figs. 4, 8). It is felt that construction of a current chart on so few data is unsafe, particularly when the indicated currents are in disagreement with the experience of most vessels in the area. These results agree, however, with the observations of Makarof in 1894 (cited by Stejneger, 1896, pp. 8-9, Pl. 2, 3) between Kamahatka and the Komandorski Islands and show a distribution of density indicating a south-directed current. Portions of the Ratmanoff chart in the region of the Near Islands have reappeared in later publications

(Goodman, et al, 1942, Pl. 37; Pattalle, et al, 1950, fig. 32).

The report of the voyage of the U. S. Coast Guard Cutter Chalan (Zeusler, 1934) contains a reference to the currents of the western Aleutians. This report states (p. 14):

> "The Kuro Suvo or Japanese current, breaks on the western end of the Aleutian chain. Half flows eastward south of the Islands and carries with it the warm moist atmosphere which is condensed on the snow packs and sinks downward in the fine and deliciousmist that gives the grass its vivid, brilliant, perpetual green. The other half passes northward into the Bering Sea."

Barnes and Thompson (1938) investigated the character of flow north and south of Adak Island in the Andreanof Group in June and again in August of 1933. They found (pp. 64-65, Pl. 24, figs. A, B) that the surface water of the Pacific 40 miles off the coast of Adak flows to the north with velocities greater than 0.3 knots. This northward movement may be accompanied by a slight easterly component. Closer inshore, the water was deflected to the west "by the Aleutian Ridge and the islands." The water in the Bering Sea just north of the islands flowed parallel to the ridge in an east and north direction. Some 40 miles north of the islands the current had a velocity component to the west of 0.1 to 0.2 knots. The westerly trend of this current in the Bering Sea was larger in August than in June. Currents in the Pacific were essentially unchanged during the interval. Between Unimak and Unalaska Islands of the Pox Group, Pacific water set north into the Bering at velocities up to 0.4 knots (the USC&GS, in a letter dated 3 July 1951, state that an average velocity to the north of 0.5 knots is used in their computation of currents in Unimak Pass). West of Unalaska Island the velocity component to the north into the Bering was less, but the general transfer of water from the Pacific into the Bering Sea was present. These observations constitute an enlargement on similar notes published earlier (Barnes, et al, 1935).

In August of 1937 the USG Bushnell occupied 18 oceanographic stations in a traverse from Adak to Cahu (Revelle, 1937). Fleming and Revelle (1939, p. 114, fig. 14) present the cross section of dynamic heights obtained from these observations. The distribution of dynamic heights indicates a general easterly movement of water south of Adak. This profile was begun about 100 miles south of Adak and the next station was 70 miles farther to the south. The profile indicates a general rise of isoharic surfaces to the south, but the distribution of stations precludes the possibility of detecting relatively small scale fluctuations in the current. Because of this the results cannot be considered to be in disagreement with the observations of Barnes and Thompson in the same area.

Sverdrup (1942, pp. 722-23, Chart VII, figs. 202, 203) discusses currents in the North Pacific at some length. He concludes that the east-flowing warm water of the North Pacific Current does not extend north of about 45°N. North of this warmer water is the Aleutian (Subarctic) Currant also carrying to the east water which is formed by mixing of Kuroshio and Oyashio waters and is modified by cooling and excess precipitation. This current is said to branch and one portion flows northeast past the Near Islands into the Bering Sea where it enters a counterclockwise gyral (p. 722, fig. 205). This gyral circles the Bering Sea, is greatly modified by cooling and eventually flows south along the Siberian coast as the cold Oyashio Current. The other branch of this current continues flowing to the east. It eventually divides again, and a portion turns north and enters the Gulf of Alaska to form the counterclockwise-moving Alaska Current. This current appears on the one hand (fig. 205, p. 727) to merge with the east-flowing Aleutian Current south of the Alaskan Peninsula, and on the other hand (Chart VII), to continue with lessened volume in a westward direction south of the Aleutian Chain to the longitude of the Rat Islands (178° to 180°E).

Although no additional oceanographic stations have been occupied, a great number of observations of ships' navigators have become available. This is due to the unprecedented activity in the Western Aleutians during World War II. These observations have been resolved and appear in publications of the U. S. Coast and Geodetic Survey and the Hydrographic Office of the Navy.

The Coast Pilot (Alaska, Pt. II, 5th (1947) ed., p. 352) makes some general remarks on currents in the Aleutian Islands which indicate the progress of knowledge.

> "Southward of latitude 50°W., there is an eastward drift across the Pacific. An eddy, accompanying this flow, sets westward along the south shore of the Alaska Peninsula and the Aleutian Islands and then drifts through the passes into the Bering Sea. These currents form a part of the general circulation of the North Pacific Ocean."

> "Through the Aleutian Island passes, the velocities of the currents caused by tidal and wind affects are large enough to mask the continual northward drift through the passes."

> "In the past, numerous reports have been received to the effect that the flood currents flowing into the Bering Sea are very much stronger than the ebb currents. These reports

> have been largely discounted by observations in a number of the passages which in general reveal equally strong ebb currents flowing through the passes from the Bering Sea. It is believed that on account of the large diurnal inequality in the current of this region, mariners have been deceived by the long periods of flood current that occur near the times of the moon's maximum declination."

This passage shows the value of a re-examination and reappraisal of the older records and observations in the light of more recent data.

Study of the Current Charts of the Northwest Pacific Ocean (H. O. Misc. No. 10, 058-A, 1944) and Pilot Charts of the North Pacific (H.O. No. 1401) for 1949, 1950, and 1951 gives a picture which differs from some of the classical concepts outlined above. Perhaps the main feature shown on these charts is the variable character of flow in the area. The currents in general change both direction and position in time, and no pattern on a single map can indicate the detailed changes in the character of flow. Second, the flow west of Attu northeast into the Bering Sea seems to be unimportant when considering an average current distribution. The only suggestions of this flow which appear in the Current Charts are shown during March, May, and August. The Pilot Charts give no indication of its presence. In both publications the currents which are depicted move in an opposite direction (i.e., to the south, southwest, or southeast) either most or all of the time. Third, the permanent flow from the Pacific north into the Bering Sea between the islands which has been referred to above appears to be invalid in the Western Aleutians. Barnes and Thompson (1938, p. 65) note a tendency for the velocity of this flow to diminish to the west from a maximum in Unimak Pass. Their observation is in close agreement with the pattern presented northwest and finally, moves to the west. This same water particle may ultimately return to the Pacific, either east or west of the Near Islands in a current with a south component of flow.

A report covering the analysis of several thousands of bathythermograph observations in the Aleutian area was recently issued (Pattulle, et al, 1950). Part of the chart of surface currents in the Bering Sea as published by Goodman, et al (1942, Pl. 37) was used in the interpretation of the data. However, these data can be interpreted in the manner suggested above which seems more consistent with the pattern of flow indicated by the work of Barnes and Thompson around Adak Island (1938), the distribution of density suggested by the bathythermograms, the observations of ships' navigators in the Western Aleutians, and the Japanese biological data. In making this alternate interpretation it must be remembered also that the water which flows through the shallow passes of the Aleutian Islands is thoroughly mixed vertically, a fact which results in cooling of the surface layers (see this report, p. 129; also Barnes and Thompson, 1938, p. 52). This cooling of the surface layers may be indicated in the downstream direction of flow as a tongue of colder water.

With these various points in mind, construction of a chart of average current directions in the Aleutian region seems feasible as shown in figure 16. In drawing this chart the great variability of currents in the region is recognized and therefore, the figure is taken to represent an average current pattern. The eastern portion is based chiefly on previous charts supplemented by observations of ships' navigators. In the central portion (the region of the in the charts of the Hydrographic Office derived largely from observations of ships' navigators. The northward flow, marked in Unimak Pass, appears to decrease in intensity to the west, to reach a zero value in the region centered around the 180th meridian, and west of this, a general reversal of this flow to one from the north seems to be indicated. Finally, the concept of a general easterly flow in the Bering Sea just north of the Aleutian Chain appears to require some modification. The counterclockwise circulation north of the Aleutians in the eastern Bering is thoroughly substantiated by numerous observations. The flow pattern north of the western Aleutians, however, can be reinterpreted using the work of Barnes and Thompson in conjunction with the current charts and the work of Japanese biologists. Japanese fisheries biologists working in the northern Pacific Ocean and the Bering Sea have detected differences in the organisms inhabiting these bodies of water. Of the animals, copapods were abundant in the Bering Sea, spreading into the Pacific between the Rat and Near Islands. On the other hand the Pacific was rich in tintianids (Aikawa, 1936). Judging from the distribution of planktonic organisms, Aikawa (1936, p. 26) states: "The Bering water flows out to the Pacific through the passage between the Rat and Near Islands, while the Pacific water invaded the Bering Sea, especially along the coast of the Rat Islands." On the basis of these data, the path of a water particle moving in the current appears to turn to the northeast as it emerges between the Andreanof or Rat Islands into the Bering Sea. Instead of continuing east, however, as has been suggested earlier, it turns back to the

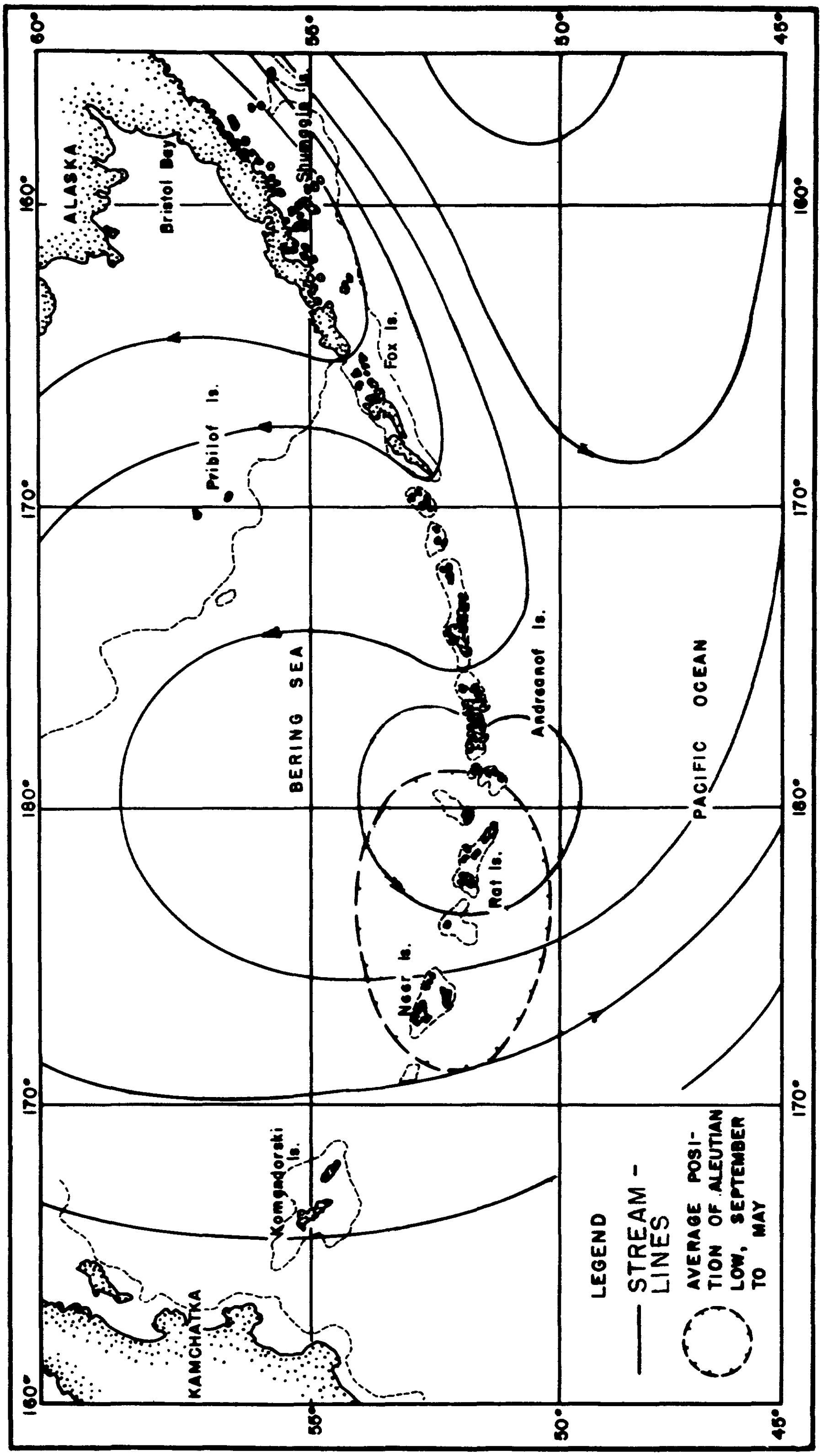
Andreanof Islands) the work of Barnes and Thompson was used as the primary framework. The western section is drawn largely on the basis of the experience of vessels in the region and the results of Japanese oceanographers and biologists, but is controlled by the density distribution suggested by bathythermograph data and further by the Ratmanoff and Makarof data in the extreme west. The chief differences in this chart and many of the foregoing ones is the presence of the counterclockwise eddy centered around the Rat Islands and the absence of the strong northeast flow into the Bering Sea west of Attu Island.

Speeds associated with this current pattern in the Western Aleutians seem to be generally low. Drifts due to semi-permanent currents observed aboard ship in this area range from zero to rarely as high as one knot. The most probable average speed appears to be of the order of 0.2 to 0.3 knots.

The foregoing synthesis and the resulting chart of average currents is not without other controls as well, although oceanographic observations are scarce. Figure 17 shows the distribution of stream lices of flow associated with this current pattern. The Pilot Charts of the North Pacific (H.O. No. 1401) show the average position of the Aleutian Low Pressure Area to center in the region of the Rat and Near Islands from September to May. The currents at the sea surface which would flow in response to the stress exerted by the counterclockwise circulation of winds around this low pressure area when a dynamic equilibrium has been attained are in good theoretical agreement with the character of flow in the Bering Sea deduced

Page 150 - Figure 16

FIGURE 17



SCHEMATIC DISTRIBUTION OF STREAMLINES OF FLOW INFERRED FROM CURRENT CHART from the considerations used in constructing the current chart.

The pattern of flow shown in figure 16 takes water from the North Pacific and subjects it to modification by cooling in the Bering Sea. During this process the water develops planktonic populations of Foraminifera and diatoms which are characteristic of these same regions, in addition to temperature characteristic of high latitudes. Southward flow from the Western Bering Sea brings these populations by the Near Islands where some of the skeletons are deposited. This process also modifies local effects of climate in determining temperature characteristics of the water.

The nature of the planktonic Foraminifera fauna of the Near Islands seems to corroborate the conclusions on the general current pattern as well. This fauna is the same as that found by Phleger (1952b) in the Canadian Arctic and in high latitudes of the Atlantic and is a characteristic high latitude fauna. The planktonic fauna reported by Nansawa (1928) is similar in most respects to that described by Parker (1948), Phleger (1939, 1942), Phleger and Hamilton (1946), and Phleger, et al (1953) from the warmer waters of the Western Atlantic. Phleger and his co-workers have found where mixing of water masses of different characteristics occurs, mixtures of the characteristic faunas are found in the underlying bottom deposits. Thus, the absence in Near Islands sediments of warmer water Foraminifera such as found by Nansawa below the Kuroshiwo suggests the warmer water masses are not introduced into this region as one component of a mixture.

Tidal Currents.

Some knowledge of local tidal currents is necessary to an understanding of sediment distribution in the Near Islands. Tidal currents frequently are strong and, in conjunction with wind waves, are of primary importance in the transportation and deposition of sediments. Such knowledge is not available directly as tidal currents in the Aleutian Islands have received little study. Currents have been measured on a more or less comprehensive basis at only nine stations throughout the Aleutians, and most of this work has been done in the eastern portion (Current Tables, Pacific Ocean, 1950, p. 125). Because of these conditions, evaluation of the distribution of tidal currents in the Near Islands must be made by reference to the character of the currents in adjacent better known areas and on the basis of visual observations and estimates. These interpretations are controlled by the few existing measurements.

Records of the U.S. Coast and Geodetic Survey indicate that in the Aleutian Islands the current generally flows into the Bering Sea on the flood and into the Pacific Ocean on the ebb. It was thought for many years that the flood currents were much stronger than the ebbs (Coast Pilot, 1931, p. 43), however, more detailed observations in a number of passes in recent years have shown this belief to be false (Coast Pilot, 1947, p. 352). In some areas the opposite is the case.

Passes between the Aleutian Islands may be the loci of very strong tidal currents. Speeds have been reported up to 12 knots in Akun Strait in the Fox Islands. However, speeds of tidal currents tend to decrease toward the west (Current Tables, Pacific, 1950, p. 125). This decrease in maximum recorded speed is in part the result of some cause other than the change which occurs in the character of the tide and may be because cross sectional areas of the western passes are greater. Increase in cross section permits the same volume of water to be transported in the same time with lower speed. In general an inverse relationship exists between the cross sectional area of a pass and the speeds of tidal currents. During periods of high winds associated with high spring tides some of the narrower passes are subject to a phenomena resembling a tidal bore (Coast Pilot, 1947, p. 353). The bottom topography also has strong control on the tidal currents; irregular bottom topography found in many of the passes causes great whirle, eddies, and reversals of flow making generalization difficult.

The Coast Pilot (1947, pp. 485-99) contains a number of qualitative references to currents at various localities in the Near Islands. In some cases these references are accompanied by estimates of current velocity. This information is primarily the result of work of the field parties of the Coast Survey which were in the area for several years. Other current observations in the form of notations of the location of tide rips appear on the field sheets prepared by these workers. The EIDER group undertook no program of current measurements. General observations were made, however, which corroborate, and in some cases amplify, similar observations of the Coast Survey. The pattern of temperature distribution obtained by the EIDER also can be used in connection with tidal current data as an aid in interpretation.

The few current measurements made by the U.S. Coast Survey are the only quantitative data available. This agency, in reply to a letter requesting all available current information in the Near Islands, gave the following statement (letter of July 3, 1951).

> "Current measurements were made near the northwest coast of Attu about 5 miles northeast of Cape Wrangell. They were made with current pole and line and represent the average current for the first 14 feet below the surface. They covered two tidal days during the period, July 17-19, 1946. Mean velocities of northeastward and southwestward strengths derived from the observations, are 1.4 and 0.9 knots respectively. These values include the resultant flow for the period of the observations, which was less than 0.1 knot and in a southwestward direction. The current sets northeastward about 9 1/2 hours and southwestward about 15 1/2 hours of the tidal day."
>
> "The only other record of current measurement in this vicinity contained in our files is that of a single current observation made off Kolobnikof Point, Attu Island on July 12, 1945, which showed a southeastward velocity of 1.1 knots."

Northeastward flow is the flood tide and southwestward flow is ebb. The Current Tables give a maximum flood velocity of 1.8 knots, a figure which gives only an indication of what the speed of the maximum current may be as the observations cover a very short period of time. The Current Tables for 1946 show the speeds at Unimak Pass for this same period to be below the maximum speeds at this station by one-third. Thus, it would appear that maximum velocities northeast of Cape Wrangell could be considerably in excess of those registered in the Current Tables.

Despite the differences between the general areal pattern and the detailed distribution in any particular region, these observations give a foundation for developing an interpretation of the tidal currents. Figure 18 shows inferred distribution and velocities of surface tidal currents. The cross-batched arrows of this chart indicate the generalized pattern of flow but nothing of the actual paths of water particles. These paths are much more complex, the water probably moving in great whirls and eddies controlled in position by topographic eminences. Current speeds over the area generally are related on the chart to the observed speeds northeast of Cape Wrangell (see arrow notation). Comparison of the cross sections of the passes between Attu and the Semichi Islands and Krysi Pass in the Rat Islands where speeds have been measured suggests currents may range up to a maximum of about four knots in the former. Temperature data show that the high speeds and the irregularities of the bottom cause flow in most of the area of the Near Islands to be highly turbulent.

Quantitative data relating the speeds of tidal currents at the surface to those near the bottom are scarce and somewhat inconclusive (cf. Stetson, 1938, p. 33), however, these currents tend to persist at depth with relatively small speed changes. Shepard (1948, p. 57) cites measurements made in the Golden Gate where the speed of a tidal current three feet above the bottom was about one-half of that at the surface. He attributed the decrease in speed to friction with the bottom. It is probably safe, therefore, to assume that speed of tidal currents on the bottom is in direct proportion to the surface speeds as modified by details of bottom topography. Temperature data also suggest this conclusion, indicating greatest turbulence in passes where speeds are highest and over irregular bottoms.

Wind Waves.

The nature of wind waves which occur throughout the year in the Near Islands is known only approximately. Larger waves are the ones of particular interest as they affect both the bottom and the water column to a greater extent than do smaller waves. Bigelow and Edmundson (1947, Pl. 9-16) give the average results of wave and swell observations by mariners over a long period of years in the North Pacific in August and February. These illustrations show that high seas and swell occur from 10-20 per cent of the time in August and from 30-40 per cent of the time in February. Sea is designated as high when waves are greater than 8 feet, whereas swell must be greater than 12 feet to be so designated.

More precise knowledge is not directly available; however, it is possible to calculate the characteristics of waves which might be encountered at different times of the year from the nature of the winds as given in the Atlas of Climatic Charts of the Oceans (1938). Using H. O. 604 or tables 4, 5, and 10 and figure 5 of Bigelow and Edmundson and making certain assumptions these calculations have been made. Table XII summarizes the assumptions and results. The summer waves are in close agreement with ones which were observed aboard the EIDER during (A) a short squall of one day duration in the middle of August and (B) a storm of nine days duration in late July. No direct check is available on the winter wave. It is felt that a wave of such characteristics is close to the maximum which

Page 158 - Fig. 18

might be experienced. The compilation of storm wave characteristics by Bigelow and Edmundson (pp. 23-26) and of seasonal variation in wave characteristics in the North Pacific by the Maritime Safety Agency of Japan (1951)[1/] suggest, however, that waves of this magnitude may be common in this area during the winter. Because of the variable wind direction and the exposed position of the Near Islands these waves probably can approach from a number of directions.

Table XII

Computed Wave Characteristics in the Near Islands Area

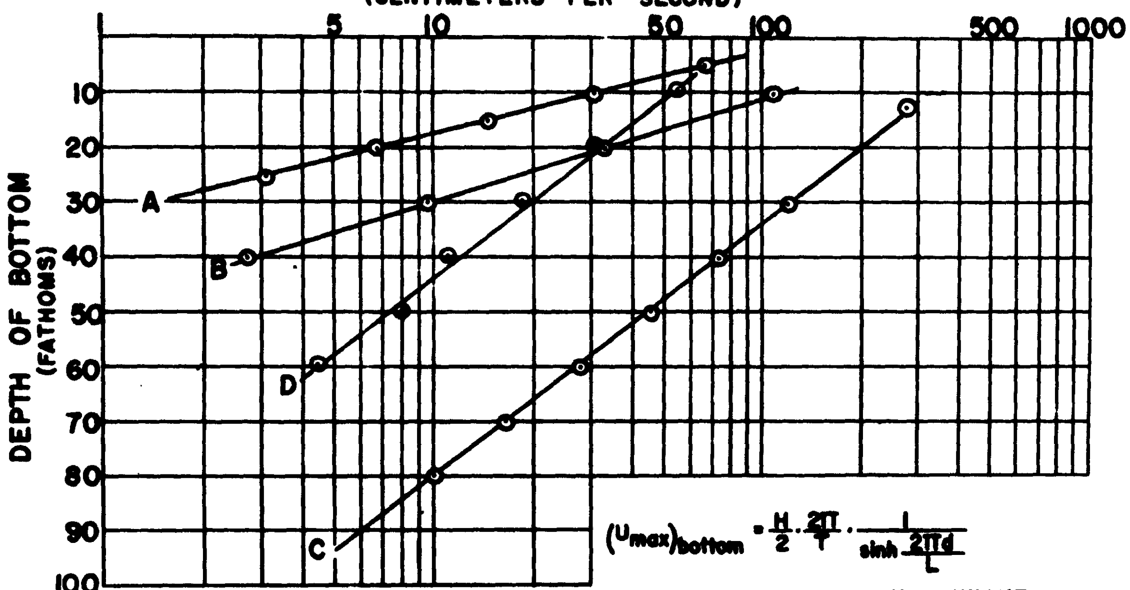
	Summer		Winter
Assumptions	A	B	C
Wind	15 knots	30 knots	40-50 knots
Duration	50 hours	20 hours	30-40 hours
Fetch	500 miles	300 miles	500 miles
Wave Characteristics			
Length	240 feet	300 feet	740 feet
Height	5.5 feet	16.5 feet	35.6 feet
Period	6.7 seconds	7.6 seconds	12.0 seconds

The depths to which waves are effective in disturbing the bottom and causing the movement of sediment is a point which often has been discussed with various conclusions being arrived at by the different authorities (cf. Johnson, 1919, pp. 76-83; Bigelow and Edmundson, 1947, p. 11; Shepard, 1948, pp. 46-47). The general concensus appears to be that the effect of surface waves extends to a depth equal to about one-half the wave length of the wave in question. Figure 19 has been prepared from theoretical equations using wave

1/ Up to 50 per cent of their observations in February showed seas to be very high, precipitous, or confused.

FIGURE 19

THEORETICAL ORBITAL CURRENT VELOCITIES DUE TO SURFACE WAVES ON BOTTOMS OF VARIOUS DEPTHS



$$(U_{max})_{bottom} = \frac{H}{2} \cdot \frac{2\pi}{T} \cdot \frac{1}{\sinh \frac{2\pi d}{L}}$$

H = HEIGHT
T = PERIOD
d = DEPTH
L = WAVE LENGTH

WAVE CHARACTERISTICS

	WAVE LENGTH[1]	HEIGHT	PERIOD
A	240 FT.	5.5 FT.	6.7 SEC.
B	300	16.5	7.6
C	740	35.6	12.0
D	740	6.0	12.0

[1] DEEP WATER

characteristics calculated above to show the maximum horizontal speeds which are associated with these waves on bottoms of different depths. The indicated speeds are to be considered as approximations because of the inadequacy of the equations to express conditions in shallow water. In addition, curve D is included to show the influence of wave height on horizontal current speed. Characteristics of wave D are the same as those of C except for height. The figure shows that the greater height of wave C makes its effect on the bottom greater than that of wave B at the same depth. Thus, the height of the wave as well as its wave length must be considered in judging the ability of waves to move sediment at a particular depth.

Wave B probably is typical of the worst storms which occur in the Near Islands during the summer. Wave C, on the other hand, may be expected in conjunction with the storms which commence in late October and continue until approximately April. This is the period in which the intense cooling of the water and the development of the thick homogeneous surface layer is experienced, and it is these high winds and waves of type C, occurring with some frequency, which must be responsible in large measure for the thorough mixing which takes place.

Distribution of Kinetic Energy.

The discussions of tidal currents and wind waves and the chart of bottom topography enable a qualitative estimate to be made of the distribution of kinetic energy on the sea bottom associated with the motion of water. Such a distribution must be qualitative and on a relative basis because of the nature of the data. Figure 20 shows the areal variation in kinetic energy level due to horizontal speeds of water particles near the bottom in terms of varying density of pattern. This diagram may represent the distribution of either kinetic energy or bottom stress as both of these forces are proportional to the square of current speed. The pattern was drawn from the areal and vertical distribution of speeds associated with tidal currents and wind waves and the modifying effects of the bottom on these currents. Modifying effects of the bottom include the refraction of waves and increasing or lowering of tidal current speeds on adjacent and downstream bottoms by topographic features.

Areas of intensive wave and/or tidal current action are shown heavily stippled, whereas areas with light stippling are protected from currents. Large waves strike the coasts of all the islands. In winter horizontal orbital speeds associated with these waves are effective in disturbing the bottom on most of the shelf. Effects of these waves are intensified on the numerous headlands of the islands by wave refraction over the seaward-extending noses (Munk and Traylor, 1947). Concentration of wave energy on headlands in this manner greatly reduces that reaching the heads of the deep bays. Southeast of Attu the irregular moraine topography further decreases wave energy in the bays. Large waves may be breaking heavily on the submerged reefs and pinnacles while comparative calm exists near shore. Tidal currents flowing across the shelf are concentrated in the passes and dispersed over the more open shelf. The moraine topography off Attu tends to direct flow of tidal currents in the north-south pass away from much of the southern shelf and to restrict higher speeds to upper water levels. Tidal currents of high speed sweep around the western end of Attu (Cape Wrangell), between the Semichi Islands, and around Ingenstrum Rocks and to a lesser extent Agattu as well. Exposed areas such as these are also loci of intensive wave action, so that energy is greatly concentrated on the bottom. During the summer of 1949 the EIDER was able to round Cape Wrangell on only one occasion because of high seas due to combined action of wind and tidal currents. Similarly heavy wave action in the harbor on Shamya (eastern Semichi Is.) on several occasions during World War II resulted in severe damage to moored vessels. The wide wave-cut benches off many of the headlands also confirm this general picture and bear testimony to the effectiveness of wave refraction. Shelf-basins are protected by the encircling sills from action of tidal currents; their depth also tends to reduce wave action.

Comparison of the chart of bottom character (fig. 4) and figure 20 shows that a general correlation exists between areas where sediment is present and where action of wave and tidal currents, deduced from other considerations, is low. Because energy distribution, to a first approximation, is inversely related to depth, this correlation between occurrence of sediment and a low level of kinetic energy appears as a correlation with depth. Table XIII summarizes the data using area of the bottom within successive depth increments covered by coarse and fine sediments and maximum horizontal current speed associated with large winter waves to indicate the relationship.

Page 164 – Fig. 20

Table XIII

Comparison of areas of rock bottom, sediment-covered bottom, horizontal current velocities associated with wind waves, and diameters of particles which wind wave currents are capable of moving.

Depth Increment (fathoms)	Median Depth (fathoms)	1/ % of area of depth increment rock	1/ % of area of depth increment sediment (incl. cobbles)	1/ % of area of depth increment fine grained sediments	2/ Maximum horizontal Orb. speed of Wave C at median depth	3/ Maximum particle size eroded by wave current	3/ Maximum particle size transported by wave current
0-25	12.5	72.7	27.3	18.0	277 mm./mmc.*	cobbles	cobbles
25-50	37.5	74.7	25.3	8.2	80 "	7 mm.	12 mm.
50-75	62.5	62.8	37.2	15.7	25 "	1.5 mm.	3 "
75-100	87.5	36.9	63.1	60.4	7 "	none	0.8 "
below 100		15.7	84.3	82.9	-- "	none	none

*Wave may break.

1/ From table I.

2/ From figure 19.

3/ From Njulstrom, 1939, fig. 1, p. 10 (data for steady current, used as illustration only).

Maximum particle sizes which can be eroded and transported by the wave-induced currents at various depths as indicated by Hjulatrom's (1939) curves for steady currents are included for comparison. These relationships indicate nothing more than the trend because Hjulstrom's curves are only approximate in nature, no consideration is given to tidal currents, and topography introduces variation of conditions. These data suggest, in addition, the importance of topography as a control on sediment distribution in the Near Islands under the existing regimen of waves and tidal currents. The area of fine grained sediments is high in the depth increment 0-25 fathoms, has a minimum between 25 and 50 fathoms, and increases with greater depth. Much of the area between 0 and 25 fathoms, however, lies within protected bays near sources of sediment, whereas the area of minimum sediment cover occurs in the open shelf environment. The increase in percentage of sediment cover in the interval from 50 to 100 fathoms partly reflects the effectiveness of the shelf-basins as sediment traps.

Grain size composition of the sediment also is different within different areas of energy distribution. Bay sediments in the most protected bays are fine, poorly sorted, and positively skewed; those of the open shelf frequently are coarse, well sorted, and negatively skewed; those of the shelf-basins are fine and tend to be positively skewed. These differences are in addition to the differences in composition in terms of terrigenous and biological components which have been discussed.

Summary on Environmental Characteristics and Effects on Sediments

The climate of the Near Islands is cold but not arctic; summers are short and maximum rainfall occurs in the autumn although variation in precipitation is not great. Winds are likely to be very strong between October and April or May. These climatic conditions, together with surface relief, produce soils consisting largely of comminuted rock fragments which are the product of direct rock disintegration. Streams are the main agent of erosion, and, sided by solifluction and land slides, are chiefly responsible for sediment transportation to the sea. Melting of the winter snow blanket causes fluctuations in stream capacity and competence which might not exist otherwise. In the past glaciers have been of primary importance, both in erosion and transportation.

The water mass surrounding the Near Islands is one of subarctic characteristics. Temperatures range from about 11°C (50°F) to 2°C (36°F) vertically and annually within the depth range studied. Salinities, less well known, probably range vertically and annually from about 30 to 33°/oo. Minor chemical components, necessary for plant life, are similar in concentrations to those found in the South Atlantic and South Pacific oceans. Characteristics of the water mass are those of Oyashio water and are developed in part while the water moves westward from the Gulf of Alaska into the Bering Sea and then southward past the Near Islands and in part by local climate. The water mass supports a benthonic foraminiferal fauna and a local diatom flora which exhibit good ecological adjustment to its physical characteristics. The planktonic foraminiferal fauna and diatom flora are not necessarily indigenous to the area, but are types which would be expected from the properties and history of the water mass.

Tidal currents may have high speeds, particularly in the passes; waves developed in response to high winter winds frequently are very large. These agents have produced clastic sediments by eroding the shore lines, probably the bottom in shallow water, and by winnowing submarine deposits of glacial drift. An analysis of the distribution on the sea bottom of kinetic energy produced by horizontal currents due to waves and tides as modified by local topography shows the importance of these three factors in determining gross sediment distribution in the Near Islands. Grain size distribution of the sediment is also related to these three factors, variation being largely a function of the relationship between intensity of current action and the availability of sediment.

Information on scarce rocks, the climate, soil producing processes, and recent geological history of the Near Islands seems to explain satisfactorily the nature of the terrigenous components of marine sediments. Components of biological origin are accounted for only in part through study of local conditions because of the effect of semi-permanent currents flowing from regions which may be of different character. Distribution of these components on the shelf and the size distribution characteristics of the sediment are the products of local conditions of wave and tidal currents, topography, and relation to source of supply.

DISCUSSION

General Statement

In the study of sedimentation much has been written about the oomplex interrelationships between the numerous variables which act in the production of a sedimentary rock. Perspective is necessary in such work, however; early study of the data which have been discussed above suggested that such perspective might be obtained on a theoretical basis if we accepted the premise that any sedimentary deposit is the product of two opposing tendencies. One of these tendencies is to deposit material at a point and the other is to remove this material. The sum of the rates of supply and removal determines the rate of sedimentation. This idea can be expressed formally by writing:

The Rate of Deposition	-	The rate of supply of material	-	The rate of removal of material

This basic statement ignores many of the details which tend to complicate the problem. Further application can be made of this statement, however, Pettijohn (1949, pp. 436, 440), among others, has pointed out that the physical character, or lithic aspect, of a sediment in large measure is a function of the rate of deposition. Therefore, not only the rate of sedimentation but the physical character or lithic aspect of the sediment as well will be controlled by this relationship. The capacity to remove fine material may be greater than the capacity to supply, in which case the rate of removal will be greater than (with erosion) or equal to the rate of supply, whereas the rate of removal of coarse material may be less than the rate of supply. On the other hand, the rate of supply of all sizes of material may be greater than their rates of removal. In the first of these hypothetical cases the sedimentary product might be a coarse, well sorted sandstone or conglomerate, and in the second case it might be a very poorly sorted sandstone or mudstone. So long as the particles are undefined, however, the statement holds equally well for dust particles collecting on a table top.

This statement, as a first approximation, is akin to the basic concept which has been advanced by petrographers to explain differences in sandstone types, and from which has grown a petrographic classification of sedimentary rocks based largely on degree of sorting, either by grain size, mineral content, or both (see Pettijohn, 1949, pp. 435-62). The petrographic approach leads them to the conclusion that, in the final analysis, sedimentary rocks are the product of one major variable, tectonics. The correlation between rock types and tectonics made by the petrographers requires in addition, however, oceanographic conditions or the factors which principally determine them in order to be universally applicable to marine sediments.

The simple statement above indicating the basic relationships which must exist in the formation of a sedimentary deposit can be expanded to indicate the complexity of the sedimentation system. Much of the complexity is introduced into marine sediments when particular types of material are substituted for undefined particles and after post-depositional changes have occurred. This expansion may be written:

$$\text{The total amount of sediment and the lithic aspect at a point} - \int_{T_1}^{T_2} \overset{\text{I}}{\text{The character and rate of supply of each terrigenous component}} + \overset{\text{II}}{\text{The character and rate of supply of each marine component}} - \overset{\text{III}}{\text{The rate of removal of each component}} + \overset{\text{IV}}{C}$$

where T - time.

Each of the terms I, II, and III in this statement is an exceedingly complex variable. The term C is introduced to make the statement general and applicable to lithified sediments. It includes post-depositional changes due to organisms or physical or chemical reactions which may occur, so that it also is a complex variable.

Application to Near Islands Shelf Sediments

An expansion from this theoretical statement has served as the basic framework for study of the sediments of the Near Islands shelf. Part of term I involves conditions at initiation of deposition following the post-glacial rise in sea level. Study of the subaerial and marine environments furnishes data for further evaluation of term I and also terms II and III. These data generally are of a qualitative nature and show in a qualitative way the relationship between environment and sediment.

Sediment which was sampled on the Near Islands shelf is of late Glacial and Post-Glacial age, and much of it was deposited on a previously glaciated surface. Much of the bottom topography and some of the sediments are the results of such glacial action. The prominent basins are principally in result of glacial erosion, whereas the irregular ridges and coarse deposits are largely products of glacial deposition. These coarse deposits have been subjected to wave and current action following sea level rise and the surface layers have been winnowed of the finer particles, some of which have probably contributed to more recent deposits. A deposit of the character of a basal conglomerate was formed by this process. Toward the outer margin of the insular shelf and below the break in slope fine grained, poorly sorted, marine deposits were formed in part from detritus freed directly by glacier wastage and in part from skeletons of marine organisms. Overlying these deposits are other glacial marine sediments which are coarser, poorly sorted, and contain a higher proportion of the skeletons of marine organisms.

All of these deposits were laid down under conditions differing from those obtaining at the present primarily because of the presence of quantities of ice. Ice also seems to have protected the shelf from surf action during the post-glacial rise in sea level, so that modern sedimentation was initiated on a relatively unmodified glacial surface.

Deposits which formed after melting of shelf and insular ice consist almost entirely of chemically unweathered rock fragments and skeletons of marine organisms in a more or less fragmental condition. Unweathered monomineralic grains constitute a small proportion of the sediments and occur only in the finer size grades.

The character of terrigenous detritus is determined by the nature of both the source material and the weathering processes which take place. Fine grained, slightly metamorphosed rocks are broken down principally through the action of physical processes. These processes are dominant because of the insular topography and the climate, both of which contribute to promote mechanical rock destruction. These same factors produced similar sediment during the period of insular ice, so that differences cannot be detected. In addition rounding of small particles is not common. This is due in part to the limited size of the source area making long unidirectional transportation impossible, and in part to lack of extensive areas where short multi-directional transportation can take place.

The rate of supply of terrigenous material to the sea is determined by the rate at which rock destruction takes place and the size of the source areas. Post-glacial erosion seems to have progressed in places at a relatively rapid rate, but because the source areas are small, the total rate of supply of terrigenous material is not great when compared to other areas such as near the mouths of large rivers.

Characteristics of the marine organisms which contribute to the deposits are determined by the nature of the sea in which they live. Of the marine properties, the low temperatures seem to be of greatest importance in exerting broad selection for the environment. The organisms which are found are capable of thriving in or withstanding low temperatures. Temperature characteristics of the water around the Near Islands are developed in part during long transit through boreal regions and in part by local effects. Insofar as these local effects are responsible for selection, the marine organisms are representative of the particular environment of the Near Islands. Salinity seems to have exerted little selection on these organisms. This also may be attributed to the small size of the source areas, since they furnish small catchment basins for precipitation and therefore probably produce insignificant salinity gradients.

Rate of supply of skeletons of marine organisms also is related to the character of the sea. Little is known of controls on rate of production; however, mineral nutrients compare in concentration with other highly productive areas such as the South Atlantic and South Pacific oceans. To the extent that abundant nutrients are basic to high production, the Bering Sea and North Pacific Ocean around the Aleutian Islands are favorable. Abundant sea- bird and mammal faunas existing on local marine life also suggest high production.

The relationship between rates of supply of terrigenous and marine components differs over the shelf. In the deep bays terrigenous material is supplied rapidly relative to the marine components, so that the deposits are largely rock fragment sands. In the shelf-basins marine components are supplied more rapidly and make up a larger percentage of the deposits. Open shelf deposits, to some degree, are intermediate between these two types, although marine components are most important in areas of high production of megascopic organisms where the supply of terrigenous debris is small.

Rate of removal of sediment is determined by the intensity of wave and current action as modified by local topography. The high level of wave and current action on the shelf suggests that rate of removal generally is great. Over most of the exposed open shelf rate of supply and rate of removal are unbalanced in favor of removal and bare rock is found. As equilibrium may exist between the rate of supply of sediment and the rate of removal where sediment occurs, in which case no additional sediment will be deposited as long as conditions are unchanged. This condition seems to exist on the outer shelf and upper slope and probably in many places on the open shelf where sediment is found. In other areas such as the shelf-basins and the most protected bays, with sediments readily available, equilibrium exists between kinds of material (i.e., terrigenous and marine components) but probably does not exist between total rates of supply and removal. This is suggested by the skewness toward smaller diameters exhibited by most of the size-frequency curves of samples from these areas. Wave and current action incapable of removing all of the fine particles which are being supplied is incapable of establishing an equilibrium between rates of supply and removal, and sediment must collect. It is probable that inner parts of protected bays (such as Massacre Bay, southeastern Attu, see fig. 21) and the shelf-basins will gradually shoal.

General Conclusions.

The sediments being deposited on the Near Islands shelf are the products of environmental sorting which determines the distribution of the sediments and in part the type of material present. The organisms which occur are those tolerant to the existing temperature conditions. Chemical destruction of mineral grains does not take place to a large extent, so that such mineralogic sorting is not rigorous. Sorting on the basis of specific gravity cannot be demonstrated because of the polymineralic composition of most of the sand but may be indicated in the shelf-basins deposits where laterally transported terrigenous sand grains occur mixed with many somewhat larger but less dense frustules and tests. Sorting by particle shape appears to be responsible for the shape characteristics of the coarse beach deposits and perhaps also for the shelf cobble and gravel deposits to a lesser extent. Size-sorting takes place on the open shelf and in the bays and to some degree in the shelf-basins and seems to control the areal and depth distribution of these sediments to a large extent.

Sorting of all types is accomplised largely by the physical processes of the Near Islands environments. Physical characteristics of the subaerial environment which seem to be of greatest importance in sorting are temperature, surface relief, and rainfall. Nature of source material, recent geologic history, and size of the source area are of great importance in determining the extent and nature of the sorting. Physical characteristics of the marine environment which seem to be of greatest importance in this area are temperature, waves, and tidal currents. Modifying effects on the marine environment are large scale semi-permanent currents which reflect the history of the water mass and the bottom topography which is in part the product of recent geologic events.

Qualitative and quantitative data of the Near Islands environments show that local and regional climate if the chief factor responsible for the physical characteristics, both subaerial and marine, which actively sort the sediments. The sediments which are produced, however, also represent the original terrigenous source material, size of the source area, recent geologic history, and the history of the water mass. These considerations indicate that sediments of the area are not, in the final analysis, a function of one major variable. They must be considered to be functions of two major variables of similar rank, tectonics and climate, which are somewhat interdecendent and are modified significantly by others.

Relative Magnitude of Local Climatic Influences

It is of interest to consider briefly the relative magnitude of local climatic effects on sediments in areas of different degrees of physical isolation in the light of conclusions based on Near Islands study. The environment of the Near Islands can be considered to be a deep sea environment on one hand and on the other a near shore environment. The island mass extends up through several thousands of fathoms of water far from the borders of typical continental areas, and many of the characteristics of the region are due to this relationship between land and sea. In this isolation in the midst of a large ocean the environment is that of the deep sea. The fact that the insular base is large, however, introduces certain aspects which are typically continental such as the wide shelf, the source of coarse terrigenous detritus, and some restriction of free circulation with adjoining areas. In these respects the environment can be considered continental. Because of the isolated source of clastic material the effects of relatively homogeneous climatic conditions in the production of this material can be appreciated.

Marine conditions in the Near Islands, however, are the product of widespread as well as local climatic variations. Water mass characteristics and semi-permanent currents are the products of more general conditions and waves may be generated over a considerable area.

These observations suggest that the relationship between climate and sediments is different for different types of marine bodies. In the open ocean the chief importance of climate seems to be in the variation which occurs with changing latitude and relations to large land masses. The lateral variation of climate is responsible for the large scale oceanic circulation which in turn seems to be responsible for many of the variations of the bottom deposits. At any given point in the open sea the local effect of climate is probably difficult if not impossible to detect in the bottom deposits. In smaller bodies of water which are more or less restricted from the open sea and are isolated by land barriers from distant sources of terrigenous detritus the local climate may become perhaps the most important single factor in determining the type of deposit which will be formed. In this case the climate will be significant in determining the character of the terrigenous material supplied to the basin of deposition and the rate at which it is supplied. Further, the nature of water circulation and the seasonal wave pattern in such a restricted area, of great importance in determining salinity, biological productivity, and the rate of sediment removal, would be the products of local climate. The smaller the degree of isolation the less will be the importance of local climatic factors in determining sediment characteristics.

Quantitative Aspects

A quantitative solution of the sediment budget is suggested by the theoretical statement but is not possible with the available data or the present state of knowledge. Such a solution must be made on the basis of either measurements of amount and kind of material supplied and deposited or the relationship between environmental factors and the amount and kind of terrigenous and marine components produced and deposited. It is possible, however, to examine some considerations bearing on quantitative aspects of the sediment budget of the area in the light of this statement. Two of these considerations of interest to geologists are the concepts of wave-base and base level of deposition (Barrell, 1917; Eaton, 1929). These concepts can be summed up as follows. Assume the bottom undergoing sedimentation slopes smoothly seaward from shoal to greater depths within an area where current conditions are uniform horizontally. If sedimentary materials of different transport susceptibility are supplied from land at a uniform rate, and if this rate of supply permits the currents at all levels traversed by the materials to sort completely the material, a deposit will be formed which portrays these conditions. This deposit will have that material which is most difficult to transport in the shoalest portions of the area, and will change progressively in character as the depth is increased until finally in the deepest water the material which is most susceptible to transport will be found. As the level of the surface of the deposit changes with respect to the vertical current velocity profile, the character of the material which is being deposited will change in grain size, shape, or specific gravity.

The basic concepts of wave-base and baselevel of deposition, developed largely from theoretical considerations, are too simple to meet the test of modern oceanographic investigations. Departures from the expected product of sedimentation according to this theory are due to variation in rate of supply and sorting ability (rate of removal) partly because of bottom irregularity. Other departures are found because sufficient time has not elapsed since the glacial-induced lowering of sea level to permit an equilibrium to be established (Shepard and Cohee, 1936; Revelle and Shepard, 1939; Stetson, 1938, 1939; Emery, 1952).

The relationship between rate of supply and rate of removal, which must be taken into account when dealing with wave-base and baselevel of deposition, is indicated by the Near Islands data. These concepts can imply no fixed surface, but one which is undulatory and variable in vertical position within a local region. Figure 20 shows the irregular configuration of the baselevel of deposition on the Near Islands shelf and departures from the theoretical conditions outlined above. Heavily stippled areas are those where this level tends to be depressed due to high wave and current action, and lightly stippled areas are those where the baselevel of deposition tends to be elevated. These departures are due in part to antecedent topography and are reflected in the distribution of the sediments. In visualizing the position of baselevel, however, the availability of sediment also must be considered. Thus, for a given energy level the baselevel of deposition is higher in the bays and in the shelf-basins than on the exposed level open shelf because the rate of supply of sediments is greater to these two types of areas. On the outer shelf and upper slope character of the sediments changed from a sandy mud to sand and gravel and finally became a nondepositional area with decrease in rate of supply relative to rate of removal. These changes of sediment character probably are due only to a decrease in absolute rate of supply. The positions of topographic features affect the equilibrium between these rates by increasing or decreasing one relative to the other partly through an increase or decrease in current or wave action. However, alteration of the equilibrium in one area alters it in adjacent areas because of changed rate of supply. Lateral transport of sediments from the exposed shelf into the shelf-basins is an example of the effect of adjacent environments. Finally, the concepts of wave-base and marine baselevel of deposition may not be applicable where sediment is supplied very rapidly and/or there is little wave and current action. Under these conditions surfaces determined by these concepts could be above sea level and land would form with the upper limit of deposition then controlled by a subaerial baselevel of deposition.

SUMMARY OF CONCLUSIONS

1. Marine sedimentation in the Near Islands was initiated prior to complete glacier wastage on a shelf which was buried beneath a Pleistocene ice cap. Deposits of glacial drift generally are thin, although a large moraine exists southeast of Attu. The surface layers of all shelf glacial deposits have been winnowed of fine material by wave and current action, but, as shown by roundness and sphericity relationships of pebbles, do not seem to have been subjected to prolonged surf action in the beach zone. Shelf topography is largely the result of glacial erosion or deposition, but has been modified by deposition in the shelf-basins and by wave action in near shore zones. Faulting probably has aided glacial scour and plucking in forming the shelf-basins and may be responsible for a long narrow basin north of Attu. The extent of ice in the Near Islands during the Pleistocene and the similarity of topographic and geographic features to adjacent island groups suggests the entire Aleutian Chain was buried beneath an ice cap during this time which was broken only at the deepest and widest passes.

2. Terrigenous detritus, consisting largely of angular to sub-angular, little altered, sand-size fragments of the fine grained rocks of the islands, has been supplied in part from soil formed by disintegration of the parent material through action of a cool wet climate on steep upland slopes poorly stabilized by vegetation. Streams, aided by solifluction and large scale land slides, are the most important transporting agents at present, although

glaciers have been in the past. Reworking by streams of alluvial or glacial deposits and by waves and currents of submarine glacial drift together with mechanical erosion by waves and currents of the shore line and shallow sea floor have supplied the remainder of the clastic sediments. Detritus from submarine glacial drift probably is of little quantitative significance in the youngest surface deposits. Terrigenous detritus is relatively most abundant in the sediments near mouths of large streams and at points where wave-generated longshore currents tend to converge. In general the rate of supply of terrigenous elements is not great because of the small source areas.

3. Biological detritus of marine origin consists primarily of the skeletons of Foraminifera, diatoms, and sponges seaward from the islands and the broken shells of a few species of mollusks and of one echinoid species near shore. The Foraminifera, diatoms, and macro-organisms are generally either cold water, deep water, or wide-ranging forms tolerant to low temperatures. Salinity does not seem to be significant in determining their distribution. These organisms grow in a subarctic water mass with temperatures between 2° and 11°C, salinities between 30 and 33°/oo, and abundant nutrients. The conservative properties of this water mass are produced by the effects of regional climate while it moves in the North Pacific Ocean and the Bering Sea. Biological constituents are relatively most abundant offshore and in nearshore areas which are removed from large sources of terrigenous clastics, and probably have been supplied rapidly because of high

organic production.

4. Bed rock is exposed over most of the shelf because of high rate of removal of sediments due to large waves and strong tidal currents. Fine grained marine sediments occur only where a ready source is available and where the bottom is protected by local topography from the action of the large winter waves and heavy tidal currents. Finest surface deposits are found in the protected bays and the deep shelf-basins; well sorted coarser material in general occurs on the open shelf. Sediment of the upper slope and outer shelf was deposited before the ice melted completely but after sea level reached approximately its present level. This sediment changed character from sandy mud to typical glacial-marine diatomaceous sand with pebbles and granules when an abundant source of fine material ceased to exist. Deposition virtually stopped in this area when the supply of ice-rafted pebbles failed, due probably to bypassing.

5. Theoretical expansion of a statement relating the total amount of sediment deposited within a given period of time and the lithic aspect of this sediment to the rates of supply and removal of material is suggested as a basic qualitative framework for interpretation of the sediments of the Near Islands. Both the theoretical statement and data from the Near Islands suggest the importance of climate, together with tectonics, in determining sediment characteristics and distribution. The magnitude of local climatic effects on marine sediments is inferred to be greatest in areas of restricted contact with

adjacent regions and least in the open sea where large scale climatic variations largely seem to control sedimentation. Quantitative solution of the Near Islands sediment budget is not possible with the data available or with the present state of knowledge concerning relationships between production of various types of sediments and environmental characteristics. However, the concepts of wave-base and baselevel of deposition can be modified in the light of relationships between rates of supply and removal as influenced by local topography.

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