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NOTES ON THE GEOLOGY OF THE ALASKA PENINSULA AND ALEUTIAN ISLANDS

BY

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NOTES ON THE GEOLOGY OF THE ALASKA PENINSULA AND ALEUTIAN ISLANDS

By Stephen R. Capps

ABSTRACT

During the spring of 1932 an opportunity was offered by the United States Navy for a geologist to accompany an expedition organized to make a reconnaissance of the western part of Alaska Peninsula and the Aleutian Islands. This expedition visited several localities the geology of which was little known. It was found, as had already been expected, that the islands west of Unimak Pass are composed mainly of basic volcanic lavas and fragmental materials, into which have later been injected dikes, sills, and considerable masses of intrusive rocks, some of which are of acidic types and of granitic texture. These westward islands are bordered both to the north and south by depressions 2,000 fathoms or more in depth, and the islands have apparently been built up from that depth by the ejection and extrusion of volcanic materials since early Tertiary time. No rocks of proved pre-Tertiary age were seen, and the only sedimentary materials present may well have been derived from the erosion of the volcanic islands after they were built up above sea level. On the Alaska Peninsula pre-Tertiary sediments through which the volcanic materials broke to the surface are abundantly present.

There is evidence that all the larger islands and the higher portions of the peninsula were severely glaciated during Pleistocene time. Each of the larger islands was the center of ice accumulation and dispersal, and the present topography, except upon recently active volcanic cones, shows strongly the effects of glacial sculpture.

INTRODUCTION

In the spring of 1932 an expedition was organized by the United States Navy for reconnaissance hydrographic work in the Alaska Peninsula and Aleutian Islands. This expedition, in command of Lt. R. H. Harrell, sailed from Bremerton, Wash., April 20 on the U.S.S. *Gannet*, a mine sweeper, and proceeded northward by way of southeastern Alaska. In addition to the regular complement of the ship the expedition included two amphibian planes with the necessary officers, pilots, and mechanics. Permission was extended by the Navy to the Geological Survey for a geologist to accompany the expedition, and it was the writer's good fortune to be assigned to that work. Inasmuch as the planes were flown as far northward as Seward, the

Gannet accompanied them to that point, with few stops. From Seward westward the planes were carried aboard ship to Unalaska and from that time forward whenever long moves were made. The main purpose of the expedition was to make a reconnaissance air survey of the shores of the Alaska Peninsula and the Aleutian Islands. To accomplish this the *Gannet* was moved to harbors at intervals of a few hundred miles, and the shores between those harbors were examined and photographed from the air.

It was recognized in advance that the program of work outlined by the Navy would give the geologist opportunity to visit only a few scattered localities and that even at those places the stops would be short and the chances for geologic work limited. Nevertheless, it was believed that whatever information could be gathered would be valuable, particularly as most of the area to be visited was difficult of access, and little was known of its geology. The following notes on the geology of the region have little areal significance, for throughout the region protected harbors are few and the coast line in general is rugged and cut into sea cliffs by the waves, so that landing by small boat is dangerous or impossible in ordinary weather. The writer therefore had opportunity to visit only the immediate shores of the harbors in which the ship was anchored. A large number of flights by plane were made, however, and these, though failing to yield detailed geologic data, served to broaden the understanding of the region as a whole. The writer wishes here to acknowledge his indebtedness to the officers of the expedition, who on all occasions assisted him in every possible way and whose unfailing courtesy and friendliness made the summer one to be remembered with pleasure. The microscopic study of the thin section of rocks collected on this expedition was made by J. B. Mertie, Jr., and he determined the rock types that will be referred to here.

GEOGRAPHY

The Alaska Peninsula and the Aleutian Islands form one of the great structural festoons with which the Pacific Ocean basin is bordered (pl. 5). This festoon is punctuated at short intervals by volcanoes either still active or so young that erosion has not yet destroyed their characteristic shape. From Mount Spurr, on the north, the northernmost vent that has been recognized, to Attu Island, on the west, a distance of 1,575 miles along the curve of the arc, there are active or moderately young volcanoes at intervals not greater than 110 miles, and for most of the distance they are separated by only 70 miles or less. Throughout the Alaska Peninsula the volcanoes have broken out through older sedimentary or igneous rocks, by which they are now flanked. In the Aleutian Islands there are few if any

exposures of the basement rocks, and the islands are largely constructional, having been built up to and above sea level by the accumulation of lavas and volcanic fragmental material ejected from below.

Little oceanographic work has been done in the region off the Aleutian Islands, but enough soundings have been made on the Pacific side to show that there the water deepens to 1,000 fathoms within 25 miles, more or less, and still farther south the bottom drops off to a deep that shows soundings between 3,000 and 4,000 fathoms. Bering Sea, northeast of a line passing from Unimak Pass just south of the Pribilof Islands, is shallow, being all less than 100 fathoms deep, and much of it less than 50 fathoms. A line of soundings taken by the fathometer on the *Gannet* in 1932, extending along an irregular course from a point north of Amukta Pass to Attu Island, at varying distances from the intervening islands, shows that north of the islands the 1,000-fathom line lies close to the island festoon and that at a distance of 50 miles or more from them there is a remarkably smooth-floored depression at a depth of 2,000 to 2,200 fathoms. The shape of this depression between the islands and the continental mass, which includes much of Bering Sea, is not known, but it is significant that the island arc rises as a sharp ridge separating deeps of 2,000 fathoms or more both to the north and south.

THE ROCKS

In the various localities visited by the writer in the Aleutian Islands in 1932 no sediments or other basement rocks were seen that are definitely older than the volcanic rocks of which the islands are chiefly composed. So far as is known, the beginning of volcanism along the great arc occurred in Eocene time. Knappen [1] reports that the Eocene sediments of the Aniakchak district grade upward into stratified bentonitic clays and volcanic sediments, and Capps [2] found volcanic materials in Eocene beds near Mount Spurr. Thus it is shown that volcanism in the belt including the Alaska Peninsula and Cook Inlet regions began sometime in the Eocene, and it seems fair to presume that volcanic activity in the Aleutian Islands began at about the same time. It is reported that sandstones and shales occur in places in the Aleutian Islands, and indeed sedimentation must have been in progress around the borders of each island ever since it first built itself up high enough to be attacked by waves or by subaerial erosion. It is possible also that considerable blocks of the basement rocks were carried upward by the up-welling magmas

[1] Knappen, R. S., Geology and mineral resources of the Aniakchak district: U.S. Geol. Survey Bull. 797, p. 195, 1929.

[2] Capps, S. R., The Mount Spurr region: U.S. Geol. Survey Bull. 810, p. 161, 1930.

or were ejected as fragments during periods of explosive violence, but the impression gained by the writer is that the islands west of Unimak Pass are composed very largely of materials of volcanic derivation and lavas, tuffs, and intrusive rocks injected into these volcanic materials and secondarily of sedimentary materials derived from these volcanic rocks by erosion.

Sedimentary rocks of Tertiary age are known to occur at intervals along the Alaska Peninsula and at a few places in the Aleutian Islands, and they have yielded collections of invertebrate fossils and of plant remains. In the present investigation such rocks were seen at Unga Island and in Pavlof Bay, where ordinary sandstones and shales occur. In the Aleutian Islands most if not all of the Tertiary fossils have been collected from volcanic tuffs that are certainly younger than the beginning of volcanic activity at those places. Among the localities where such fossiliferous Tertiary materials occur may be listed Umnak,[3] Unalaska, Akutan, and Atka Islands.[4] Atwood[5] lists a number of fossiliferous localities on the Alaska Peninsula that have yielded both invertebrate and plant remains, which were assigned to the Eocene. More recent studies of the invertebrate fossils, however, point to an age within the Tertiary younger than Eocene. At any rate, inasmuch as these fossils are all of Tertiary age and as volcanism in this area is known to have begun at least by early Tertiary time, these fossiliferous beds do not necessarily represent basement rocks through which the volcanic materials found their way to the surface but more likely are sediments deposited on the flanks of preexisting land masses. On the Alaska Peninsula there is abundant proof that a pre-Tertiary land mass existed, and that the volcanoes there broke through Jurassic and Cretaceous sediments. In the Aleutian Islands, so far as the writer knows, there are no unquestioned occurrences of pre-Tertiary rocks, and it appears likely that those islands did not come into existence until they were built up to the surface of the ocean by volcanic activity, probably in early Tertiary time.

Many writers who have discussed oceanic volcanic islands have assumed that the presence on them of rocks of granitic composition and texture indicates that these granitic rocks are a part of the basement through which the vents broke and are older than the volcanoes themselves. The facts observed in the Aleutian Islands seem to cast some doubt upon this assumption, or at least to raise the question whether it is not possible for lavas of granitic or dioritic composition

[3] Hulten, E., letter to author.

[4] Grewingk, Constantin, Beitrag zur Kentniss der orographischen und geognostischen Beschaffenheit der Nordwest Küste Amerikas, mit den anliegenden Inseln: Russ.-k. mineral. Gesell. St. Petersburg Verh., Jahrg. 1848–49, pp. 123–278, 1850.

[5] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U.S. Geol. Survey Bull. 467, pp. 49–58, 1911.

composing a part of the series of magmas from a volcano to be injected into earlier flows and tuffs, and there to cool under sufficient cover to yield typical granites or diorites. Such granitic rocks were observed on Unalaska Island, at the head of Captains Bay, where fairly coarse quartz monzonite and medium-coarse quartz-pyroxene diorite were collected. These coarse-grained intrusives have been interpreted as indicating the presence there of an old granitic terrane which existed before the volcanoes came into being and through which they broke their way to the surface. No opportunity was available to study the contact relations of these rocks with the associated volcanic materials, but inasmuch as most of Unalaska Island is unquestionally volcanic, it seems possible that the diorites are intrusive into the volcanic rocks, rather than that they are older than the volcanic activity. This inference is strengthened by the occurrence on other islands of smaller intrusive masses of acidic composition and fairly coarse grain in places where there seems no reason to doubt that they represent intrusives into lavas and tuffs. Thus on Adak Island an andesite or latite porphyry was found intruded into volcanic tuff. On Kiska Island small masses of quartz latite cut basalts and basalt tuffs. On Attu Island sodic diorite is intrusive into basalts. The case for believing that the granitic rocks of the Aleutian Islands are of Tertiary age and therefore later than the beginnings of volcanic activity there is strengthened by the fact that granitic intrusive masses of monzonitic habit are numerous in southwestern Alaska, where they have been definitely determined to be of Tertiary age.

With the exception of the acidic rocks just mentioned, all the specimens collected in the Aleutian Islands are of basic composition and include a considerable variety of basalts, basalt porphyries, basalt tuffs, and obsidian.

Although all the larger islands of the Aleutian chain are composed mainly of volcanic rocks, it is a notable fact that most of the active or comparatively young volcanic peaks rise near the north ends of the larger islands, or on the northern islands in the chain, whereas in general erosion has attacked the southern islands and the southern portions of the larger islands so vigorously as to destroy the conical shape of the vents, and indeed to make difficult the identification of the sites of the volcanoes that served as vents for the materials of which the islands are built. It thus appears that the earlier volcanoes tended to lie some distance south of the line upon which the present vents occur, and that there has been a slight northern migration of the line of activity.

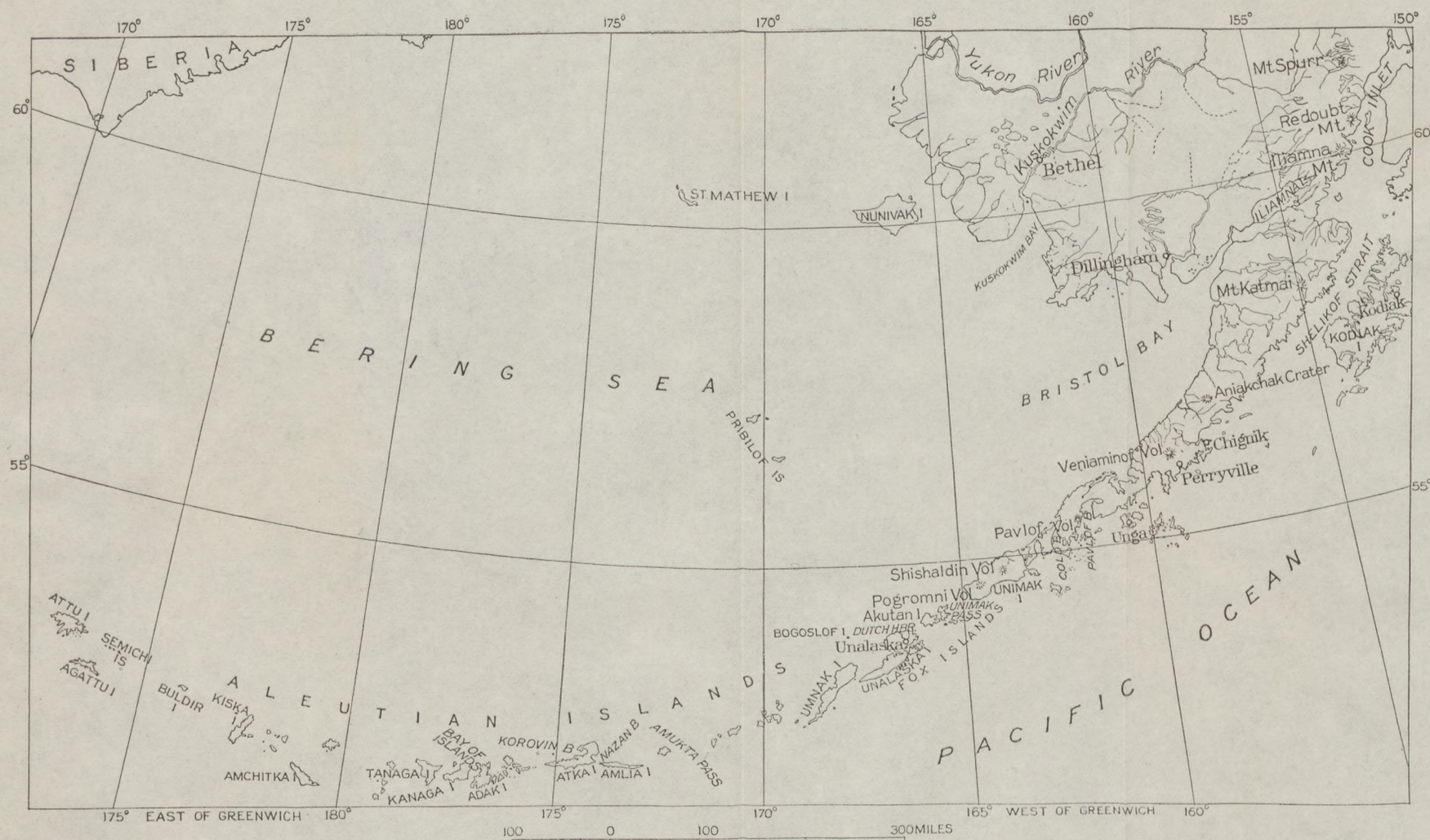
The visitor cannot help being impressed by the striking linear arrangement of those vents that are still active or that still possess their characteristic geomorphic form. No volcanic cone was recog-

nized on the Near Islands, at the westward end of the arc, though the Semichi Islands and Buldir Island may be volcanic. But from Kiska Island eastward to Unimak Island and thence northeastward to Mount Spurr, west of Cook Inlet, the recognizable volcanic cones lie along a smoothly arcuate line with remarkable closeness. The only conspicuous departure from this irregularity is Bogoslof Island, which lies about 30 miles north of the line. It thus appears that this great chain of volcanoes lies along a single great rift or tear in the crust, with perhaps a short spur running through Bogoslof. In the westward islands the rift lies toward the northern edge of the island festoon. At Unimak Island and in the lower part of Alaska Peninsula the volcanoes lie about centrally between the Pacific and Bering Sea, but still farther north the rift swings to the east of the peninsula and lies close to the Pacific littoral. This shift from the north edge of the islands to the northeastern part of the peninsula in no way affects the perfection of the great arc or the remarkable alinement of vents along it.

GLACIATION

All the larger and more mountainous of the Aleutian Islands that were visited, as well as the mountainous portions of the western part of Alaska Peninsula, show pronounced evidence of severe glaciation during Pleistocene time, and in a few places of high elevation on the peninsula valley glaciers still persist. Thus an ice stream flows southwestward along the base of the Aghileen Pinnacles, just west of Pavlof volcano, and its sapping of a jointed lava flow has produced the extraordinary ruggedness of the ridge on which the Pinnacles stand. At the time that area was seen from the air, in late June, the high mountains were so extensively covered with snow that it was impossible to make out the actual extent of glacial ice, though the glacier appeared to be several miles long. Another rather short glacier has its source in the crater of the enormous extinct Veniaminof volcano, west of Chignik, and flows southward to the base of that volcanic mountain to drain into the Pacific.

The small development of the existing glaciers, however, is no measure of the extent of the ice at the climax of the Pleistocene glaciation, for all those areas that reached an elevation of as much as 2,000 feet were able to hold perpetual snows and to generate glaciers. On the Pacific side of the peninsula these glaciers pushed down into the sea and developed a rugged, fiorded coast. On the Bering Sea side they pushed out onto the lowlands, and although the limits they reached have not been accurately determined, it seems certain that a combination of glacial deepening of basins



MAP OF THE ALASKA PENINSULA AND ALEUTIAN ISLANDS.

and glacial deposition of morainal material has provided the sites for many of the large lakes that form so conspicuous a feature of these lowlands. Throughout this area, however, including both the peninsula and the Aleutian Islands, the glacial ice was of local origin, and as the distance to the sea was nowhere great, the ice streams never reached great length.

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. The former presence of great glaciers on these islands is witnessed by such features as broadly U-shaped valleys heading in cirques, sharp, rugged interstream ridges, tarn lakes, fiorded coast lines, erratic boulders, and a multitude of other features characteristic of regions that have been covered with ice. One can picture in mind what a forbidding region this must have been at the time of maximum glaciation, and how effective a barrier to the migration of land animals along the coast this almost continuous mass of ice must have interposed.

The accomplishments of normal erosion agencies since the retreat of the last great glaciers are relatively trivial. Some sharp postglacial gulches mark the mountain slopes, the stream valleys in many places present an alternation of shallow rock canyons with basins of deposition, and beaches, bars, and spits have been built by waves and currents in protected places, but on the whole the landscape is much as it was when the ice first melted away from it.

LOCAL OBSERVATIONS

UNALASKA ISLAND

In traverses carried along the shores of Iliuliuk Bay and on Amaknak Island (the island on which Dutch Harbor is situated) the only rocks observed were basic lavas and tuffs that have a prevailing dip of about 15°–30° N. These volcanic rocks are cut by numerous dikes and sills of similar composition. The southeast shore of Iliuliuk Bay was not examined in detail but appears also to be composed entirely of volcanic rocks, though their structure is more diverse than that of the rocks on Amaknak Island. In thin section three specimens of rock taken from the shores of Amaknak

Island proved to be basaltic tuff, basalt porphyry, and olivine basalt porphyry. No rocks other than those of volcanic origin were seen.

A short trip to the head of Captains Bay, southwest of Unalaska, showed the presence there of abundant granitic gravel discharged by the Shaishnikof River, which flows from the high interior of Unalaska Island northeastward into the head of Captains Bay. The pebbles of this gravel, examined in thin section, were found to be fairly coarse grained quartz monzonite, of a type which the writer saw nowhere else in the Aleutian Islands. Associated with the quartz monzonite gravel on the bars of the river are minor amounts of chloritized tuff and a small proportion of volcanic rocks ranging from light-colored lavas and porphyries to basalt. A short trip southward from the head of Captains Bay showed quartz-pyroxene diorite in place. The abundance of quartz monzonite and of diorite in the gravel of the Shaishnikof River indicates that a large part of its basin lies in granular intrusive rocks, although the portion of the island bordering all of Unalaska Bay except the upper end of Captains Bay is evidently made up of volcanic materials. The cliffs in the neighborhood of Cape Cheerful at the west end of the bay, show a great thickness of lava flows; those toward the base of the cliffs are relatively thin, but three flows from 200 to 500 feet thick appear toward the top of the cliffs.

A brief examination of the shores of the head of Chernufski Harbor, on the northwest coast of Unalaska Island near the site of an abandoned village, showed that this portion of the island is also composed entirely of volcanic rocks. Two specimens of bedrock both proved to be basalts. On the Pacific slope of the bar on which the village is located the beach is composed almost exclusively of highly polished pebbles of a dark to light green fine-grained rock that in thin section proved to be an obsidian tuff composed of both rounded and angular fragments of unaltered volcanic glass, now silicified and cemented together by very fine grained quartz. Some fragments of plagioclase and other original minerals are still visible, but the bulk of the rock is made up of the volcanic glass. Native stone implements of a similar rock have been found in the region by archeologists, and it is likely that the material for them was obtained from this locality. The rock, though hard to work, takes on an exceptionally smooth polish and can be shaped into superior pointed weapons.

Unalaska Island, like all the other high mountainous islands of the Aleutian chain, was severely glaciated in Pleistocene time by glaciers that originated on the mountain slopes and pushed radially out to sea in all directions. This island apparently acted as the

center for the development of a local ice cap, so that not only the mountain valleys but the lowlands and the lower portions of the intervalley ridges were overridden and sculptured by glacial ice. In places this ice scour has given strong surface expression to the structure of the underlying lavas and tuff. Thus on Amaknak Island, in the area between Dutch Harbor and the head of Iliuliuk Bay, glacial plucking has developed a series of steplike ridges that as viewed from the air show steep scarps on their south face and smooth dip slopes on the north slope. The whole island bears conspicuous evidence of strong glacial sculpturing, and except for the steep wave-cut cliffs on exposed shores and the building of deltas, bars, and spits in protected places, postglacial erosion has been slight, and the land forms are much as they were when the glaciers receded.

ATKA ISLAND

A portion of the shore of Nazan Bay, Atka Island, near the village of Atka, was examined, and the rocks there all proved to be volcanic. Two thin sections cut from rocks collected near the village were both found to be porphyritic basalts, considerably altered. In one the phenocrysts of plagioclase were almost entirely altered to chloritic minerals and epidote. Some of the basalt flows show prominent columnar jointing, and associated with the flows are hard, well-cemented tuffaceous rocks in which large angular fragments are distinguishable.

It is reported that the natives formerly mined native copper on Sait Island, a small island that lies just northwest of the center of Atka Island. This copper probably occurs in an amygdaloidal lava flow. At the time of visit the higher peaks of the island were concealed in clouds, but it is said that the volcanic peak on the north end of the island shows signs of having been active at no very remote date, though the cone is considerably dissected. It is also reported that a hot spring a few miles above the head of Korovin Bay, on the northwest side of Atka Island, boils violently at intervals.

ADAK ISLAND

Opportunities for close observation of the geology of Adak Island were confined to the Bay of Islands and the head of Three Arm Bay, on the west shore of the island, though a comprehensive view of all the north half of the island, except where concealed by clouds, was obtained from the air. The portion of Adak Island studied is composed entirely of volcanic rocks, none of the basement rocks through which the volcanic materials were erupted being seen. The south and west shores of the Bay of Islands are made up of dense, hard flow rocks and massive tuffs. The flows include andesite or latite por-

phyry and basaltic greenstone. The islands at the entrance of the bay appear to consist dominantly of tuffaceous material, with only subordinate amounts of flow rocks.

Between the Bay of Islands and Andrew Bay, on the north shore of Adak Island, there is a volcanic peak whose top was continually in clouds during the time of visit but whose lower slopes contain large quantities of loosely consolidated ashes, tuff, and fragmental material, indicating comparatively recent activity. The materials, being little indurated, have suffered much more from postglacial erosion than the harder rocks around the Bay of Islands, and they have slumped extensively on being undercut by the waves.

Adak Island as a whole shows severe glacial erosion and appears to have been almost entirely covered by a local ice cap at the time of its maximum glaciation. The Bay of Islands, Three Arm Bay, and the Bay of Waterfalls (on the south shore) are all glacial fiords, and high on the slopes of the bordering mountains glacial lakes lie in basins excavated by the ice in the volcanic rocks. Erratic boulders occur, even on the high slopes, although over most of the surface of the island the bedrock has been ice-scoured and is covered only by a thin layer of rock-disintegration products, soil, and vegetation.

KISKA ISLAND

Opportunity was offered to study that part of Kiska Island immediately adjacent to Kiska Harbor, on the east shore. On entering this harbor, Little Kiska Head, at the northwest extremity of Little Kiska Island, stands out as a fine example of columnar basalt, exposed in steep, wave-cut cliffs. The north and west shores of the harbor are composed mainly of loosely indurated volcanic tuff, with fragments 1 inch in diameter or less. This tuff is bedded, dipping 5°–10° N., and, though standing in nearly vertical cliffs where wave erosion is active, is nevertheless so poorly indurated that it crumbles readily under the hammer. Near the north entrance to the harbor the tuff is overlain by basaltic lava. The shores and the mountain on the south side of the harbor are composed of lava flows that include dark basaltic rocks, some of which are partly glassy, and lighter-colored lavas, among which a quartz latite was identified.

Only the shores of Kiska Harbor were studied at close range, but as seen from the air Little Kiska Island and all of the eastern and northern portion of Kiska Island appear to contain only volcanic rocks.

At the northern end of Kiska Island is a volcanic cone some 4,000 feet high that was entirely snow-covered almost to sea level in late May 1932. Its slopes show only moderate dissection, and the aviators of the expedition thought they detected fumaroles on its upper slopes.

Kiska Island shows the effects of glacial erosion, but as most portions of the island are less than 1,500 feet above sea level the glacial scouring was in most places not severe.

ATTU ISLAND

As seen from the air Attu Island is a rugged mountainous island, of which the main peaks and ridges rise to elevations of 3,000 to 3,500 feet. So far as is known, there are no active volcanic vents on this island, and indeed no mountains were seen whose contours were constructional. The whole island has been heavily glaciated during Pleistocene time, and the present topography has been produced by the glacial modification of the preexisting stream-eroded landscape. As in most of the other islands of the Aleutian chain, the shores of Attu Island are exposed to the full force of the surf and are generally clifflike, with little or no beach exposed. Attu Island has almost no low-lying areas, the mountains nearly everywhere descending abruptly to the shore and being edged by steep cliffs against which a constant surf breaks, so that landing by a small boat is dangerous or impossible, and access on foot is difficult. Close-range study of the geology was confined to the shores of Chichagof Harbor, on the north side of the island, in the vicinity of the village of Attu. At the time of visit, in late May, the island was almost entirely snow-covered down to the shore line, and tidal lagoons were still covered with ice.

The north shore of Chichagof Harbor is composed mainly of basaltic lavas, some of which are full of irregular crusts. Associated with the basic flow rocks are some coarser-grained acidic rocks that in thin section are seen to consist of sodic diorite, in which chlorite and epidote are present as alteration products. Some unaltered pyroxene is present, and magnetite and epidote were noted as accessory minerals. This sodic diorite is believed to represent an intrusive into the more basic lavas. At one place it is cut by a stockwork of quartz stringers that have a fairly definite linear arrangement, striking northeast and dipping nearly 90°. No metallic mineralization was noted in this quartz.

The south shore of Chichagof Harbor is composed of a series of massive basalt flows, some of which are amygdular, and of coarse massive basic tuffs consisting of lava fragments in a lava matrix. These beds dip about 45° NE. Some of the basalt beds contain small cubes of iron pyrite, both as scattered grains in the matrix and as bunches along tiny cracks. There are also a good many quartz stringers cutting the basalts, but no metallic minerals were seen in them.

COLD BAY AND LENARD HARBOR

A brief examination of the shores of Lenard Harbor, an arm of Cold Bay near the southwest end of Alaska Peninsula, showed that the rocks bordering the harbor are composed exclusively of volcanic materials. One specimen, as studied in thin section, proved to be glassy basalt porphyry, with phenocrysts of plagioclase and smaller ones of augite in a matrix composed of plagioclase, magnetite, and a reddish-brown glass. Another very similar rock had phenocrysts of plagioclase and augite in a fine-grained groundmass of labradorite, augite, and magnetite. The rocks in place, as well as the boulders on the beach, include a considerable variety of lavas and tuffs, ranging in color from brick-red through gray, brown, and green. Some are highly vesicular, and others are fairly coarse grained and massive. In places the cliffs show well-developed columnar jointing.

The mountains bordering Lenard Harbor show strong evidence of glacial erosion. A large valley tributary to the harbor from the north shows glacial sculpturing to a height of 1,500 feet above its floor, and its tributary valleys are cirques. At the mouth of Lenard Harbor the glacier surface formerly stood at least 500 feet above sea level. Similarly the mountains west of Cold Bay show glacial erosion, and the valleys are well-sculptured glacial troughs.

The west and northwest shores of Cold Bay are bordered by a fairly flat foreland faced at the water's edge by steep wave-cut bluffs that rise almost vertically for 50 to 100 feet above sea level. At the one place where these bluffs were examined the material was found to consist mainly of fine bedded sandy silt studded with pebbles and boulders as large as 4 feet in diameter. The silt was certainly deposited in standing water, yet the boulders and pebbles are as certainly of glacial origin, for many are beautifully striated and faceted. The upper few feet of the bluff is composed of sandy silt containing no large boulders and only a few small pebbles. This upper layer is probably wind-blown material.

The material exposed at the locality examined appears to represent sediments deposited in a lake or a protected bay at a time when the bordering mountains were glaciated and the glaciers were discharging into the water. At that time the land surface stood at least 100 feet lower than at present, and much of the area now bordering Cold Bay on the west was submerged. Glacial ice pushed down into this area from the mountains both east and west of Cold Bay.

DOLGOI ISLAND AND PAVLOF BAY

The shores of upper Dolgoi Harbor, Dolgoi Island, are composed of dense, hard volcanic tuff that consists of subangular to well-rounded fragments of various basaltic rocks and individual crystals

of plagioclase and augite. This tuff exhibits extensive alteration. It dips 10°–15° S. Locally the tuff is overlain by flows of columnar basalt, and the islands of the lower harbor are also basalt flows. These flow rocks in thin section are seen to consist of a glassy basalt porphyry in which phenocrysts of plagioclase and augite lie in a matrix of plagioclase, magnetite, and a reddish-brown glass. Similar flows of columnar basalt were observed from the air on the shores of Volcano Bay, northwest of Dolgoi Island. A brief examination of the east shore of Pavlof Bay, near Settlement Point, showed that the point itself is composed of basaltic lava, lying with apparent conformity upon a series of well-indurated impure gray sandstone that weathers buff. Associated with the sandstone are a few thin shale beds, but they are so thin that they form a very small percentage of the total exposure. Both sediments and the overlying lava dip a few degrees to the northwest.

A large creek that flows into Pavlof Bay just northeast of Settlement Point discharges gravel that includes, in addition to basic lavas, a considerable proportion of pebbles of hard black argillite. Nothing definite is known of the age of the sandstone, described above, or of the argillite. The light color and moderate induration of the sandstone suggests that it is of Cretaceous age or younger.