Geology of Northern Adak Island, Alaska

By ROBERT R. COATS

INVESTIGATIONS OF ALASKAN VOLCANOES

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PREFACE

In October 1945, the War Department (now Department of the Army) requested the Geological Survey to undertake a program of volcano investigations in the Aleutian Islands–Alaska Peninsula area. The first field studies, under general direction of G. D. Robinson, were begun as soon as weather permitted in the spring of 1946. The results of the first year's field, laboratory, and library work were assembled as two administrative reports. Part of the data was published in 1950 in Geological Survey Bulletin 974–B, Volcanic activity in the Aleutian arc, by Robert R. Coats. The remainder of the data has been revised for publication in Bulletin 1028.

The geologic and geophysical investigations covered by this report were reconnaissance. The factual information presented is believed to be accurate, but many of the tentative interpretations and conclusions will be modified as the investigations continue and knowledge grows.

The investigations of 1946 were supported almost entirely by the Military Intelligence Division of the Office, Chief of Engineers, U. S. Army. The Geological Survey is indebted to the Office, Chief of Engineers, for its early recognition of the value of geologic studies in the Aleutian region, which made this report possible, and for its continuing support.

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ABSTRACT

The geology of the northern part of Adak Island, largest of the Andreanof group of the Aleutian Islands, was mapped in the summer of 1946. The part of Adak Island mapped comprises two physiographic and geologic divisions: A deeply glaciated southern area of folded, faulted, and intensely altered volcanic rocks of Paleozoic(?) age, intruded by gabbro and rocks of intermediate composition; and a mountainous northern area comprising remnants of three distinct basaltic volcanoes of Tertiary or Quaternary age. In the northern part of the southern area there are five volcanic domes of light-colored andesite porphyry, probably of early Tertiary age; they cannot be correlated with any of the three recognized volcanic centers of the northern area. Minor amounts of sedimentary rocks are associated with the volcanoes. The volcanoes have been trimmed by marine erosion, and locally dissected by subaerial and glacial erosion. The glaciers have disappeared. A blanket of volcanic ash from volcanoes on nearby islands covers most of the lowland area.

Volcanic activity probably will not be resumed on Adak Island in the foreseeable future. Frequent earthquakes however, indicate that the earth's crust is unstable in that area; whether this instability signifies the beginning of a new volcanic cycle remains to be determined by further investigation.

INTRODUCTION

Northern Adak Island was mapped during the summer of 1946 as part of a geologic reconnaissance of the western Aleutian Islands. Because no reports of volcanic activity on the island have been made by visitors to the area, and because aerial photographs indicate deep erosion since the last important activity, it has been assumed that the volcanoes present no immediate threat of eruption. Geologic mapping of parts of the island was undertaken to determine the local geologic history, and on this basis to test the foregoing assumption.

The report is the result of 25 days of field work by Robert R. Coats, geologist, assisted by Will F. Thompson, Jr., recorder.

Acknowledgment is made of the cooperation of many officers and men of the U. S. Army stationed at Adak, especially Lt. Col. R. E. Ware, post engineer, and Lt. Col. C. E. Johnson, port commander.

GEOGRAPHY

LOCATION

Adak Island is the largest of the Andreanof group of the Aleutian Islands. It lies between the parallels of 51°35′ N. and 52° N., and between the meridians of 176°25′ W. and 177° W., and has a total area of more than 280 square miles (fig. 4). An area of about 73 square miles, herein called northern Adak Island (pl. 9), was mapped in 1946.

PHYSIOGRAPHY

All but the northernmost part of Adak Island is characterized by short, diversely trending ridges, numerous rock-basin lakes, and a coastline deeply indented by fiords. This topography has been developed largely by intense glaciation of the Finger Bay volcanics (pl. 10*A*), a sequence of relatively resistant rocks. The locations of stream valleys, lakes, and fiordlike inlets such as Finger Ray, have been determined principally by faults that hare cut the Finger Bay rocks. Only the northern part of this region is included in the area mapped. Results of a reconnaissance study of Adak Island as a whole are given by Bradley (1948).

The physiography of northernmost Adak Island has been largely controlled by volcanic activity originating at three centers—Mount Moffett, Andrew Bay volcano, and Mount Adagdak, named in order from west to east. The highest point on the eroded cone of Mount Moffett is 3,876 feet in altitude. The remnant of a parasitic cone, 3,250 feet in altitude, stands on Mount Moffett's northeastern flank (pl. 1) The central vent of the Andrew Bay volcano was located west of the present eastern shore of Andrew Bay, where steep cliffs now expose a section through its remnants. Most of the remainder of the peninsula northeast of Andrew Lagoon and north of Clam Lagoon (pl. 9) constitutes a single volcanic structure—Mount Adagdak—the culminating point of which is 2,072 feet in altitude.

Mount Moffett has been deeply dissected, except on its southeast slope (pl. 12). Numerous valleys descending from open, stcep-walled cirques narrow downstream into deep V-shaped canyons cut by glacial melt water and by later stream erosion. Similar evidences of glaciation are absent on Mount Adagdak, probably because its isolated position and low altitude were unfavorable for the accumulation of glacial ice.

Vigorous wave erosion has created imposing cliffs as much as 2,500 feet in altitude on the north sides of Mount Moffett and Mount Adagdak (pls. 11 and 13). Remnants of marine terraces, partly destroyed by marine erosion, are visible in the cliffs.

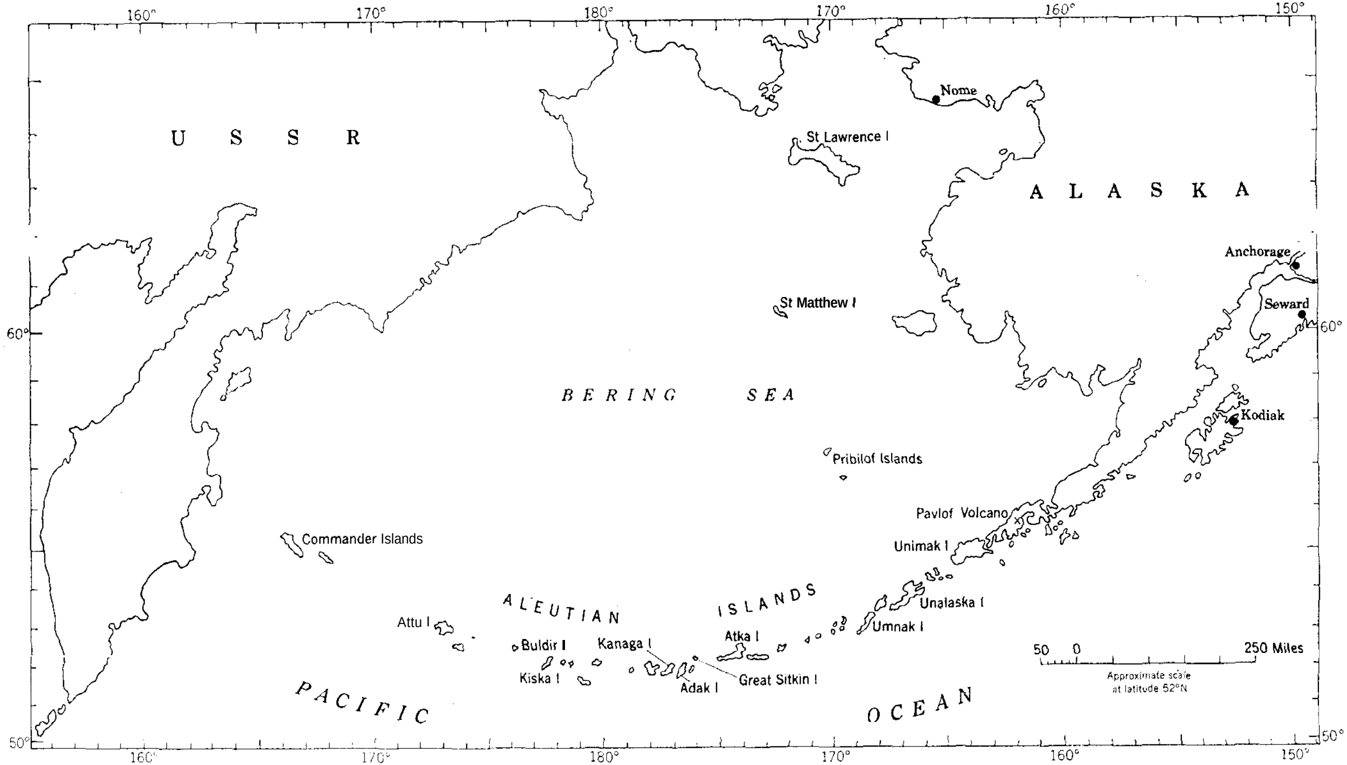

FIGURE 4.—Map of the Alaska Peninsula and Aleutian Islands.

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DRAINAGE AND WATER POWER

In the northernmost part of the island, stream courses are relatively short and steep, and most drainage basins are less than 1 square mile in area. The larger streams of this area, which drain Mount Moffett and Mount Adagdak, have deeply incised canyons and a fairly uniform flow, maintained in late summer by snow banks at high altitudes, and in part by percolation of ground water from permeable lava flows on the slopes of the mountains. Ample water supply for the military base is available. The topographic setting is, in general, favorable to the development of water power. Streamflow is not uniform, however, because of the steep slopes and lack of soil cover over much of the area. Therefore, expensive water-storage facilities would be required if development were undertaken.

The drainage basins in the southern part of the mapped area are more irregular in shape and are larger than those in the northern part. Slopes are steeper, and much more bedrock is exposed. The bedrock is denser and less pervious than that in the northern area. Valleys are predominantly U-shaped in cross section, rather than V-shaped, and the streams have less regular profiles, because of the lakes and alluviated areas along their courses. The size of the drainage basins and the presence of numerous lakes are favorable to the development of surface-water supply, while the scantiness of soil cover and the imperviousness of the bedrock are unfavorable to the development of ground-water supply.

GEOLOGY

The rock units of northern Adak Island, shown on plate 9, comprise volcanic and intrusive rocks of Paleozoic(?) age in the southern part of the area; Tertiary or Quaternary volcanic rocks, most of which make up the cones in the northern part of the area; and Quaternary rocks, largely glacial drift and other unconsolidated materials.

ROCKS OF PALEOZOIC(?) AGE

FINGER BAY VOLCANICS

Rocks believed to be of Paleozoic age include the Finger Bay volcanics and a gabbro that intrudes them.

The southern part of northern Adak Island is underlain by a sequence of volcanic rocks consisting of black, dark-gray, purplish-gray, greenish-gray, and grayish-yellow-green basaltic tuff, basalt flows, basaltic tuff-breccia, agglomerate, and dikes, and a few small rhyolitic flows and dikes. These rocks are well exposed in Finger Bay and are here designated the Finger Bay volcanics (pl. 10*A*). Some of the rocks are conspicuously porphyritic, containing abundant phenocrysts of hornblende and plagioclase. The hornblende ranges in color from black to dark green. It commonly lacks the thick resorption border of magnetite that characterizes the hornblende of extrusive rocks. The unaltered plagioclase ranges from calcic bytownite to labradorite, but much of the plagioclase has been albitized and calcitized. In general these rocks have been intensely altered and locally recrystallized near intrusions.

The degree of deformation of the rocks is not everywhere the same. In the area west and south of Kuluk Bay dips are steep and the attitudes irregular; in the area north of Kuluk Bay, which is isolated from the other area, the attitudes of the rocks are more regular and the dips less steep. The southern part of this northern area consists largely of basaltic flows and sills; the northernmost outcrops, just south of the abandoned runway of Mitchell Field (not shown on the map), reveal rocks consisting largely of sandstone and tuffaceous sandstone interbedded with basaltic flows and nearly contemporaneous sills. In 1948 a few impressions of leaf rosettes were collected from a bed of coarse sandstone, ranging in color from pale yellow to weak yellow-green-yellow (Munsell system), exposed on the south side of the west end of the airstrip. These leaf impressions have been identified by R. W. Brown as *Annularia stellata* (Schlotheim) Wood, of Pennsylvanian or Permian age.

Because of the lack of recognizable key horizons and because of the complicated deformation, the thickness of the Finger Bay volcanics has not been determined. Continuous exposures without apparent repetition of beds indicate a minimum thickness of 2,000 feet. The total thickness may be as much as 15,000 feet.

The age of the Finger Bay volcanics is not known with certainty. In 1946 the writer was inclined to correlate these rocks, on lithologic grounds, with rocks of probable Triassic age in the Iliamna region (Martin and Katz, 1912) and at Alinchak Bay on the Alaska Peninsula (Martin, 1926). The well-preserved and certainly identified leaf impressions (*Annularia stellata*) should, however, be given more weight than this long-distance lithologic correlation. For the present, the writer is content to regard the Finger Bay volcanics as Paleozoic(?) in age. It must be recognized, however, that the isolation of the sequence in which the fossil was found from the type area about Finger Bay and Sweeper Cove introduces the possibility that rocks of more than one age are included in the mapped unit; if so, the rocks in the type area are probably older than the fossiliferous rocks. In the type area abrupt changes in the degree of deformation of rocks of a given age occur within a short span. Therefore, these rocks are not necessarily older, because they are more deformed, than the rocks north of Kuluk Bay.

GABBRO

The Finger Bay volcanics are intruded by a large mass of gabbro, which crops out south of Finger Bay. The gabbro is a dark-gray rock whose nearly equal amounts of dark augite and white plagioclase of uniform grain size give it a salt-and-pepper appearance. Close to the margin of the mass almost all the augite has been altered to a pale-green amphibole. Magnetite is the chief accessory; apatite, only a small amount of which is present, is also an accessory.

About a mile from Finger Bay, close to the fault that forms much of the southwestern margin of the gabbro mass, is a body of augite-quartz syenite of undetermined size and shape that is thought to be a differentiate of the gabbro. It is a dense, pinkish-gray rock containing white flecks that resemble phenocrysts, and wisps of dark-green augite. The white flecks are even-grained aggregates of microperthite that include minor amounts of interstitial micropegmatite. The augite is locally replaced by serpentine and epidote.

The original shape of the gabbro mass was not determined. The gabbro cuts the Finger Bay volcanics, but none of the younger rocks. It is as much faulted as the Finger Bay volcanics, and it resembles them in degree of alteration. The gabbro seems more closely related in age to the Finger Bay volcanics than to the younger rocks and is therefore tentatively assigned to the Paleozoic era.

In the quarry on the hill about half a mile southwest of the head of Sweeper Cove a small irregular intrusive mass, which probably is made up of diorite, is exposed. It has not been separately mapped. Much pyritization of the intruded rock and the intrusive mass obscures the contact. Assays of the pyritic rock showed negligible quantities of gold and silver.

ROCKS OF CENOZOIC AGE

The mountainous northern portion of Adak Island consists largely of volcanic rocks associated with three main eruptive centers of Tertiary or Quaternary age. The petrography and chemistry of these rocks are discussed in another report (Coats, 1952). Bouldery conglomerate and marine sandstone, some of which is fossiliferous, are interbedded with volcanic rocks from one of these centers. Five small domes of andesite porphyry in the vicinity of Kuluk Bay are also believed to be of Tertiary age. These volcanic rocks and associated sedimentary rocks are found in two areas separated by Andrew Bay and the lagoon at its head. The southwestern area is occupied by Mount Moffett; the northeastern area includes Mount Adagdak and remnants of an older volcano, herein called the Andrew Bay volcano. These rocks have been assigned a Tertiary or Quaternary age because they overlie or intrude the Finger Bay volcanics, and they have been extensively glaciated. Fossils from the marine sandstone are probably Tertiary species that have a wide time range.

Other Quaternary rocks of northern Adak Island occur as glacial drift, including ground moraines, lateral moraines, and fluvioglacial deposits; marine-terrace boulder gravel; and Recent unconsolidated beach, delta, lagoon, alluvial, and aeolian deposits that have been accumulating since the retreat of the glaciers. The results of a study of the relative ages of some of these deposits have been given by Judson (1946).

ANDERITE PORPHYRY DOMES

Five domical masses of andcsite porphyry lie close to the margin of Kuluk Bay, two north of thr entrance to Sweeper Cove and three at, and north of, Zeto Point. The largest of the masses, about 230 feet thick, lies north of the entrance to Sweeper Cove (pl. 10*B*). This body has been extensively quarried for road material and riprap. Comparison of the present shape of these domes with the shapes of similar domes in volcanic areas elsen-here suggests that they are preserved in essentially their original thicknesses. The masses have all been glaciated; excellent striae are prescrvcd on the dome that forms what is locally called 90-mm Hill,' about a mile north of the entrance to Sweeper Cove (pl. 10*B*).

All the rocks have abundant calcic plagioclase phenocrysts as much as 1 centimeter in length, numerous smaller needles of hornblende, and accessory magnetite in a medium-gray to light-gray groundmass. The rocks locally contain phenocrysts of quartz, augite, and biotite. The groundmass consists of blocks of prismatic plagioclase and magnetite granules and interstitial orthoclase(?).

The andesite porphyry domes intrude the Finger Bay volcanics, but show none of the deformation or alteration associated with them. On the other hand, they have been glaciated and on this basis are older than latest Pleistocene. They are therefore presumably Tertiary in age, but their relation to other Tertiary rocks on the island is not known. They arc considered older than the sequences of Tertiary rocks of the three principal volcanic centers, because their present topographic form is erosional rather than constructional. Furthermore, they differ petrographically from rocks of the other Tertiary sequences, and show no geographic relationship to the later volcanic centers. For these reasons they are considered to be the only remaining exposed representatives on northern Adak Island of an earlier sequence of Tertiary volcanic rocks.

: Place name not shown on standard maps but used for convenience in this report.

NORTHEASTERN AREA

The northeastern area comprises the peninsula north of Clam Lagoon and east of Andrew Bay. The rocks of the northeastern area include the volcanic rocks erupted from the Andrew Bay volcano and Mount Adagdak and some sedimentary rocks that accumulated before the development of Mount Adagdak. The rocks of Andrew Bay volcano make up the ridge that rises steeply from the water's edge on the east shore of Andrew Bay; the rocks of Mount Adagdak constitute most of the peninsula; and the sedimentary rocks crop out along the eastern margin of the peninsula.

BOCKS OF ANDREW BAY VOLCANO

A thick accumulation of breccia, tuff-breccia, and lava flows crops out on the east side of Andrew Bay. These rocks are the products of an ancient volcano—the Andrew Bay Volcano—the vent of which was apparently west of the present eastern shore of Andrew Bay.

The cone of the ancient volcano was composed of interbedded tuff-breccia and lava flows. Exposed in the base of the steep cliff that forms the eastern face of Hill 1045 [2] is about 500 feet of tuff-breccia, which probably was formed as a series of mudflows, dipping about 5° S. 30" E. Some of the fragments art as much as 6 feet long; 90 percent are more than half an inch long. These mudflows include fragments of olivine-hypersthene basalt, hypersthene andesite, and hornblende-hypersthene andesite, ranging in texture from compact to porous, and in color from dark gray to medium gray or pinkish gray. Overlying the mudflows is a flow of pale-gray compact hornblende-hypersthene andesite, 300 feet thick, characterized by reddish-brown hornblende, augite, hypersthene, and plagioclase phenocrysts. The dip of the flow is about 16° S. 30" E.

At the north end of the area are high cliffs of breccia composed of blocks of hornblende basalt as much as 4 feet across that contain phenocrysts of labradorite, brownish-green hornblende, and augite, and grains of magnetite in a fine-grained groundmass. This breccia appears to make up the rocks offshore from the cliffs. Small masses of horizontally bedded, fine-grained, silicified tuff crop out sporadically on the sea cliff near the southern edge of the area of breccia. The tuff and breccia are underlain by a large irregular mass of dark-gray to medium-gray hornblende andesite porphyry, in which the phenocrysts are sodic labradorite and hornblende, calcitized and chloritized. The accessory minerals are magnetite and apatite. The groundmass is a mosaic of quartz, feldspar, and calcite. The breccia, the hornblende andesite porphyry, and the silicified tuff are all regarded as parts of the filling of a lateral vent on the Andrew

[2] Place name not shown on standard maps but used for convenience in this report.

Bay volcano. The maximum thickness of the rocks that now remain of the main cone of the Andrew Bay volcano is about 1,000 feet, but the original thickness was much greater.

A few small outcrops of poorly indurated sandstone and conglomerate dipping about 20° S., occur south of the rocks of Andrew Bay volcano, along the shore about a mile southeast of the north end of Andrew Lagoon. These beds are composed of angular to rounded fragments derived from the Finger Bay volcanics. They are believed to represent stream deposits laid down during an erosional interval before the deposition of the rocks of Andrew Bay volcano, but for convenience they have been included with the rocks of Andrew Bay volcano on the geologic map.

BOULDER CONGLOMERATE

A thickness of a few hundred feet of poorly bedded, bouldery conglomerate is exposed in the cliffs on the coast east of Mount Adagdak, beginning about 1½ miles north of the northeast corner of Clam Lagoon and extending northward about 3,000 feet. The beds observed by the writer dipped steeply eastward. The boulders range in length from a few inches to 10 feet; the larger boulders are somewhat angular; therefore, some of the beds are classed as breccia. The material consists of volcanic rocks, some of which resemble the rocks of Mount Adagdak (see below), and some, which are light-colored, are apparently andesitic rocks. No rocks known to be older than the conglomerate are in contact with it.

These rocks are probably marine talus deposits that accumulated against. a steep coast. They may have been deposited at the same time or before the rocks of Andrew Bay volcano were deposited.

FOSSILIFEROUS MARINE SANDSTONE

A fossiliferous marine sandstone is exposed west of the southern part of the bouldery conglomerate and overlies the conglomerate unconformably. Because of its softness this formation is poorly exposed, but it is probably several hundred feet thick. On the steep cliffs just above the conglomerate outcrops, the fossiliferous rocks strike N. 30° W. and dip 80" W.

The rocks are predominantly soft yellow-to-gray sandstone, but contain lenses of dark pebble conglomerate. The sandstone is cross-bedded and contains lenses rich in fragments of marine fossils. The fossils are not diagnostic: species, and most of them appear to be of genera represented on the present beaches of the Aleutians. It is inferred from the characteristics of the fossils and the degree of deformation of the rocks that the sandstone is probably of late Tertiary age. Its relationship to the interbedded basalt flows and tuffaceous sandstone of Mount Adagdak is obscure; the contact is probably along a fault or is unconformable.

ROCKS OF MOUNT ADAGDAK

Interbedded basalt flows and tuffaceous sandstone.—Interbedded basalt flows and tuffaceous sandstone make up most of the southern half of Mount Adagdak. They are best exposed on the sea cliffs on the east side of Mount Adagdak, from half a mile to 1½ miles north of the northeast corner of Clam Lagoon (pl. 14*A*). The flows of this sequence form the main structure of a shield volcano, of which only the southern half remains. Their total thickness probably exceeds 1,000 feet. Horizontal beds of fine-grained tuffaceous sandstone in the lower part of the section appear to have accumulated in quiet, shallow water far from the volcanic center. They probably form the foundation on which this part of the shield volcano was built. The enrlicst lava flows probably did not extend far from the vent, but later flows lapped farther and farther out on the horizontal upper surface of the sandstone part of the sequence. The lava flow in immediate contact with the upper surface of the sandstone also is horizontal at that point, but presumably is steeper toward the core of the cone. Following is a section on the face of the sea cliff on the east side of Mount Adagdak.

Section on cliff on east side of Mount Adagdak

[Thickness estimated from barometric altitudes]

	Feet
Erosion surface.	
Olivine basalt	40
Light-colored hornblende andesite pumice, and dark basaltic boulders	70
Olivine basalt	100
Reddish-brown tuffaceous sandstone, poorly indurated	25
Black sandstone, rich in basaltic debris, poorly indurated	15
Brown and gray sandstone, poorly indurated	10
Dun-colored sandstone, poorly indurated; some beds rich in breadcrust bombs of basalt as much as 1½ feet long; fills channels in underlying bed	0–15
Nearly massive, coarse, volcanic sandstone, containing a few well-rounded black basaltic pebbles and grains, and some scattered angular fragments as much as 1 foot long; upper surface channeled; base not exposed	10–25
	285

The two lava flows in this section are similar. The lower flow is pinkish gray, containing conspicuous phenocrpsts of dark-green augitc, as much as 4 millimeters across, and of light-brown olivine, as much as 1 millimeter across; the upper flow is medium gray, and contains more olivine and less augite. In addition to augitc and olivine, the rocks contain basic bytownite phenocrysts and accessory magnetite. The

A. HILLS SOUTHWEST OF SWEEPER COVE.

From hillone-half mile west of head of cove. Shows the rough topography characteristic of areas underlain by Finger Ray volcanics and later overridden by glacial ice. Smoother slopes in foreground are blanketed by postglacial ash.

R, DOME OF COLUMNAR ANDESITE PORPHYRY

One mile west of Gannet Rocks. Contact with Finger Bay volcanics is near right edge of picture, but is obscured hy glacial drift. Glaciated surface of porphyry is overlain by a mantle of windblown sand and volcanic ash.

C, CAPE ADAGDAK.

The marine terrace, covered hy boulder gravel, is built on mudflow.

AERIAL VIEW OF MOUNT MOFFETT FROM THE NORTH.

The highest cliffs transect the parasitic cone of Mount Moffett. Photograph by U. S. Navy.

AERIAL VIEW OF CAPE ADAGDAK FROM THE NORTH.

Recent faults in the older composite cone of Mount Adagdak are outlined hy snow. In the distance is the main mass of Adak Island. On the right are the constructional slopes of Mount Moffett. Photograph by U S. Navy.

AERIAL VIEW OF MOUNT MOFFETT FROM THE SOUTH.

Gentle constructional slopes of the composite cone are smoothed by mudflow material from the volcano. Ice-contact slopes represented by steep faces of terraces are visible below the snowline. Photograph by U. S. Navy.

VIEW ON EAST SIDE OF MOUNT ADAGDAK.

Olivine basalt flow overlies poorly consolidated tuffaceous sandstone with apparent conformity.

VIEW EASTWARD ALONG RECENT FAULT.

On the north face of Mount Adagdak, showing sag pond.

WELL-STRATIFIED POST-GLACIAL VOLCANIC ASH.

In road cut near Finger Bay.

groundmass, which forms only about 20 percent of the rock, is made up of blocky plagioclase, augite grains, and magnetite granules in a mosaic of quartz and orthoclase.

This sequence of flows accumulated against a sea cliff cut in the lavas of the Andrew Bay volcano, and is therefore younger than that sequence. It is undeformed and therefore inferred to be younger than the fossiliferous marine sandstone, which is folded. The older composite cone of Mount Adagdak rests upon it and is the next younger phase in the development of the volcano.

Older composite *cone*.—Viewed from the south, the long, gentle grass-covered slopes of the shield volcano that forms the substructure of Mount Adagdak are seen to be crowned by the steep, relatively smooth, bare slopes of a wide, low cone. The break in slope occurs at altitudes ranging from 800 to 1,000 feet; the smooth slopes of the upper cone are locally broken by crags developed on small lava flows. This cone represents an older composite cone of Mount Adagdak. It consists largely of lapilli-tuff beds, but includes subordinate lava flows and necks of hornblende andesite. This material accumulated first as a cone about 800 feet high, the sides of which arc as steep as 26°, on the top and the deeply crodcd northern flank of the shield volcano. A later explosive episode, centering about a vent northwest of the earlier one, produced an inner, eccentrically nested crater, the summit of which was as much as 1,920 feet in altitude, about 200 feet higher than the outer rim. The time interval between the formation of the two craters was probably very short. The fragmental material ejected from the craters consists of pale-gray to dark-gray, porous-to-compact hornblende andcsitc, and pinkish-gray porous hornblende andesite, containing conspicuous feldspar and hornblende phenocrgsts. Some of the fragments are angular blocks of glassy lava, which apparently cooled under. reducing conditions. The flows are made up of reddish-gray hornblende basalt. All the rocks arc characterized by labradorite phenocrysts, and augite and magnetite arc generally present. The groundmass consists of plagioclase microlites, magnetite granules, and interstitial orthoclase.

Younger composite cone.—A sequence of mudflows consisting largely of fragments of hornblende andesite, capped by two thin hornblende andesite lava flows, makes up the western flanks of Mount Adagdak. These rocks represent a younger cone built after the sea had partly eroded the older composite cone. The mudflows are composed mainly of fragments of medium-gray porous rock that contain phenocrysts of white plagioclase and black hornblende, as much as 2 millimeters long, and smaller phenocrysts of brown augite. Magnetite is the common accessory mineral, and the groundmass consists of plagioclase laths and magnetite granules in a cryptocrystalline mosaic, apparently of quartz and feldspar. The matrix of the mudflows is fragmental material of finer size and lighter color than the fragments but of similar composition. The two thin flows of reddish-gray hornblende andesite that cap the mudflows are similar in composition to the fragments in the mudflows.

Basalt and andesite domes.—Two hornblende andesite domes occur in the crater of the younger composite cone, and a basalt dome occurs low on the southern flank of the older one. The northern and larger of the two crater domes shows planar banding, which trends roughly parallel to the contact and dips steeply. The rock is pale gray and contains conspicuous phenocrysts of labradorite and greenish-brown hornblende. The southern and smaller crater dome is light pinkish gray, and its hornblende grains are reddish brown. The groundmass of both rocks consists of plagioclasc microlites but includes interstitial orthoclase. Apparently the domes arose toward the end of the period of eruptions during which the younger composite cone mas built.

Correlation of the two crater domes with the dome on the southern flank of Mount Adagdak is based primarily on similarity of topographic form rather than similarity of composition. The rock of the flank dome is reddish gray and contains phenocrysts of dark-green augite, black hornblende, and white calcic bytownite. Magnetite is an abundant accessory rnincral. The groundmass consists of plagioclase laths, augite rods, magnetite grains, and interstitial glass.

SOUTHWESTERN AREA

Volcanic rocks erupted from Mount Moffett and from a parasitic cone on its northeastern flank make up the southwestern area.

BOCKS OF MOUNT MOFFETT

The composite cone of Mount Moffett and the parasitic cone on its northcastern flank form a mountain mass that dominates the entire northwestern part of Adak Island. Small domes of basalt have been extruded on the flanks of both cones. Late in the history of the main volcano, after the volcano had been considerably eroded, a summit cone of coarse tuff-breccia was formed. An andesitic plug that rose in the crater of this cone now forms tlic summit of Mount Moffett.

Composite cone.—Rocks of a composite cone exposed on the sea cliff forming the north face of Mount Moffett for a distance of several miles west from Andrew Lagoon are the oldest rocks attributed to the Mount Moffett eruptive center. The colic consists chiefly of layers of tuff-breccia and breccia, whose angular fragments are as much as 5 feet long, but includes a few lava flows near its top. The breccia fragments consist of pale-gray hornblende basalt, red hornblende andesitc that is partly scoriaceous, and dark-gray to black basalt that contains conspicuous feldspar phenocrysts.

Interbeddod with the pyroclastic rocks are two thin beds of rounded boulders, 40 and 60 feet above sea level, respectively. These beds, each about 2–4 feet thick, strike parallel to the cliffs and dip seaward. They are probably of marine origin, and the tuff-breccia interbedded with them is interpreted as being the product of mudflows deposited in part under water. The sequence of tuff-breccia beds is at least 400 feet thick and is overlain by massive lava flows and by lapilli-tuff similar in lithology to the fragments in the tuff-breccia.

All of the earlier lava flows are gray, but locally they have been reddened near the base, presumably by steam rising from the surface over which they flowed. The conspicuous crystals consist of plagioclase, dark-green augite, brown olivine, and in some flows, deeply resorbed black hornblende. The plagioclase is zoned from sodic bytownite to sodic labradorite. Magnetite is a common accessory mineral. The groundmass contains plagioclase, magnetite, augite, and interstitial material that is probably orthoclase.

The later lava flows of Mount Moffett include dark-gray compact-to-porous lava; light-gray porous lava; and pale pinkish gray lava. Most of the rocks are made up of hornblende basalt that contains phenocrysts of labradorite and prismatic black hornblende, as much as 3 millimeters long, and subordinate augite and magnetite. The groundmass consists of plagioclase and magnetite granules and interstitial orthoclase(?). Some of the rocks contain hypersthene and olivine phenocrysts and are classed us olivine-hypersthene basalt.

Basalt domes.—Five basalt domes occur on the slopes of Mount Moffett. Two are high on the southeast flank, one is near sea level on the southeast flank, and two are on the north flank. These bodies were examined only briefly. Some may prove to be the termini of thick flows, or abnormally thick dikes, rather than domes. The three on the southeast flank are described in the following three paragraphs.

Hill 2416,[3] 1½ miles southeast of the summit of Mount Moffett, is composed of pale-gray hornblende basalt that contains inconspicuous glassy labradorite and conspicuous black hornblende phenocrysts as much as 2 millimeters long. Augite and magnetite are abundant. The groundmass consists of augite rods, plagioclase laths, and magnetite granules in a mosaic of quartz(?) and orthoclase(?).

Hill 1981,[3] about 2½ miles southeast of the summit of Mount Moffett, is made up of a compact medium-gray rock that contains plagioclase crystals as much as 2 millimeters long and augite grains as much as 1 millimeter long. Magnetite is abundant, and hypersthene, olivine, and basaltic hornblende are common but irregularly dis-

[3] Place names not shown on standard maps but used for convenience in this report.

tributed. Plagioclase laths, augite grains, and interstitial orthoclase make up the groundmass.

The hill known locally as Red Bluff,[4] on the north side of the east-west runway of the airbase, 2¼ miles south of the southern extremity of Andrew Lagoon, is made up of fine-grained, tough, slightly porous, medium-gray basalt. The basalt contains scattered small phenocrysts of augite and plagioclase, as much as 1 millimeter across, in a groundmass of bytownite laths and interstitial magnetite, augite, and glass.

Tuff-breccia cone and its andesitic vent filling.—Remnants of a small cone of coarse, poorly stratified tuff-breccia, erupted from a vent about 'on the site of the present summit of Mount Moffett, rest unconformably on the lava beds of the composite cone of Mount Moffett. The tuff-breccia cone was built after deep erosion of the composite cone. The crater of the tuff-breccia cone is filled with porous, light pinkish-gray hornblende-hypersthcne andesite. Most of the phenocrysts consist of zoned labradorite and augite, but some consist of basaltic hornblende and hypersthene. Magnetite and apatite are common accessory minerals. The groundmass consists of plagioclase, augite, and magnetite in a cryptocrystalline mosaic. Secondary tridymite lines many vesicles.

The tuff-breccia cone has largely been destroyed by glacial erosion; presumably its age is early Quaternary or pre-Quaternary. It is younger than the composite cone and the basalt domes of Mount Moffett.

Basalt $ow.—A small basalt flow crops out 1⅝ miles west of the head of Sweeper Cove. The lava apparently issued quietly from a small vent and flowed southward down the hill for about 2,000 feet. It has been cut through by a small stream near its terminus, where a maximum thickness of about 20 feet is exposed.

The basalt is a fine-grained, medium-gray rock, containing many irregular, flattened vesicles commonly lined with trid-mite. Sparse small plagioclasc phcnocrysts and considerable accessory magnetite are set in a groundmass of blocky plagioclase, interstitial augitc grains, magnetite, and brown glass.

The flow unconformably overlies the Finger Bay basalt. No glacial striae were observed, but the presence of small rock basins on the surface and the absence of coarsely vesicular rocks that were expected near the original upper surface of the flow suggest that it is preglacial in age. The basalt flow appears to be one of the youngest extrusive rocks attributed to the Mount Moffett center. It is probably late Tertiary in age, but may be early Quaternary.

[4] Since this report was written the hill has been removed.

PARASITIC CONE OF MOUNT MOFFETT

On the northeast flank of Mount Moffett is a composite parasitic cone, **3,250** feet in altitude, which was formed rather early in the life of the host volcano. Its vent is filled by gabbro and basaltic agglomerate. On its southeastern flank is an eruptive basaltic dome. Judging from the amount of erosion, activity at the cone ended before the latest activity at Mount Moffett proper.

The cone occupies approximately the northeast quarter of the area underlain by Mount Moffett rocks. On the northern sea cliff, the lowest beds of lava of the parasitic cone overlap the beds of lava and the tuff-breccia of Mount Moffett. Some of the rocks of the parasitic cone probably interfinger with late flows from the main rent of Mount Moffett.

The parasitic cone is composed of rather uniform lava flows, 5–10 feet thick, interbedded with coarse basaltic lapilli-tuff containing scoriaceous fragments as much as 6 inches long. A typical flow consists of purplish-gray porous olivine basalt, displaying dark-green augite phenocrysts as much as 4 millimeters long, yellowish-brown olivine phenocrysts as much as 2 millimeters across, labradorite phenocrysts from 0–1.5 millimeters long, and accessory magnetite. The groundmass is made up of plagioclase, augite, magnetite, and interstitial orthoclase.

Fine-grained olivine gabbro plug and associated basaltic vent agglomerate.—Light-colored rocks that form the summit of the composite cone can, even at a distance, be readily distinguished from the dark interstratified lava flows and beds of lapilli-tuff forming the dissected outer slopes of the cone. This central light-colored material constitutes a plug that filled the former vent of the cone. Its main constituent is pale purplish gray fine-grained olivine gabbro. Intricately mixed with the gabbro arc masses of basaltic vent agglomerate, in places hydrothermally altered.

Basaltic dome.—Hill 1848,[5] about a mile west of Andrew Lagoon, is a basaltic composite dome. It is made up of one of the youngest volcanic rocks on northern Adak Island. Tho dome is tripartite, the two outer parts being the remnants of what is assumed to have been a continuous ring that has been trimmed away by erosion on the north and south. The rocks of the central, highest part represent a slightly later intrusion, which broke through and forced apart the rocks of the original ring. The outer parts of the dome consist of a medium-gray porous lava, containing very irregular vesicles into which crystals of the lava project. The phenocrysts are made up of plagioclase and green augite in a groundmass of plagioclase laths, magnetite, augitc, and interstitial brown glass.

[5] Place name not shown on stnndard maps but used for convenience in this report.

The central part of the composite dome consists of rock similar to the gray rock that makes up the outer part of the dome, but it has been reddened and contains xenoliths of the gray rock.

GLACIAL DRIFT

Most of northern Adak Island was covered by glacial ice during part of Pleistocene time. The chief deposit of this ice is a ground moraine left by an ice sheet that moved into the mapped area from highlands to the south. It covered most of the southern part of the area and lapped up on the southern and southeastern slopes of Mount Moffett and Mount Adagdak. The ground moraine is as much as 12 feet thick, and contains numerous subangular and rounded boulders, many of them faceted, set in a tough and clayey matrix. The surface of the ground moraine is comparatively smooth, and the till has been oxidized to a depth of only a fraction of an inch. A thin blanket of volcanic ash and, adjacent to the coast, a blanket of windblown sand rest unconformably on the ground moraine.

Near the base of Mount Moffett much of the material carried by the ice sheet mas deposited as irregularly stratified beds of sand and fine gravel. These beds are intermingled with beds of unsorted boulder gravel, some of which may have been brought down the slopes of Mount Moffett. In places, where more material was brought down the mountain slopes, relatively flat terraces were formed, bounded on their down-mountain side by steep ice-contact slopes. At other places swales, bounded on the down-mountain side by low ridges of moraine, mark successive positions of the ice front during its retreat.

Ground moraine, swales, and terraces similar to those described are present on the southern slopes of Mount Adagdak, where they reach an altitude of nearly 500 feet. Sediment brought by glacial streams from the Mount Adagdak area and other areas was ponded in a pocket between arms of the ice sheet, forming an extensive terrace north of the east end of Andrew Lagoon.

Valley glaciers, which headed in cirques on the north and northeast sides of Mount Moffett, built prominent lateral moraines as well as some ground moraines. Locally, a large outer lateral moraine was succeeded by a smaller inner one. One of these outer moraines, exposed in the sea cliff on the northeast face of the parasitic cone of Mount Moffett, is about 400 feet thick and a little more than 4,000 feet long. Immediately south of this moraine is a younger moraine that is only about half as long and half as thick. Other great moraines form much of the higher parts of the sea cliffs on the northwest side of Mount Moffett.

MARINE TERRACE BOULDER GRAVEL

Marine terraces veneered with boulder gravel a few feet thick occur in 3 areas; 2 large ones on the shores north of Mount Moffett and Mount Adagdak (pl. 10*C*), respectively, and 1 small one on the east side of Mount Adagdak. The terraces on which the boulder gravel lies range in height from 20–100 feet above sea level. The terrace on the north side of Mount Adagdak slopes both eastward and westward from a maximum altitude of 100 feet to a minimum of 20 feet. Individual boulders on the outer edges of the terraces are as much as 3 feet across. On their inland margins these deposits grade into talus and alluvial fans. The gravel-covered terraces have been cut back by wave action but have not been dissected by streams. They are postglacial in age.

RECENT UNCONSOLIDATED DEPOSITS

Patches of Recent unconsolidated beach, delta, lagoon, alluvial, and aeolian deposits are scattered throughout the area. Because of the intensity of the wave attack on exposed coasts during the violent storms of the Aleutians, the present beach deposits consist mostly of coarse materials, ranging in size from that of gravel to that of boulder gravel. Boulders as much as 2 feet across are shifted appreciably by storm waves.

Streams emptying into protected bays have built deltas of mappable size. The material of the deltas is subangular to subrounded; some of the fragments are of cobble size. The delta deposits consist largely of reworked pyroclastic and glacial deposits, as few streams have been able to excavate deeply in the hard bedrock since glacial time. Similar alluvial deposits form small patches along some of the streams, particularly where these streams empty into the numerous lakes in the glaciated areas.

Aeolian deposits include sand dunes and deposits of ash; the ash was carried by winds from eruptions on other islands. Large areas of sand dunes occur on both sides of the entrance to Clam Lagoon. The sand supplied by longshore currents is concentrated on tide flats, from which it is picked up by the wind during low-water periods. Smaller patches of sand dunes are found on the spits of Shagak Bay and on the bar enclosing Andrew Lagoon. Sand dunes were present also in the area north of Sweeper Cove before extensive construction work began there. The maximum height of the dunes is about 100 feet. All appear to be stable, except those whose cover of native vegetation has been recently disturbed.

Most of the lower slopes of northern Adak Island are covered by a volcanic-ash layer of strikingly uniform thickness (pl. 14*C*). The ash layer has been omitted from the geologic map in order to show the bedrock geology. The ash is composed largely of fine fragments of brown-to-black basalt, but contains layers of coarser, lighter colored pumice which may be andesitic. Near Finger Bay it is 5.8 feet thick, and on the west side of Clam Lagoon, 5.3 feet. In a quarry 3 miles east of the head of North Spit, on the southern slope of Mount Moffett at an altitude of 400 feet, the ash is 7.5 feet thick.

The lower 3.4 feet of ash exposed in the quarry is preserved only in the small valley in which the quarry is located. It is overlain unconformably by a younger layer of ash. The deposit has a greater total thickness in this valley than in the other areas where it was measured, probably because the valley was not covered by glacial ice at the time the ash was deposited, whereas the other areas were covered. One of the striking features of the ash blanket at lower altitudes is its uniform thickness, which is almost independent of steepness of slope. The general presence of stem and root casts suggests that this uniformity is due at least in part to the material having been held in place by vegetation. If part of the ash had been derived from one of the volcanic centers on Adak Island, the coarseness and thickness of some layers should vary inversely with distance from one of those centers. This variation has not been observed, hence it is concluded that all of the deposit has been derived from explosive eruptions of volcanoes on other islands. It is further concluded that the deposit must be largely postglacial, as glacial erosion would have removed preglacial ash from most of the area.

STRUCTURE

The structure of northern Adak Island is diagrammatically shown on the geologic sections of plate 9. The internal structure of the Finger Bay volcanics is not shown by the sections. In response both to deformation and to erosion this sequence has acted as an essentially homogeneous unit. It formed the irregular surface upon which the three younger volcanoes were erected. The volcanic structures of Tertiary and Quaternary age are relatively simple, and largely reflect the processes of construction, rather than of tectonic deformation. The present crustal instability of the area is indicated by the numerous earthquakes felt at Adak. None is believed to have been due to movement along any of the faults that have been mapped.

Many persistent and well-defined faults occur in the southern part of the area. Most of them appear to be steeply dipping normal faults of small displacement. The predominant trends of these faults range from N. 60° E. to N. 60° W. and from N. 20° E. to N. 10° W., but faults of intermediate trend are present, and some faults curve through a wide range of trends. The age of these faults is not definitely determinable. They do not appear to cut any of the

Tertiary rocks of the island, but they do cut the Finger Bay volcanics and the gabbro that intrudes the Finger Bay volcanics. Some of the faults shown on the geologic map extend beyond the borders of the mapped area; those whose trends average about N. 65° E. are apparently part of a system present on other islands of the Andreanof group lying to the east of Adak.

The rocks near the summit of Mount Adagdak are cut by Recent faults (pls. *13* and 14*B*). The fault shown in plate *14B* is the upper fork on the right side of the fault most conspicuously outlined by snow in plate 13. The apparent throw of the upper fork is about 4 feet and the throw of the lower fork of the same fault is about 8 feet. The downthrown sides of both forks are those nearest the center of the mountain, as are those of most other Recent faults in the area. Only the more active talus cones have overridden the sags formed where the faults cross the bottoms of gullies. The faults are at most only a few thousand years old.

GEOLOGIC HISTORY

The geologic history of northern Adali Island is essentially the history of the formation and destruction of the series of cones that are represented today by the rugged mountains of Mount Moffett and Mount Adagdalr.

The geologic record begins in the pre-Mesozoic with the accumulation of a thick sequence of basaltic extrusive rochs and dikes—the Finger Bay volcanics. These rocks mere folded, intruded by bodies of gabbro, and attacked by hot solutions. Afterward, numerous faults developed, then a long interval of erosion occurred, unmarked by notable volcanic action.

In Tertiary time volcanic activity was resumed. Five masses of nndcsitc porphyry were formed as steep-sided viscous protrusions near the prcsent east coast. A central vent, west of the prcsent eastern shore of Andrew Bay, became active, building a cone largely of andesitic Iava flows and mudflows—the Andrew Bay volcano.

Coincident with or before the accumulation of the rocks of Andrew Bay volcano, several hundred feet of extremely coarse conglomerate accumulated along what is now the eastern side of the Mount Adagdak peninsula. The coarse conglomerate was tilted and eroded, and fossiliferous sandstone, containing lenses of pebble conglomerate, was deposited.

After a period of volcanic quiescence, in which the sedimentary rocks were again tilted and the Andrew Bay volcano was almost completely destroyed by marine erosion, volcanic activity recurred at a new center near the prcsent Mount Adagdak volcano. The eruption at first was explosive and perhaps submarine, and tuffaceous sands were deposited around the base of the new volcano. Later, thick flows of basalt and olivine basalt accumulated to form a broad low dome, attaining an elevation of perhaps 1,500 feet and a diameter of more than 2 miles. This shield volcano was attacked by marine erosion, particularly on the north, creating a cliff which gradually was cut back almost to the volcano's center. Activity was then renewed, and a composite cone, made up primarily of lapilli-tuff and andesite flows, but containing small andesitic intrusions, was formed around the same vent. After a brief cessation of activity, a nested crater was constructed, the center of which was about half a mile to the northwest of that of the older and larger crater. A long period of quiescence ensued, permitting marine erosion to cut away the northern half of the composite cone. The accumulation of a series of mudflows, succeeded by the extrusion of hornblende andesite as two flows from and two domes in the crater, completed the volcanic history of Mount Adagdak. An olivine basalt dome on the southeastern flank of the mountain may date from this final period of extrusion.

The rocks of Mount Moffett and those of Mount Adagdak are nowhere in contact, thus making the relative dating of geologic events in their histories practically impossible; however, it appears likely that the two were at least in part contemporaneous. Early eruptions from a vent south of the present summit of Mount Moffett produced tuff-breccia and flows of olivine and hypersthene basalt; later, hornblende basalt was extruded as flows. Late in the history of Mount Moffett, steep-sided viscous domes of basalt formed on the flanks of the cone. A period of erosion followed, during which the main cone of Mount Moffett was considerably dissected. By a series of explosive eruptions, a steep cone of coarse basaltic tuff-breccia was constructed, centered about a vent which occupied approximately the position of the present summit of Mount Moffett. The vent was later filled by an intrusion of andesite. Basalt that forms a flow 1⅝ miles west of Sweeper Cove was erupted at about this time.

A steep-sided parasitic cone on the northeast flank of Mount Moffett was built contemporaneously with the tuff-breccia summit cone. This parasitic cone consisted largely of a succession of thin flows of olivine basalt, but included a few beds of basaltic scoria. After formation of the cone a viscous, partly cooled mass of fine-grained olivine gabbro rose into the vent, dragging up the flows adjacent to its margin. Subsequently, a minor explosive eruption blasted **a** small vent through the central plug; the vent was later filled with basaltic vent agglomerate. Apparently the most recent event in the history of this parasitic cone was the extrusion of a basaltic dome about 2 miles west of the center of Andrew Lagoon.

During early Quaternary time much of Adak Island was covered by glacial ice. The principal collecting ground was the highland lying south of the latitude of Sweeper Cove. From this area the ice moved as a sheet northward to Mount Moffett, where it divided. Part of the ice flowed westward into Shagak Bay and into the area now occupied by Adak Strait. The other part advanced northward and eastward to the slopes of Mount Adagdak, where it again divided. One arm, at its greatest extent, reached the sea along a front which probably lay in what is now Andrew Bay. The other arm reached the sea along a front which lay somewhere on Kuluk Bay, and which may have extended eastward as far as Great Sitkin Island. The retreat of the ice front was gradual, interrupted by numerous halts. During each of these halts fragmental material, carried down from the easily erodible tuff-breccia deposits higher on the mountain slopes, w-as deposited against the ice margin to form long, narrow terraces. Several flights of terraces mere thus built, each with a gently sloping upper surface and a steep face. The terraces are comprised of both glacial and mudflow material.

Similar but less conspicuous terraces were formed on the southern flank of Mount Adagdak. Most of the material for these terraces was supplied by glacial erosion of rocks to the south.

Five small glaciers appear to have occupied valleys on the east, northeast, north, northwest, and west sides of Mount Moffett, but all disappeared thousands of years ago. At some stages the valley glaciers on the east and northeast sides may have descended the mountain slopes far enough to join the ice sheet. Altitudes on the island are not great enough to permit the formation of glaciers under present climatic conditions.

After the withdrawal of the glacial ice from the shoreline, large areas of poorly consolidated Tertiary volcanic rocks and unconsolidated glacial deposits were exposed to vigorous marine erosion. A wide wave-cut bench was carved along much of the northern coast. Longshore currents are now constructing imposing bars and spits that shut off Andrew Lagoon, Clam Lagoon, and Shagak Bay from the sea. Fine material exposed above water level has been transported inland by the wind to form a blanket that mingles imperceptibly on the landward side with the blanket of volcanic ash laid down in post-glacial time by eruptions from the volcanoes on nearby islands. Where the supply of sand has been unusually abundant, sand dunes, now mostly stabilized by vegetation, have formed. In relatively recent times the remnants of the wave-cut bench mere uplifted to form terraces a few tens of feet above sea level. Perhaps related to this uplift was the development of peripheral normal faults on Mount Adagdak, by which the central part of the mountain subsided a few feet relative to the outer slopes.

FUTURE VOLCANIC ACTIVITY

The volcanoes of northern Adak Island apparently have not been active since early Quaternary time. The postglacial volcanic ash on the island is believed to have been derived from explosive eruptions of volcanoes on nearby islands, chiefly Kanaga and Great Sitkin. On this basis, it appears that the volcanoes, if not extinct, can reasonably be expected to remain inactive in the foreseeable future.

On the other hand, there is abundant evidence that volcanic activity has been renewed several times in the past after long periods of quiescence. Judging by the amount of marine erosion before each renewal, each has occurred after a period of quiescence that was longer than the present quiet period. The length of time that has passed since the building of the tuff-breccia cone on Mount Moffett and the extrusion of the basalt that formed the dome on its parasitic cone—the latest episodes in the volcanic history of Mount Moffett—is probably about the same as that of some of the previous periods of quiescence in the history of these cones, perhaps several thousand years. The possibility of a new cycle of volcanism on northern Adak Island cannot, therefore, be dismissed.

Frequent earthquakes felt at Adak indicate that the earth's crust in that area is unstable. It remains to be determined by investigation whether this instability is directly related to local volcanic activity, and may thus herald a new volcanic cycle on Adak, or whether it is related only in a general way to volcanic activity in the Aleutian arc.

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