Geology of Southern Adak Island and Kagalaska Island, Alaska

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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 the general direction of G. D. Robinson, were made during the years 1946–48. The results of the first year's field, laboratory, and library work were hastily assembled as two administrative reports, and most of these data have been revised for publication in Geological Survey Bulletin 1028. Part of the early work was published in 1950 in Bulletin 974–B, Volcanic activity in the Aleutian arc, and in 1951 in Bulletin 989–A, Geology of Buldir Island, Aleutian Islands, Alaska, both by Robert R. Coats. During the years 1949–54 additional fieldwork was done under the direction of H. A. Powers. Unpublished results of the early work and all the later studies are being incorporated as parts of Bulletin 1028. The geologic 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. From 1947 until 1955 the Departments of the Army, Navy, and Air Force joined to furnish financial and logistic assistance. 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, and to the several military departments for their support.

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By George D. Fraser and George L. Snyder

ABSTRACT

Southern Adak and Kagalaska Islands are composed of Finger Bay volcanics of probable Tertiary(?) age, an altered andesitic and basaltic sequence of marine pyroclastic deposits and lava flows with minor argillite and graywacke beds, intruded by composite granodiorite, quartz-diorite, diorite, and gabbro plutons of probable middle to late Tertiary age; many aphanitic dikes and sills, generally altered, which cut plutonic rocks and Finger Bay volcanics; and surficial deposits, mostly volcanic ash and soil, which obscure much of the bedrock below elevations of 1,500 feet.

The Finger Bay volcanics and many of the dikes are altered to greenstone and keratophyre with crystallization of albite, epidote, and chlorite. Some of the alteration preceded the plutons, and some either accompanied or followed them. A narrow zone of pyroxene-labradorite hornfels is discontinuously formed along major intrusive contacts. Elsewhere late aplitic magmas or solutions appear to replace areas of country rock. A dark border zone is present in the granodiorite plutons in many areas. Most diorite and gabbro are found in this dark border zone or in apophyses located in what is interpreted as a shattered roof zone over the main plutons. In some areas the evidence for assimilation is compelling, and here the mafic borders are interpreted as hybrid rocks. Elsewhere recrystallization in place of mafic country rock and other processes appear to have produced the gabbro and diorite.

Adak Island and Kagalaska Island may be considered as a portion of the crest of a 1,900-mile mountain range that rises, in this area, 28,000 feet above the foredeep and 13,000 feet above the backdeep. Quaternary volcanism is limited to a belt along the north edge of the islands outside the map area of this report. The Finger Bay volcanics are conspicuously fractured and mildly folded, but no dynamic metamorphism is apparent. Major intrusive activity, dated as middle to late Tertiary elsewhere in the chain, apparently preceded deformation and uplift.

Remnants of a composite marine platform are found on southwest Adak Island and perhaps elsewhere. This surface formed prior to the latest extensive Pleistocene glaciation, which has gouged out bold mountains in the higher central portion of the area and scoured the peripheral lowlands. Most of the glacial debris has been dumped in the sea.

A surficial ash and soil mantle accumulated by small increments through a long epoch of Recent volcanism. The presumed sources for the ash component are volcanoes within the Andreanof Islands, but probably neither Mount Moffett nor Mount Adagdak, both of which became extinct before or very shortly after glaciation ceased.

INTRODUCTION

Southern Adak Island and Kagalaska Island were studied in 1952 and 1953 as part of a larger program of volcano investigations in the Aleutian Islands. Previously northern Adak Island and several other areas in the Andreanof Islands had been studied. Figure 55 is a regional index map and figure 56 a larger scale index map showing areas covered by various Survey reports on the Andreanof-Delarof Islands area.

Fieldwork on southern Adak Island was done by two-man reconnaissance teams from 12 separate base camps established in various bays and inlets. A total of about 40 such traverses were made and 200 square miles were mapped during the summer of 1952 by R. E. Wilcox, geologist-in-charge, H. F. Barnett, B. H. Bieler, G. D. Fraser, E. H. Meitzner, W. H. Nelson, R. A. Robie, and G. L. Snyder. Fieldwork was supplemented by frequent observations from the Survey vessel *Eider* and by study of aerial photographs.

Kagalaska Island, 46 square miles, was mapped in 1953 from five separate base camps. A total of 20 traverses were made by G. D. Fraser, geologist-in-charge, V. E. Ames, H. F. Barnett, E. H. Meitzner, R. P. Platt, H. B. Smith, G. L. Snyder, and L. D. Taylor.

Captain Carl Vevelstad and Engineer Charles Best served as key men on the *Eider* during all Aleutian investigations since 1949. Their experienced help was essential to the amphibious operations.

Mapping on both Adak and Kagalaska Islands was done on Army Map Service topographic sheets, scale 1:25,000; but detail commensurate with map scale was seldom attempted. Physical limitations imposed by amphibious beach operations, adverse weather conditions, and extensive surficial cover emphasize that the information gathered and conclusions reached cannot be considered detailed or final. Key beds for deciphering structure were not found during the reconnaissance.

Kagalaska Island is uninhabited and completely undeveloped. Most of Adak Island is similarly primitive, but there are military installations in the Kuluk Bay area and elsewhere. Air and sea access to the Adak base is possible with military permission. Kuluk Bay is the only all-weather harbor for large vessels, but there are many anchorages on both islands for small vessels and partial protection from weather in many bays and inlets.

HISTORY

Adak Island was discovered on September 9, 1741, when the Russian vessel *St. Paul*, under command of Captain Alexei Chirikof, anchored in a small bight on the south coast. At that time 20,000 to 25,000

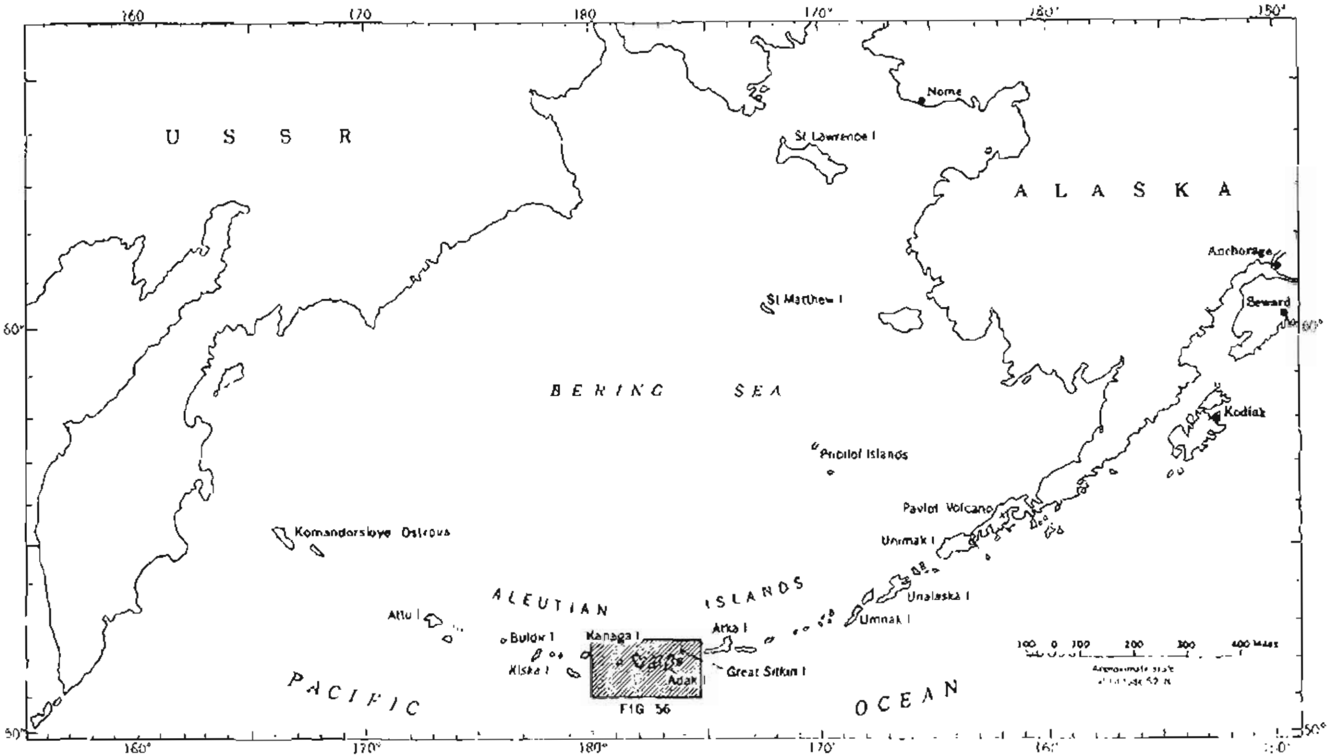

FIGURE 55.—Map of the Alaska Peninsula and Aleutian Islands, showing location of index map, figure 56.

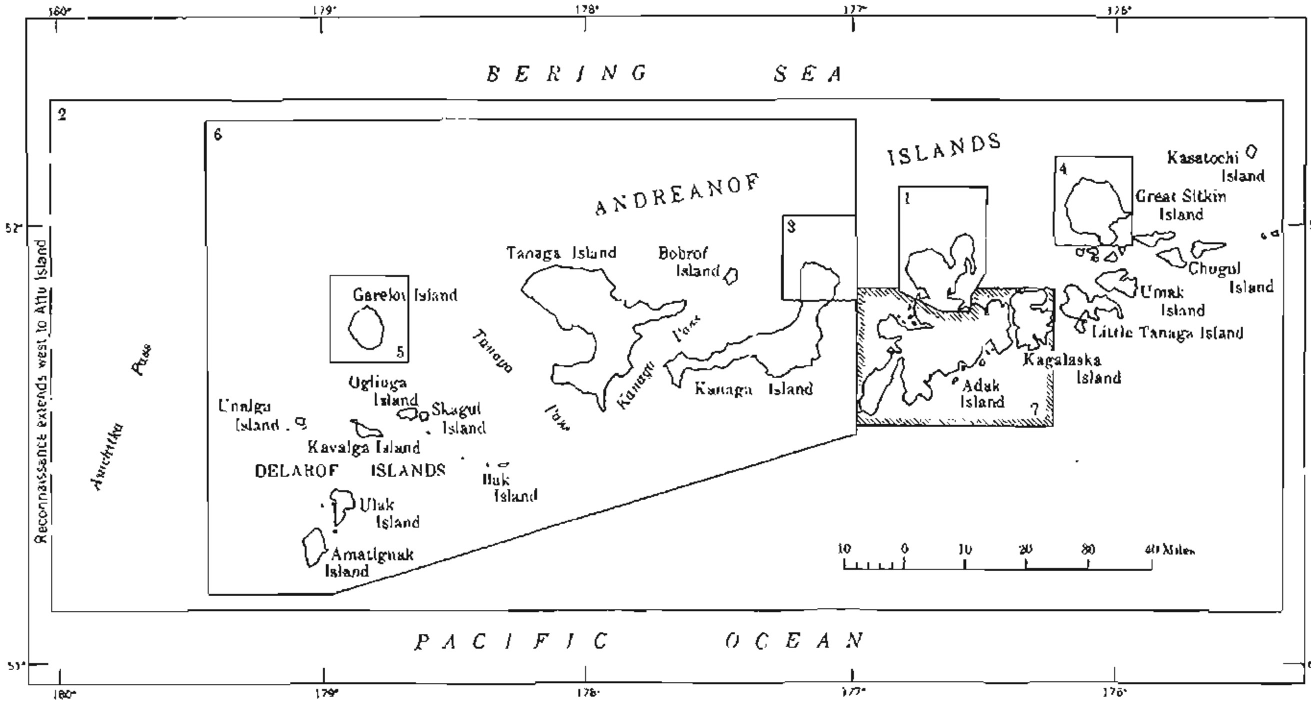

FIGURE 56.—Index map for areas covered by U.S. Geological Survey reports in the western Andreanof and Delarof Islands in Bulletin 1028. (1) Coats, 1956a; (2) Coats, 1956b; (3) Coats, 1956c; (4) Simons and Mathewson, 1955; (5) Coats, 1959; (6) Fraser and Barnett, 1959; (7) This report.

Aleuts, an Eskimauan people, are estimated to have lived in the hundreds of villages from Attu Island to the Alaska Peninsula. Nearly every island, including Adak, was inhabited (Collins, and others, 1945, p. 2–10). Today there are only about 1,000 Aleuts and four villages remaining in the islands—all east of Adak Island. Prior to World War II foxes were introduced and trapped on Adak Island and many of the other islands, but trapping has not been resumed since the war. None of the trappers' cabins are used today, and many of them are in poor repair.

GEOGRAPHY

Adak Island is located close to the middle of the Aleutian chain, in the Andreanof Islands (figs. 55 and 56). It is about 8 miles east of Kanaga Island and one-fourth mile west of Kagalaska Island. The geodetic position for the head of Kuluk Bay is 51°53′ N., 176°39′ W. Adak Island is 32 miles long and 21 miles wide, but very irregular in shape. It is the largest island (289 square miles) and strategically the most important in the central Aleutian Islands. Kagalaska Island, separated from Adak Island by narrow Kagalaska Strait, is 10 miles long (north) and 6.5 miles wide with an area of 46 square miles.

Adak and Kagalaska Islands are characterized by four types of topography listed in order of decreasing areal importance: rugged mountain areas, broad rolling lowland areas, modified volcanic cones (northern Adak Island only), and narrow beaches backed by sea cliffs. The rugged mountain areas, unrelated to constructional volcanic landforms, result from Pleistocene glacial erosion and stream erosion of altered volcanic deposits and large plutonic masses (fig. 59). Parts of southern Adak and Kagalaska Islands, here included with the mountain areas because of rugged topography, probably contain glacially dissected marine platforms that, genetically, should be grouped with the lowland areas (fig. 58). The broad lowland areas, of greatest extent on Yakak peninsula, probably result from preglacial wave planation modified by stream and glacial erosion (fig. 60.) The volcanic landforms on northern Adak Island are outside the area of this report and have been discussed elsewhere (Coats, 1056a). The shoreline, except where straightened by fault scarps, is very irregular, a result of glaciation and further crenulation by vigorous wave action. Sea stacks, rugged offshore rocks and islands, and precipitous sea cliffs, generally about 200 feet high, are characteristic (fig. 60). Northern Adak Island includes local areas of lagoons, tidal flats, and sand dunes.

The Aleutian Islands are well known for their foggy, wet, and stormy climate. From short-term weather observations a few general statements can be made concerning the climate of Adak Island. Local shifts of wind and rapid changes of velocity are common so that figures for average wind velocity are of limited value in understanding actual conditions. For example, average wind velocity at the Adak base is 15 miles per hour, but extreme wind in winter may exceed 100 miles per hour, and summertime gusts frequently exceed 50 miles per hour. Total annual precipitation is only 47 inches, but during summer months the sky is usually overcast and fog, drizzle, or rain is very common. Average annual snowfall is 71 inches, limited largely to winter months. Little snow accumulates except in topographically favorable upland areas, and there are no glaciers at the present time. Mean annual temperature is 40° F with seasonal variations of about 10° F and correspondingly small diurnal changes (U.S. Air Force, 1950, Chart 20).

The lower parts of Adak and Kagalaska Islands support heavy vegetation with grass and flowers attaining heights of 5 or 6 feet late in the summer. Patches of moss and lichen become increasingly dominant with increasing height above sea level. At altitudes above 1,500 feet, there is virtually no grass and many ridges are bare rock. There are no native trees, but there are many flowering plants, ferns, grasses, and mosses. A tough mat of vegetation frequently forms bridges over gullies and between talus blocks and dams small lakes.

The only land mammals are blue fox, rats, and mice, all introduced in recent years. Birds, trout, and salmon are common and the sea abounds with shallow-water invertebrate species. Sea otter were rare in 1952 but appear to be expanding eastward from the Amchitka area. Seals, and to a lesser extent sea lions, are common along the coastline.

SUMMARY OF GEOLOGY OF NORTHERN ADAK ISLAND

Coats has described the geology of northern Adak Island (1956a). Part of his abstract is quoted here to give a background for the geology of southern Adak and Kagalaska Islands.

> 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, introuded 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 rock 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.

Constructional volcanic landforms and volcanic rocks of late Tertiary and Quaternary age are limited to northern Adak Island. Upper Tertiary fossiliferous marine sandstone crops out in a small area on Cape Adagdak (Coats, 1956a, p. 53, 54). The relation of these beds to the later Tertiary and Quaternary volcanic rocks and to the Finger Bay volcanics is uncertain, but Coats has grouped them with the younger volcanic rocks. The age of the Finger Bay volcanics is discussed in Coats' report (1956a, p. 49) and on pages 383 and 384 of this report.

PETROLOGY

The rocks on southern Adak and Kagalaska Islands may be divided into four units: Finger Bay volcanics, the most abundant rocks in the area; granodiorite, quartz-diorite, diorite, gabbro, and associated rocks in large intrusive masses; aphanitic and porphyritic-aphanitic rocks, mostly andesite, in small intrusive bodies; and Pleistocene and Recent surficial deposits including an extensive ash-soil blanket over much of the area. These units are listed and described in order of decreasing geologic age, except in the case of the third unit, the aphanitic andesite, which probably embraces rocks of several different ages, both younger and older than the granodiorite plutons.

FINGER BAY VOLCANICS

The name "Finger Bay volcanics" was applied to rocks near Finger Bay, northern Adak Island, by Coats (1947, p. 75). Minor dikes, which Coats included with the Finger Bay volcanics, will be discussed in a separate section because some of them appear to be more closely related to the major plutons, and some of the dikes may belong to an independent volcanic episode.

The Finger Bay volcanics (pl. 52) cannot be subdivided by reconnaissance methods. They are dominantly pyroclastic deposits and lava flows—andesitic and basaltic rocks rendered more or less homogeneous in outward appearance by pervasive alteration and an intricate joint pattern. The color is generally a low chroma variation of medium-gray or medium dark gray, roughly reflecting the initial color index. Greenish hues resulting from the presence of chlorite, epidote, and nontronite are most common. Hues grading through yellow, red, purple, and brown are also common and they reflect various types and amounts of iron oxides.

Lava, pillow lava, agglomerate, tuff breccia, autoclastic breccia, lapilli tuff, tuff, volcanic wacke, argillite, and minor porphyritic masses have been recognized.[1] Rhyolite mentioned by Coats (1956a, p. 48, pl. 9) has not been found on southern Adak or Kagalaska Islands. Many gradations exist between the various rock types, and in the field it is difficult to determine the precise character and origin of a particular rock. Perhaps 70 percent of the rocks are pyroclastic, 20 percent lava flows (including probable sills whose relationships are obscure), and a scant 10 percent truly sedimentary deposits.

Total thickness is unknown, but a very approximate value—obtained from the geologic map (pl. 52) for the area from Hatchet Lake to Bay of Islands is 8,000 feet. This value is probably less than the true thickness, because neither top nor bottom is exposed.

LAVAS

In a group of 30 thin sections of lavas from the Finger Bay volcanics, 13 appear to be andesite, 6 basalts, and 11 are so altered or thermally metamorphosed that the original character cannot be estimated. Most of the lava sections probably are pyroxene andesite or feldspathic basalt, but extreme alteration and an average of 80 percent aphanitic groundmass make even this general statement uncertain. The most common lava flows contain 10–20 percent phenocrystic plagioclase and 1–5 percent phenocrystic augite; rocks with more augite phenocrysts than plagioclase are less abundant. Greenstone and keratophyre are useful group names for the suite, but absence of general alteration of the pyroxene and irregular development of probably secondary keratophyre make either term somewhat ambiguous.

Distinctly basaltic rocks, some containing pseudomorphs after olivine, were sampled in the following areas: North Arm of Three Arm Bay, south of Gannet Cove, southwest coast of Boot Bay, and southeastern Adak Island along Kagalaska Strait; but andesitic rocks were also found in or near the same areas, and no large area is known to be dominantly basalt.

Rocks that originally were hornblende andesite or dacite and are now largely keratophyre or quartz keratophyre have been found 4 miles south of Finger Bay, between Bay of Islands and Three Arm Bay, and on Yakak peninsula. Olivine-bearing basalt and dacite thus mark the probable original compositional limits for the bulk of lavas from the Finger Bay volcanics.

Specimen 6 (table p. 385) is the only analysed rock from the Finger Bay volcanics. It is porphyritic, brownish-gray albitized pillow lava

[1] Names for pyroclastic rocks follow Wentworth and Williams (1932). *Volcanic wacke* is defined by Gilbert (Williams, Turner, and Gilbert, 1954, p. 303) as "composed principally of debris eroded from volcanic terranes * * *."

from the southwest shore of Boot Bay, Adak Island. About 15 percent of the rock is tabular cloudy albite crystals (4 mm) altering to clay minerals and containing small patches of epidote; 5 percent of the rock is fresh, euhedral to subhedral augite crystals (1.1 mm). Some of these phenocrysts are clustered together in subophitic patches. About 10 percent of the rock is subspherical, chertlike greenish masses (1–4 mm), either vesicle fillings or foreign pellets, containing chlorite, stilpnomelane, iron-rich mineraloids, and central masses of quartz. Some of the quartz is intergrown with orthoclase. About 70 percent of the rock is a cloudy fine-grained groundmass containing devitrified glass (chlorite, nontronite, epidote), altered albite microlites and skeletal crystals (0.3 mm), and elongate clinopyroxene microlites (0.3 mm), commonly in splayed aggregates. The groundmass is crowded with needlelike skeletal crystals of opaque oxide. The original composition of this rock is unknown; the altered rock might be called albitized trachyandesite. Albite, quartz, and orthoclase may all be secondary.

Most of Mount Vincennes is a mass of porphyritic pyroxene andesite, and some parts of the mass are less altered than others. One small area about 150 feet below the summit is dark, surprisingly fresh, olivine-bearing andesite. Further mapping may show that these rocks are not properly part of the Finger Bay volcanics.

PYROCLASTIC ROCKS

Large areas of Adak and Kagalaska Islands are underlain by altered tuff breccia and lapilli tuff. Altered tuff, flow breccia, and lava commonly are intercalated with the tuff breccias and lapilli tuffs. The coarser pyroclastic rocks (tuff breccia and lapilli tuff) probably make up more than half of the Finger Bay volcanics. Most of them show little or no bedding and cannot be traced by reconnaissance mapping. The largest area known to be dominantly coarsely clastic rocks is the area from the Bay of Islands to Three Arm Bay. The southeast part of Kagalaska Island and large areas in southern and northern Adak Island also are dominantly coarse pyroclastic rocks.

In the field the nature of fragmental rocks was in doubt in many instances. Many rocks, whose matrix megascopically appears to be igneous, have a tuff matrix rich in broken crystals, and most of the rocks contain enough angular unsorted pyroclastic material to rule out origin by conventional sedimentary processes. Most of the rocks, consequently, are classified as tuff breccia or lapilli tuff, and are believed to represent pyroclastic deposits or mud flows. Criteria for identfying deposits that have moved en masse as subaerial or submarine mudflows were not found, so that the importance of mass movement cannot be assessed.

Compositions, as far as can be determined in the altered pyroclastic rocks, were originally those of andesite and feldspathic basalt. In a group of 20 rocks, 11 are classified as andesitic, 3 as basaltic, and 6 unknown. Fourteen of the rocks are conspicuously albitized, and all contain epidoate-clinozoisite or chlorite or both.

Many of the pyroclastic deposits contain coarse angular fragments as much as several centimeters in diameter, and a few rounded bombs or lapilli. Some contain abundant bombs and can be classified as agglomerate, but no vent areas were recognized. Lapilli tuff with a coarse fraction of mostly angular crystalline rock fragments between 1 and 8 mm is common. Coarser lapilli tuff and tuff breccia are also common, but proportions of the various grade sizes are unknown. Rock fragments are altered hyalopilitic or intersertal, porphyritic andesite and basalt and less commonly devitrified basic glass. One coarse-grained diorite or gabbro fragment (5 cm) was found in a tuff breccia from the south shore of Quail Bay, Kagalaska Island. This is the only plutonic rock fragment found. Broken crystals of altered plagioclase (4 mm) and generally fresh pyroxene (1–2 mm) are common. The coarse fragments are set in a tuffaceous matrix of similar composition.

SEDIMENTARY ROCKS

There are few sedimentary rocks in the Finger Bay volcanics on southern Adak and Kagalaska. Most of them have a direct pyroclastic component; and probably all are ultimately derived from volcanic rocks. Greenish-gray, banded, siliceous and probably tuffaceous argillite and medium- to coarse-grained volcanic wacke are both sparsely represented in the dominantly igneous and pyroclastic sequence.

There are several thin argillite beds ($\pm$ 20 feet) in the Gannet Cove area. Similar argillite and siltstone beds, some with structures connoting penecontemporaneous deformation, crop out in the Wedge Point area. Pebbles of a chertlike, finely banded, and minutely faulted argillite were found on the west beach at Blind Cove. No argillites were found on Kagalaska.

Well-bedded pyroclastic rocks or volcanic wacke are common in the following locations and sparse elsewhere; Ringgold Island, around the head of Bay of Islands, in the Boot Bay area (some show graded bedding), on Boot Point, and on Yakak peninsula—especially in the Wedge Point area. These rocks are intercalated and gradational with poorly bedded pyroclastic deposits. The poorly stratified rocks in most cases are demonstrably pyroclastic, and many of the stratified rocks may be more pyroclastic than epiclastic.

On the northwest shore of Bay of Waterfalls highly altered lapilli tuff contains angular accidental fragments. The rock is very calcareous and a few of the fragments appear to be limestone. This suggests that limestone may be present in the Finger Bay volcanics or immediately below them.

Further mapping may reveal separable parts of the Finger Bay volcanics, such as the sequence of rocks containing fairly well bedded clastic rocks that appear to be crudely peripheral to Adak Island on the west, southwest, and south sides, and local members will probably be found within the sequence. Present information indicates that all these rocks are highly altered and precede the granodiorite in age.

ALTERATION AND METAMORPHISM

Alteration of rocks of the Finger Bay volcanics is pervasive. Nearly all of the rocks, regardless of original lithologic character and proximity to plutons, have been subjected to chloritization, epidotization, albitization, silicification, and other diverse low-intensity alterations. Locally albitization, silicification, epidotization, and potash metasomatism have been inferred within the plutons and in immediately adjacent country rock, but not all the alteration can be related directly to late stage solutions from the plutons. Narrow zones at the contact with plutonic rocks have been thermally metamorphosed, but no dynamic metamorphism has been noted. No tight folding or regional shearing is apparent.

The alteration products and secondary minerals observed are: chlorite, epidote, clinozoisite, albite, quartz, chalcedony, nontronite and other clay minerals, sericite, calcite, prehnite, zeolites, iron-rich mineraloids and iron oxides. Most pyroxenes are surprisingly fresh, but a few have been altered to uralite, bastite, chlorite, epidote, and other minerals. Bowlingite-antigorite locally is pseudomorphous after olivine. Disseminated pyrite and potash feldspar are common near plutonic borders and sparse elsewhere. Spessartite (?) was observed in one slide. This mineral is not out of equilibrium in a mineralogical environment of this type (Williams, Turner, and Gilbert, 1954, p. 222) and may be sparsely represented elsewhere in the sequence.

Nearly all rocks contain epidote and chlorite, especially in plagioclase and devitrified parts of the rock. About 60 percent of the rocks examined are conspicuously albitized, and many contain albite as the sole plagioclase. All gradations from unaltered calcic or intermediate feldspar relicts through clinozoisite and plagioclase, veined, rimmed, and partly albitized plagioclase, chessboard albite, and cloudy or even clear albite are visible. Fewer lavas than pyroclastic rocks appear to be completely albitized. In a few rocks a radiating aggregate, texturally like some zeolites, is actually albite, suggesting that albitization may have accompanied or followed zeolitization.

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Many of the crystalline rock fragments in pyroclastic rocks, and even the entire rock, may be chertlike and brittle. Argillite also is chertlike and commonly breaks with conchoidal fracture. These features and the abundant silica veinlets in many areas suggest that pervasive silicification may be more important than is apparent in the generally enigmatic thin sections.

In many areas, especially near Bay of Waterfalls and in northeastern Adak Island, a narrow hornfels zone occurs in the Finger Bay volcanics at the contract with plutons. The hornfels texture generally obscures or obliterates original texture, but phenocrysts and breccia fragments may, locally, be identified. Labradorite and clinopyroxene is perhaps the most common mineral association; but andesine, orthopyroxene, hornblende, tremolite or actinolite, and biotite are also common. Magnetite is a conspicuous accessory mineral. Fine-grained amphibolite without hornfels texture forms the septa of country rock in the Blind Cove area where granodiorite selectively invades the Finger Bay volcanics. Some of the fine-grained amphibolite may be metasediments.

In general the hornfels plagioclase is unzoned, but relict zoning has been observed in a few grains. In some slides poikiloblastic but otherwise homogeneous labradorite crystals (recrystallized phenocrysts) contain pyroxene arranged in zones which strongly suggest clinozoisite alteration patterns found elsewhere in lavas of the Finger Bay volcanics. The general absence of albitization in the hornfels rocks and occurrence of the zonally arranged pyroxene suggests that these rocks were hydrothermally altered prior to intrusion and thermal metamorphism.

In some areas a third episode of change is also apparent: albite, epidote, quartz, and potassium feldspar derived from the plutons have modified the plutonic borders and invaded the hornfels zone. This last stage is similar to the earlier pervasive alteration, but includes some potash metasomatism and is usually limited to veins and small areas near the pluton.

The source for the pervasive solutions that altered the Finger Bay volcanics before plutonic invasion is not known; several possibilities to be considered are: sea water, deuteric solutions from the Finger Bay magmas, activated connate water, and fluids emitted from the granodiorite plutons before or during intrusion. Abundant petrographic evidence for secondary changes eliminates the possibility of initial crystallization of the Finger Bay volcanics in their present state.

Marine volcanic rocks of very similar original lithologic character are not altered on most of Kanaga Island, Tanaga Island, and the central Delarof Islands (Fraser and Barnett, 1959, p. 217). This forces the conclusion that sea water and deuteric solutions from the volcanic emissions themselves are probably inadequate to cause the type of alteration common in the Finger Bay volcanics. Part of the Finger Bay alteration may have been diagenetic or deuteric, but general alteration has exceeded any early palagonitization or extremely low intensity changes that may have resulted from the nearly syngenetic processes. Apparently a period after the deuteric and preceding the granodiorite epoch of hydrothermal activity is required. This requirement is met by activated connate waters or juvenile fluids from the plutons. The altering wave of solutions, regardless of source, may have been driven upward by the advancing plutons.

These conclusions are in general agreement with those presented in an extensive review of the keratophyre-spilite problem (Gilluly, 1935) and are similar to views recently expressed by Waters (1955, p. 710) for altered andesitic rocks in the Cascade Mountains. Waters considers alterations in the Cascade Mountains as essentially independent of the later plutons. We agree that alteration precedes intrusion, but believe that there may be a relationship between the two events on Adak.

There is a further possibility that the Finger Bay volcanics are themselves a very early product of the same magmatic cycle, so that a single process culminating in major intrusive activity may control most of the seemingly separate events recorded on southern Adak and Kagalaska Islands.

REGIONAL RELATIONSHIPS AND AGE

Coats (1956a, p. 49) included a small body of fossiliferous yellow sandstone of volcanic composition, basaltic flows, and sills that crop out between Clam Lagoon and Andrew Lake in northern Adak Island in his Finger Bay volcanics as mapped. The rocks are of Pennsylvanian or Permian age as indicated by impressions of *Annularia stellata* (Schlotheim) Wood, identified by R. W. Brown, U.S. Geological Survey. The relations of these fossiliferous rocks to the rocks of Finger Bay, which are continuous with those mapped as Finger Bay volcanics in southern Adak Island (and identical with those of Kagalaska Island) are uncertain.

A sequence of volcanic and sedimentary rocks containing some pillow lava deposits occurs on Kanaga Island, 10 miles west of Adak Island (Fraser and Barnett, 1959, p. 217). From Kanaga Bay north for several miles these rocks have been epidotized. Miocene(?) marine fossils have been found in this locally altered sequence. These rocks are certainly as much like the deposits on Yakak peninsula as are the Paleozoic sandstone beds, 25 miles north on Adak Island, and a correlation in one direction is as reasonable as a correlation in the other.

We therefore hesitate to adopt the age of the volcanic sandstone beds of northern Adak Island as fixing that of the Finger Bay volcanics of the type area. They are doubtless terrestrial sandstone beds as suggested by the leaves, whereas we interpret the Finger Bay volcanics of both our area and the type area as marine. Although the age assignment for these rocks on northern Adak Island has been Paleozoic(?), the authors believe that a Tertiary(?) age is more probable for the Finger Bay volcanics elsewhere on the island and on Kagalaska Island.

GRANODIORITE AND RELATED ROCKS

Plutons, composed largely of granodiorite, but varying locally to quartz monzonite, quartz diorite, diorite, and gabbro invade the Finger Bay volcanics in several areas (pl. 52). The largest of these masses, located in south-central Adak Island, covers an area of about 40 square miles. Other plutons occur in central, north-central, and northeastern Adak Island and in Kagalaska Island. Five chemical analyses of these rocks are given in the following table. The several varieties are not separated on the map, but most of the rocks examined petrographically have enough potash feldspar to be classified as granodiorite according to Lindgren's definition (Lindgren, 1900).

The plutonic rocks, characteristically, are medium gray and of medium-sized grain, granitoid in appearance, with biotite and hornblende as the dark minerals. The color index (percent total mafic minerals) is generally less than 20 and may be as low as 8. Small aplite and pegmatite dikes are common locally, especially near the contact in both wall rock and pluton. Near some of the contacts and in areas of many inclusions, the color index may rise to 40, pyroxene is an important constituent, the feldspars are more calcic, and the rocks are diorite and gabbro.

PETROGRAPHY

GRANODIORITE AND QUARTZ DIORITE

In the common granodiorite and quartz diorite zoned andesine-oligoclase is the main feldspar, usually making up 55–60 percent of the rock. Other minerals are: quartz 10–25 percent; orthoclase and perthite 7–15; hornblende 2–15; biotite 1–8; clinopyroxene, orthopyroxene (rare), magnetite, epidote, apatite, and sphene usually total less than 5 percent. In some specimens, near the border zones of the plutons, albite is conspicuous in perthite, rims on other plagioclase, irregular masses, and as crystals containing a chessboard pattern of twins. Irregular masses and rims of orthoclase and also antiperthite have been noted, but euhedral orthoclase was not found. Patches

TABLE 1. *Chemical composition of rocks from Adak Island, Alaska*

[E. J. Tomasi, analyst, U.S. Geological Survey]

	Specimen No.					
	1	2	3	4	5	6
SiO_2	62.02	63.20	52.86	45.68	58.32	56.66
Al_2O_3	16.94	17.21	18.06	18.77	18.75	15.46
Fe_2O_3	2.61	1.90	4.24	5.64	3.23	3.94
FeO	2.77	2.33	4.78	5.13	2.70	4.69
MgO	2.47	2.48	4.53	6.74	1.81	3.09
CaO	5.39	5.39	8.69	12.93	6.16	5.60
Na_2O	4.17	4.11	3.30	2.02	4.56	4.86
K_2O	1.81	2.15	1.12	.11	2.52	2.19
H_2O-	.08	.04	.07	.22	.02	.23
H_2O+	.58	.45	.79	1.37	.38	1.59
TiO_2	.68	.46	1.03	.74	.92	.93
CO_2	.02	.00	.03	.35	.02	.05
P_2O_5	.26	.18	.31	.05	.46	.38
Cl	.05	.02	.06	.01	.07	.02
$F-$	.03	.04	.05	.02	.07	.06
S	.00	.01	.01	.00	.00	.00
MnO	.10	.08	.16	.14	.12	.14
	99.98	100.05	100.09	99.92	100.11	99.89
Less O	.02	.02	.03	.01	.05	.03
Total	99.96	100.03	100.06	99.91	100.06	99.86
Powder density				2.90	2.72	
Locality	Bay of Waterfalls, southwest Adak Island.	Kagalaska Strait, northeast Adak Island.	Beyer Bay, south Adak Island.	Chapel Cove (Bay of Waterfalls) southwest Adak Island.	Bay of Waterfalls, southwest Adak Island.	West shore of Boot Bay, south Adak Island.
Name and occurrence.	Biotite quartz diorite, pluton.	Granodiorite, pluton.	Diorite, pluton border zone.	Olivine gabbro, sill.	Feldspathic granodiorite porphyry, pluton border zone.	Albitized pillow lava (Finger Bay volcanics).

of quartz monzonite are found in orthoclase-rich areas, usually in association with gabbroic rocks, which may also have been albitized and veined with orthoclase.

Analyzed specimen no. 1 (see table) is representative of the quartz diorite. It is a gray, medium-grained biotite quartz diorite with a color index of 16. Volume percentages are: zoned and unzoned andesine-oligoclase, 56; orthoclase, 7.2; quartz, 21; biotite, 8.0; hornblende, 3.6; clinopyroxene, 2.4; opaque oxide, 1.0; chlorite, 0.4; apatite, 0.3; sphene and epidote, trace. This rock, from the east shore of Bay of Waterfalls, is located near the edge of the largest pluton. Coarser and darker border phases with septa of recrystallized basaltic rocks occur just a few yeads from this rock, but the main contact is underwater in Bay of Waterfalls (pl. 52). Characteristically, rocks this close to the border are more mafic than the main mass, and appear blotchy from irregular concentrations of dark minerals.

The rocks 1,500 yards south of Blind Cove have a color index near 10 and are more felsic than most of the granodiorite. These rocks contain a few dark rounded fine-grained patches as much as several centimeters in diameter that appear to be recrystallized and partly assimilated wall rock. A marked preferred orientation of biotite and hornblende was noted in some outcrops. A peculiar texture, suggestive of mortar structure, is visible in thin section. This texture consists of large (3 mm) zoned plagioclase crystals with narrow interstitial bands of granular quartz (0.4 mm) and orthoclase (0.2 mm). The quartz and orthoclase crystallized later than the plagioclase; possibly magma motion helped to produce the texture. A modal analysis of one of these rocks (analyzed specimen no. 2) gives the following volume percentages: zoned andesine-oligoclase, 57; orthoclase, 11; quartz, 21; biotite, 4.7; hornblende, 4.5 (some of these in blocky crystals with a maximum diameter of 8 mm); opaque oxides, 0.9; chlorite (mostly after biotite), 0.8; sphene, apatite, and zircon, total, 0.1.

Many variations of the main granodiorite exist along the borders and in small outliers. Near the contact of a small pluton on Kagalaska Strait (Campers Point) a dike of quartz diorite shows conspicuous clusters of hornblende needles as much as 2 cm long. On Kagalaska near Chaika Point the contact is rich in hornblende—here apparently recrystallized Finger Bay volcanics. In many areas dark-colored phases are developed at or near the border.

DIORITE

Diorite is common near the borders of plutons, but is volumetrically insignificant. Analyzed specimen no. 3 is medium-dark-gray, medium-grained diorite from the west shore of Beyer Bay. It came from an outcrop containing abundant xenoliths and large tabular septa of basaltic country rock. The xenoliths and septa have a conspicuous hornfels texture. Clinopyroxene, amphibole, orthopyroxene, biotite, magnetite, and sodic labradorite are common in the recrystal lized rock. Large biotite flakes rim the xenoliths, and magnetite crystals are visible in them. Under the microscope a few large crystals of plagioclase can be seen in the xenoliths. These crystals are not zoned, but they show interior and zonal patterns of minute inclusions suggesting that the original rock contained zoned feldspar and was porphyritic. Xenoliths occur in all stages of fragmentation and change toward diorite, and those that have been greatly made over appear as vague dark-colored clots in the diorite.

The pluton here is low-silica diorite whose clotted amphibole and poikilitic biotite suggest contamination of an originally granodioritic magma. The estimated mode of the diorite (specimen no. 3) exclusive of recognizable xenoliths is as follows: zoned plagioclase (An_{65-45}), 60 percent; hornblende, generally in clusters around a pyroxene nucleus, 15 percent; biotite, many with sieve textures, 10 percent; clinopyroxene, altering to hornblende, 5 percent; magnetite, 5 percent; quartz, 5 percent.

GABBRO

Gabbro occurs in several border areas and as a few isolated small intrusive deposits. The border zone gabbro appears to be directly related to the granodiorite, but the relationships of the other masses are less clear. The detached masses could be genetically related intrusive rocks injected into an altered and shattered roof zone in advance of the main plutons, or they could belong to an earlier epoch of more mafic intrusions.

Analyzed specimen no. 4 is coarse-grained gabbro from a sill(?) 500 yards south of the head of Chapel Cove, Bay of Waterfalls. Similar gabbro and diorite appear in small patches nearby (pl. 52). The irregularly intruded area south, east, and northeast of Chapel Cove is interpreted as a roof zone over a large pluton. The area south of Chapel Cove contains at least three sill-like masses of gabbroic rock that intrude altered tuff breccia and lapilli tuff of the Finger Bay volcanics. The gabbro in this area is extremely variable with a variable color ratio and local porphyritic facies. Specimen no. 4 is the most mafic rock analyzed or examined. It is a bytownite-labradorite olivine gabbro with abundant magnetite. Small chips of the rock can be picked up with a pocket magnet. Dark minerals occur in single crystals or as clusters as great as 1 cm in diameter, but usually less than 5 mm. These dark constituents are set in a finer (less than 3 mm) matrix of feldspar laths. Feldspars are subhedral and the clinopyroxene generally anhedral. An estimated mode gives the following volume percents: zoned bytownite-labradorite, 65 percent; clinopyroxene, 15 percent; magnetite, 7 percent; olivine pseudomorphs (antigorite?), 8 percent; interstitial and pseudomorphic penninite and carbonate, 5 percent.

Some of the dark border rocks, interpreted in the field as gabbro, have been so changed by sodic, potassic, and silicic solutions that their original characters are uncertain. Some dark quartz-diorite and granodiorite have probably been mistaken for gabbro or diorite in the border zones. The essential fact is that the border facies commonly is conspicuous for dark minerals, and locally intense deuteric alteration that produced light-colored (aplitic) masses as well.

Coats (1956a, p. 50) described a gabbro pluton containing quartz-rich phases in north-central Adak Island near Finger Bay. This mass is probably related genetically to the other plutons, and thus the exposed rocks may be largely peripheral or roof rocks on a more silicic pluton.

FELDSPATHIC GRANODIORITE PORPHYRY

Near the contact with Finger Bay volcanics, a dark-gray porphyritic feldspathic granodiorite, color index commonly 10 to 15, is a conspicuous and characteristic rock. Analyzed specimen no. 5, from the contact at the north end of Bay of Waterfalls, is one of these. About one-third of the rock is large (± 7 mm) crystals of cloudy, dark-gray zoned plagioclase that give it the appearance of anorthosite. A preferred orientation of these crystals was observed in several outcrops. The large plagioclase crystals are set in a fine, subhedral-granular matrix. The mode is: plagioclase, 65.5 percent; alkali feldspar and orthoclase, 13 percent; quartz, 8.2 percent; hornblende, 7.6 percent; clinopyroxene, 1.6 percent; opaque oxide, 3.0 percent; biotite, 0.4 percent; chlorite, 0.3 percent; apatite, 0.3 percent, and sphene, 0.1 percent.

This rock was never found in the interiors of plutons; its appearance, on a traverse through granodiorite, was used to help locate a contact with Finger Bay volcanics. Rocks of this type are usually associated with gabbro and diorite, and by increase in mafic constituents and calcic feldspar grade into them. Differential development of albite and orthoclase, as overgrowths on previously formed plagioclase, obscure the original nature of the feldspathic granodiorite.

PETROGENESIS

HORNFELS AND FLOW STRUCTURE

The hornfels zone—estimated to be between 1 and 50 feet thick on clean steep contacts and possibly much thicker in roof zones, surrounded septa, and intricately injected areas such as the mixed zone on Kagalaska Island (pl. 52)—demonstrates a steep thermal gradient across many of the plutonic borders. This zone is interpreted as evidence for hot magma injection.

Mineral orientation was not mapped but was noted in widely separated areas. This suggests that parts of the magma were moving during crystallization. A dimensional orientation of large tabular inclusions or septa (pl. 52) may be interpreted as relict orientation, reflecting joints or bedding in rocks of the Finger Bay volcanics, and cannot be used as evidence for movement without more field work.

MAFIC BORDER ROCKS

Most mafic rocks are limited to narrow border zones on larger, more felsic plutons. Wide roof zones of mixed hornfels and basic plutonic rocks have been mapped on Kagalaska Island. These zones usually contain abundant dark-colored recrystallized and rounded xenoliths of basaltic or andesitic country rock. Clinopyroxene and subordinate orthopyroxene are abundant in hornfels and xenoliths, less abundant in the dark igneous rocks, and rare in the interiors of plutons. Sieve texture in biotite, pyroxene, and amphibole is common in xenoliths and in immediately adjacent diorite and gabbro but is uncommon in the interior of plutons.

In several areas a fine-grained, porphyritic, quartz diorite was noted in small separate plutons. These suggest that when a pluton was small enough it was chilled and the chilled part is more silicic than the border rocks of large plutons. Thus basic border rocks are not merely chill zones, especially as most are coarse grained; they must result, at least in part, from reactive assimilation or recrystallization of dark wall rocks. Xenoliths and xenocrysts by reaction would precipitate minerals in equilibrium with the early hot magma, and a hybrid mafic rock would result (Bowen, 1928, p. 197 ff). Some mafic rocks, however, appear not to have moved at all—they have a very coarse grained metamorphic fabric and are simply recrystallized basalt and pyroxene andesite; they could be partly metasomatic. Gabbro away from the border zone may represent early-phase basic magmas or peripheral hybrid rocks injected into the shattered roof zone. Their sill and dike-like character argues against a purely metasomatic emplacement.

MIGRATION OF FELSIC MATERIAL

There is abundant evidence of migration of aplitic and pegmatitic material at a late stage within the plutons and also in the adjacent wall

FIGURE 57. Replacement breccia at granodiorite contact, southeast shore of Blind Cove, Adak Island. Dark rock is recrystallized Finger Bay volcanics; light-colored material is granodiorite (nearly aplite) with seams of epidote along fractures and at contact between light-colored and dark rock. Photograph by B. H. Bieler.

rocks. Dikes, small masses of quartz monzonite, and quartz veinlets are conspicuous. In addition, a more delicate but commonly fracture-controlled silicic infiltration is apparent under the microscope. Albitization, potash metasomatism, epidotization, and silicification within the pluton and in closely adjacent areas are probably directly related to the granodiorite magma, but widespread pervasive alteration (p. 381) may have occurred earlier.

Figure 57 is one type of contact between granodiorite and country rock. Here the wall rock was intricately fractured and then infiltrated with aplitic magmas or solutions; no strong motion is apparent, but some of the structures suggest dilation as well as replacement. Epidote is abundant as veins in the central fractures in dikes, along contacts with recrystallized Finger Bay volcanics, and as disseminations and clusters especially in the light-colored rocks. The wall rock here is a medium- to fine-grained biotite-plagioclase-quartz-epidote rock. The biotite is green aggregate of fine grains and flakes and may be transitional between chlorite and hornblende.

The light-colored aplitic rock is extremely variable. One rock has a color index of 25 with abundant pleochroic green to brown hornblende and mostly unzoned sodic andesine feldspar. This same rock contains 10 to 15 percent quartz. Another specimen from the same outcrop shows a sharp contact with wall rock and contains no hornblende, sparse biotite "masses" detached from the wall rock, and abundant quartz. This rock is about 60 percent albite, and epidote clusters are conspicuous. The rock types in the replacing dikes vary from syenodiorite to light-colored albite granite. Apparently the light-colored phases can be differentially contaminated by dark wall rock.

Replacement, evident at such contacts, is locally important, especially as at late-stage phenomenon associated with aplitic rest magmas. That entire plutons were so emplaced seems improbable in light of evidence for magmatic emplacement.

SUMMARY AND AGE

The processes discussed above all tend to produce contrasting rock types close to the borders and roof zones. In general these peripheral rocks are mafic, but late-stage felsic magmas and solutions have modified some areas. Moreover, the central zone of the pluton would be the locus for strongest vertical movements and latest surges of the presumably more felsic magmas; but the mafic sides would be retarded by friction and early crystallization. Generally the hybrid rocks of the roof zone were removed by erosion, exposing a pluton with a clean felsic center and a contaminated mafic border. Probably neither extreme represents the source magma which may have been diorite or quartz diorite—a logical partial melt from a mafic basement.

Age of the main plutons is unknown. All dated plutons within the Aleutian Islands are Tertiary, but several cannot be dated. A mid-to late-Teritary intrusive episode, followed by uplift and erosion, has been postulated for the Aleutian arc (Gates, Fraser, and Snyder, 1954) and probably the plutons on Adak Island are part of this episode.

ANDESITIC DIKES AND SILLS

Small, generally porphyritic dikes and sills of andesite, dacite, rhyodacite, and keratophyre cut Finger Bay volcanics and granodiorite on southern Adak and Kagalaska Islands. Sixteen of these small intrusive bodies were sampled and studied petrographically.

DIKE ROCKS IN THE FINGER BAY VOLCANICS

The Finger Bay volcanics are cut by many small dikes and a few sills. A few of the larger dikes and sills have been mapped (pl. 52) but many undoubtedly were missed because of poor exposure, similarity with the wall rock, and incomplete coverage. These intrusive rocks probably range from basalt to rhyodacite, though no basalt was detected among those studied in thin section. They are dominantly andesitic and are known to range from pyroxene andesite to rhyodacite. Two of seven studied rocks are keratophyre and one is quartz keratophyre. Typically the dikes are porphyritic or microporphyritic with plagioclase, hornblende, augite, and altered orthopyroxene (bastite?) as common phenocrysts. The groundmass is generally a felted or trachytic mass of feldspar microlites, clinopyroxene grains, and opaque oxides; some rocks show a protoclastic structure. One dike contains abundant interstitial chlorite, believed to be devitrified glass.

All dikes and sills examined in the Finger Bay volcanics have been altered like the host rock—epidote and chlorite are in every slide. In some albite is the sole plagioclase. Vein albite, clear patches of albite in masses of cloudy albite, and associated chlorite, epidote, and calcite suggest that these rocks are albitized andesite and dacite or secondary keratophyre (Gilluly, 1935; Williams, and others, 1954). If the original magma had been as sodic as the present rock, the amphibole and pyroxene (mostly unaltered) should likewise be sodic, but they are not.

DIKE ROCKS IN THE GRANODIORITE

Dark dikes are more conspicuous in the light-colored plutonic rocks than in the dark Finger Bay volcanics, but are probably less abundant. Near the pluton margins tabular septa of hornfelsed Finger Bay volcanics with the same general dimensions as the average intrusive dike are easily mistaken for dikes, and some may have been so mapped.

Nine dikes cutting granodiorite were sampled. They are mainly andesitic, but range in composition from dark-colored hornblende andesite to dacite. Two are unaltered, but the others are chloritized, and most contain epidote and sericite. Abundant carbonate was found in three slides. One quartz keratophyre and one hornblende keratophyre contain albite as the sole plagioclase; these are believed to be albitized dacite and andesite. One trachyandesite is the only sampled dike rock with appreciable potash feldspar.

SUMMARY AND AGE

The abundant small intrusives in the rocks of southern Adak and Kagalaska Islands are dominantly andesitic—more silicic than the andesite and basalt of the Finger Bay volcanics. Many of the dikes, especially the sporadic orthoclase-bearing ones, are probably late apophyses from the deeper, uncrystallized granodiorite magma, but some of those that cut only the Finger Bay volcanics are probably feeders and associates of the country rock.

Alteration of the dikes that intrude the plutons does not prove that all the alteration of the Finger Bay volcanics and dikes postdates the emplacement of the plutons. There is evidence for at least two stages of differential albitization: one widespread epoch preceding major plutonic invasion, and one localized epoch accompanying and closely following plutonic invasion (see p. 382). The earlier alteration epoch may still be related to the plutons—as indeed some lavas of the Finger Bay volcanics themselves may be related—in an indirect, preliminary way. Possibly some lavas, of the Finger Bay volcanics, early dikes, and altering solutions were precursors of the grandiorite just as some later dikes and alterations may be after effects of the intrusion.

Coats (1956a, p. 51) reports five andesite porphyry domes along the northwest coast of Kuluk Bay and typically developed at Zeto Point. These domes are outside the area of this report and were assigned by Coats to an independent sequence of Tertiary volcanic rocks, younger than the larger intrusive masses but older than the volcanic rocks at Mount Moffett and Mount Adagdak. The relationship of these domes to the dike rocks just discussed is unknown.

SURFICIAL DEPOSITS

GLACIAL DEPOSITS

Visible glacial deposits are extremely rare on southern Adak and Kagalaska Islands because most of the glacial debris was dumped in the sea, and the remainder has been covered by subsequent ash layers. Nevertheless scattered small deposits of till and occasional erratics have been found on southern Adak Island (Bradley, 1948, fig. 11), and more extensive deposits have been mapped on the northern part of the island (Coats, 1956, pl. 9).

VOLCANIC ASH AND SOIL

Recent ash layers, soil, and vegetation cover much of the bedrock below 1,500 feet. These deposits are nearly continuous at lower elevations and have been omitted from the map. A typical surficial mantle on southern Adak and Kagalaska Islands would consist of about 5 feet of gray to brown volcanic ash, banded with soil and reddish-brown layers, and capped with a still-forming, dark-brown soil-vegetation layer as much as 3 feet thick. The bedded ash is unstable on slopes, commonly showing distortion of layers by solifluction. It is always saturated with water, but so impermeable that small ponds form wherever vegetation has been broken by slump or wind scour. Despite the tendency for mass movement, the streams cutting the mantle remain clear throughout the year (Bradley, 1948). Bradley states further that the ash mantle probably accumulated above the level of streams, so that streams, which are apparently incised, formed by removing ash as fast as it settled—much as a stream removes falling snow.

Kellogg and Nygard (1951, p. 39) have measured and described the present soil on Adak Island, which they classify as tundra without permafrost, and in another place as alluvial-tundra soil. They have demonstrated an incomplete tundra zonation in the measured profile (30 inches) of tundra without permafrost. Bradley (1948) records 4 or 5 buried soil horizons in addition to this most recent layer. Elsewhere in the Andreanof Islands, Anderson and Bank (1952, p. 84) and Bank (1953, p. 497) have measured profiles through the entire sequence.

In the Adak Island to Great Sitkin Island area (Bradley, 1948) and on nearby Kanaga Island (Coats, 1956b; Fraser and Barnett, 1959) a coarse pumiceous layer commonly lies at the base of the ash-soil mantle. This coarse layer is extremely widespread and may have originated during an episode of catastrophic eruption related to caldera formation on Tanaga, Kanaga, or Great Sitkin Volcanoes.

Judson (1946) has emphasized the layering in stabilized dunes on northern Adak Island, but his study is of an uncommon type of surficial deposit whose relations with the more general ash-soil mantle are not clear. Apparently three late episodes of dune formation occurred on northern Adak Island, and these wind-deposited beach sands mask and perhaps intertongue with the ash-soil mantle. The thickness of the dunes reported by Judson (as much as 70 feet) is far in excess of the thickness in the uniform mantle over most of Adak, Kagalaska, and Kanaga Islands.

Coats (1956a) and Bradley (1948) have remarked on the uniform thickness of the ash-soil mantle on Adak Island, and have used this uniformity as evidence for a distant rather than local source for the ash beds. It must be emphasized, however, that the mantle is a composite of many fine ash layers, possibly from many sources, and a few thin soil or humic zones which may not be of islandwide significance. The uniform thickness suggests that the mantle is approximately correlative throughout the area, but does not demonstrate equivalence of the various layers in widely separated areas. The thickness is maintained over most of the area considered in this report, where, for example, on southern Kagalaska the mantle aggregates 3 to 5 feet. Local variations are believed to result largely from an interplay of topographic factors, wind, and subsequent erosion. Bradley pointed out that volcanic activity on Adak Island was mostly preglacial and ash deposition postglacial; this also indicates a distant source. The presumed sources are volcanoes of the Andreanof Islands.

AGE OF THE ASH-SOIL MANTLE

Deposition over glacially striated surfaces and local till dates the surficial mantle as younger than the latest extensive glaciation and suggests a Recent (post-Wisconsin) age for most of it. Radiocarbon dates for modern beach shells and for shells and peat from an Aleut midden on Adak Island (all above the bedded ash-soil mantle) are anomalous. Three dates have been reported (Kulp and others, 1952, p. 412). These dates are about 1,900 years for shells, which contained living organisms when collected; 4,600 years for Aleut midden shells; and 3,300 years for buried peat stratigraphically below the midden shells. The peat has artifacts strewn on its upper surface and possibly within it. All these dates come from samples collected by H. A. Powers in the Clam Lagoon area. The midden shells and peat come from a measured section above 4 feet of stratified ash. Buried beach or tsunami deposits are interstratified with the midden material.

As the radiocarbon dates are undependable, it is only safe to call all the ash mantle postglacial (Recent). The earliest Aleut habitation is younger than most of the ash mantle. Thin soil or humic zones may lack the age significance of soil zones developed elsewhere because here volcanic ash may bury and separate easily established vegetation layers that elsewhere would appear as a single unit.

BEACH AND ALLUVIAL DEPOSITS

Raised beach deposits on northern Adak Island, 20–100 feet above present sea level, have been noted by Coats (1956a); another beach deposit, 10 feet above present sea level and below stratified dune deposits, was described by Judson (1946). Three beach or tsunami deposits, slightly above present sea level, are reported by H. A. Powers (oral communication): two below and one above an Aleut midden at Clam Lagoon, and all above a still older deposit of artifacts, peat, and bedded volcanic ash. Similar raised beach deposits probably exist on southern Adak and Kagalaska Islands, but none have been found. Precise ages for the various raised beaches, and particularly the highest levels, cannot be established. The lower levels are definitely postglacial.

Only a few of the more recent surficial deposits on southern Adak and Kagalaska Islands are mappable on the scale of plate 52. These include stream valley deposits and alluvium filling interior drainage basins and lakes; the present beach deposits, commonly composed of talus blocks and boulders, are all too small to include on plate 52.

STRUCTURE

REGIONAL SETTING

The largest and most obvious structural element, of which Adak and Kagalaska Islands are a part, is the island arc extending about 1,300 miles from the Komandorskiye Ostrova to Unimak Island with a 600 mile extension on the Alaska Peninsula (fig. 55). At the northeastward extremity of this belt active volcanism decreases and the arc trend becomes part of a more complex zone of mountain ranges that curve sharply to the southeast (see U.S. Geol. Survey, Alaska Map E, shaded relief, 1954).

South of Unimak Island and increasingly well developed through the Shumagin Islands, Kodiak Island, and Kenai Peninsula a well defined outer nonvolcanic arc parallels the inner arc; the Aleutian Trench, foredeep for the arc system, swings out to the seaward side of the double arc portion (Murray, 1945, pl. 1). The outer arc, if present at all in the Aleutians proper, is only crudely formed beneath the sea in a narrow zone between the crest of the Aleutian Ridge and the Aleutian Trench (the "Aleutian Bench" of Gates and Gibson, 1956, p. 143).

The axis of the Aleutian Trench is about 70 statute miles south of Adak Island, where the trench is 24,000 feet deep. North of Adak Island the bottom drops abruptly to about 9,000 feet in 10 miles and then gradually to about 12,000 feet. The 1,900-mile mountain range thus rises almost 28,000 feet above the foredeep and 13,000 feet above the backdeep in this area.

Abundant pre-Tertiary and regionally metamorphosed rocks are in the double arc segment east of Unimak Island, but at only one locality are the rocks older than Late Cretaceous, and no regional deformational metamorphism is known in the Aleutian Islands proper. Apparently the outer arc of the peninsular segment is older than the less deformed island segment, though the oldest rocks known from the

Aleutian arc proper lie on the northern side of Adak Island—toward the inner side of the arc.

The Adak-Kagalaska portion of the arc is typical of a large segment of the Aleutians in that central-type, shallow-marine, and subaerial volcanism of Quaternary age and all constructional volcanic landforms are limited to the north edge of land areas. Capps (1934) remarked on the linear arrangement of Aleutian volcanoes and suggested a major fault control. Gates and Gibson (1956), Fraser and Barnett (1959), and Snyder (1957) have also favored a major fault or faults for localizing volcanoes along the north edge of the arc. In the Adak Island area this fault, if present, is masked by the Bering Sea and volcanic debris. A major change in the trend of volcanoes occurs over Kuluk Bay. From Tanaga Island to Adak Island the volcanoes are on a straight line and from Great Sitkin Island to Atka Island there is a similar linearity—on an offset and slightly different trend.

FRACTURE PATTERN

In the map area of this report (pls. 52 and 53) similar fracture patterns are developed in the granodiorite and Finger Bay volcanics, and the resistance to erosion is about the same for both rock types. Consequently, it is often impossible to tell from aerial photographs or from shipboard and mountain-top observation whether a distant rock mass

FIGURE 58.—Aerial view north-northwestward from first bay north of Beyer Bay, Adak Island. *Note the conspicuous fracture pattern in the granodiorite pluton.* In the distant highlands, parts of the same pattern can be detected in Finger Bay volcanics (contact hidden). Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force.

is granodiorite (fig. 58). This fact, coupled with extensive surficial cover, makes reconnaissance geology less productive than in areas of strong physical contrast between major rock units. Curiously, the surficial cover, quite effective as a mask for some of the geology, fails to conceal the intricate pattern of linear features (best seen from the air) that have been interpreted by Bradley (1948, fig. 2) as joints and faults and are similarly interpreted here.

Three factors may have been instrumental in projecting the linear pattern through a thick ash and vegetation mantle: glacial scouring accentuated the fracture pattern prior to deposition of the surficial cover; gradual accumulation of thin ash layers may have effectively "painted" over the irregularities and preserved minute differences in relief; and Recent movement on some fractures is possible in this seismically active area.

The fracture pattern is deduced from hundreds of straight lines, many several miles long, which are visible on topographic maps and aerial photographs (pl. 53, figs. 58 and 59). Topographic lineation is conspicuous even on 1:250,000 maps and particularly on the shaded relief map (U.S. Geol. Survey, Alaska reconnaissance topographic series, Adak, Alaska, 1951). Bradley (1948, fig. 2) has plotted the more conspicuous lines: those on the north half of the Yakak penin-

FIGURE 59.—Aerial view of south-central Adak Island. View is northwestward from Beyer Bay. Conspicuous linear features on the mountain in the foreground are joints or small faults in granodiorite. Note that a linear projection of the lake shore in foreground reflects a conspicuous fracture zone. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force.

sula are known to be bedding traces, but nearly all of the remaining lines represent probable fractures. From Bradley's plot, and from study of annotated maps and photographs, many of the linears appear to be grouped in sets; the northeast direction is strongest, but northwestward-trending linears are also common. Regional abundance and grouping of linears, and their presence in granodiorite as well as Finger Bay volcanics, suggests that they are of tectonic origin and mostly postdate the granodiorite in age. Ten linears coincide partly with faults mapped in the field, but most of them, on field evidence, can be interpreted as joints or groups of joints accentuated by glacial erosion.

Several field observations show that most joints trend northeastward and are vertical or dip steeply to the northwest. The topographic lineation produced by joints is especially conspicuous near the south-central coast of Adak Island (pl. 52). Many lakes are alined or have angular shapes that reflect this joint pattern.

In addition to the fine-grained linear pattern certain major topographic alinements (lineaments), both subaerial and submarine, are suggestive of much larger structures—structures that may have been instrumental in blocking out or segmenting the islands. Among these are the Finger Bay and Adak faults of Bradley (1948, fig. 2) and the Adak Strait, Kagalaska Strait, and Little Tanaga Strait lineaments. The Adak fault of Bradley shows topographic discordance on a major scale; comparable displacements cannot be demonstrated elsewhere, though depth contours suggest that the east side of Adak Strait has been uplifted 3,000–5,000 feet south of Cape Yakak, and irregularities in depth curves suggest that the lineaments of Kagalaska Strait and Little Tanaga Strait extend for many miles south of the islands (U.S. Coast and Geodetic Survey chart 8863, reproduced in part by Bradley, 1948, p. 219).

Faults mapped by both Coats (1956a, pl. 9) and by us all appear to have minor offsets. Joints and small normal faults appear to characterize the structure within the island blocks. This fact plus the existence of abundant dikes and the absence of tight folding suggest that significant compression was not operative at the level now exposed by erosion. The rocks reacted as a brittle mass in a near-surface environment, but the nature and origin of the deforming stress remain obscure. Gates and Gibson (1956) interpret the arc as an arched and faulted, asymmetrical fault wedge, and this explanation seems to fit the facts as far as they are known.

FOLDS

Random dip observations on southern Adak Island suggest a major east-northeastward-trending arch through north-central Adak

Island. Apparently there is a general dip reversal near Bay of Islands, and layered rocks south of this latitude commonly show southerly dip components (pl. 52). Bradley suggested the presence of a volcano remnant in the Bay of Islands area (1948, fig. 10); but its presence was not confirmed by our fieldwork. We interpret the dip reversal in this area as an elongate arch rather than a domelike structure. No volcanic landforms and no structural evidence for ancient central-type volcanoes were found in the area.

A similar, very approximately located arch was postulated for the area just west of Adak Island (Fraser and Barnett, 1959, pl. 27), and a projection of its axis falls close to the area of reversal near Bay of Islands. Probably this arch trend lies close to the crest of the much larger and more complex Aleutian arch, which can be inferred from regional subaerial and submarine topography.

The syncline on Yakak peninsula reverses the general southerly dip on the south flank of this arch, and the presence of this syncline near Boot Bay on the east side of the main pluton (pl. 52) is strongly indicated. Thus the main pluton in south-central Adak Island appears to occupy a syncline, although this structure may be one of many broad flexures within the regional arch. The fold on Yakak peninsula was found by plotting linear bedding traces on aerial photographs; reexamination of field data confirmed the presence of the fold and demonstrated its synclinal nature. Southwest of the mouth of Bay of Islands the presence of a series of curved linears indicates that there is another fold in the Finger Bay volcanics, but, because bedding attitudes noted in the field do not confirm this no fold is plotted.

Local strike and dip variations are common, and recorded observations are not available in most areas so that open folds of the Yakak type may have been missed. Erratic dips ranging from 5° to 45° may indicate mild folding, doming by subjacent plutons, tilted fault blocks, or drag along faults. Steeply dipping platy fractures were observed near a few plutonic contacts; the best explanation for them is that they are sheared areas related to forcible intrusion.

GEOMORPHOLOGY

An excellent reconnaissance report of the geomorphology of Adak Island is already available (Bradley, 1948), and little can be added here. Nearly all physiographic features, large as well as small, reveal an angular fabric controlled by fractures. This controlling fabric is so conspicuous that many nonstructural factors affecting the surface features have here been slighted.

MARINE PLANATION

Broad rolling lowlands border or transect part of the area and are particularly well developed between Mount Moffett and the central highland, on southwestern Adak Island, and on central Kagalaska Island. The peripheral lowland is much dissected and very irregular in south-central Adak Island (fig. 58); but here, as in other locations, the mountains seem to begin at about 700 feet, and below that level the area gives the impression that it had once been a surface of low relief (Bradley, 1948).

The largest lowland area is the gently undulating surface of the Yakak peninsula (figs. 60 and 61). It is possible that this represents

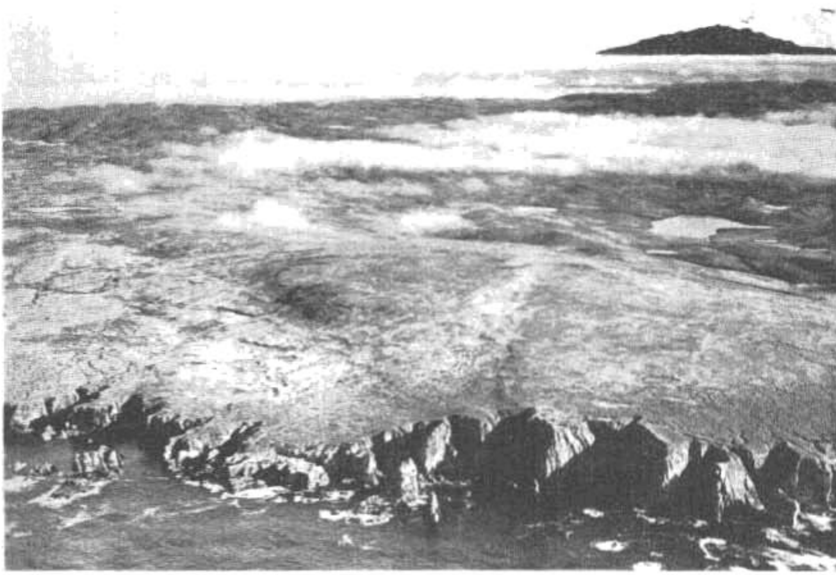

FIGURE 60.—Aerial view northward along Yakak peninsula. Mount Moffett is visible in background. Note the lake-dotted surface of low relief believed to result from several stages of marine planation followed by glaciation. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force.

a series of wave-cut benches later smoothed by glacial erosion, as suggested by Bradley. The surfaces of planation grade into each other by gentle slopes and thus, if marine, are either tilted or modified later. The subsequent glaciation has reworked any stacks, beach gravels, or other unequivocal evidence of marine origin of these surfaces; indeed they may be products of subaerial erosion by streams and solifluction. If they are marine they imply uplift of about 670 feet, presumably in Pleistocene time.

Similar surfaces have been found on many islands west of Adak Island, Kanaga Island, Tanaga Island, the central Delarof Islands,

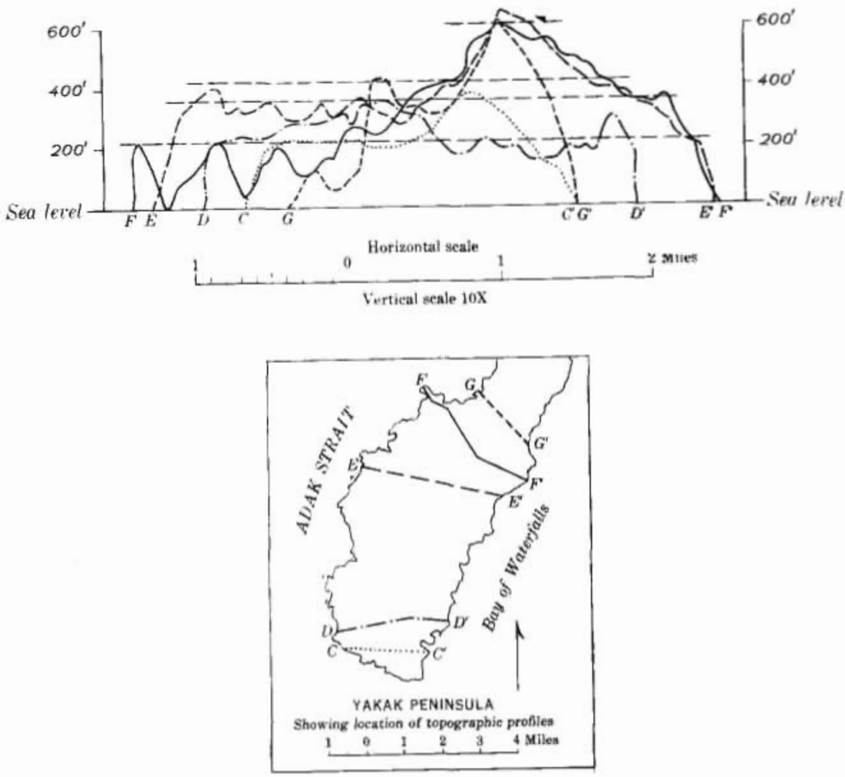

FIGURE 61.—Topographic profiles of Yakak peninsula, Adak Island. Profiles were prepared from 1 : 25,000 topographic maps; contour interval is 20 feet. The presence of incomplete wave-cut surfaces are suggested at levels indicated by horizontal broken lines.

Amchitka Island, and the Near Islands (Fraser and Barnett, 1959; Powers, Coats, and Nelson, in press). These surfaces, generally interpreted as marine platforms, may indicate a regional uplift during Quaternary time. Where data are available, planation and uplift occurred during preglacial or interglacial time.

Besides these extensive older surfaces, minor benches and raised beach deposits on many islands indicate uplift in the Recent or a change in sea level of 6–10 feet. In general the latest deposits record relatively stable conditions; but local structural disturbance of the youngest levels has been noted on Attu Island (Gates and others written communication) and on northern Adak Island (see Coats, 1956a, p. 63, pls. 13 and 14B, and p. 394 this report).

GLACIATION

The latest major agents of erosion that sculptured southern Adak and Kagalaska Islands were glaciers. Glacial striae are common on most recently exposed surfaces; roches moutonnées, cirques, and fiords are abundant; and the scoured appearance of glaciated terrain is immediately apparent from aerial photographs. The cirques and fiord pattern indicates an east-northeast highland through central Adak Island from which glaciers moved to the north and south. Prior to valley glaciation, which has left its characteristic topography, an ice cap probably covered nearly all of the island (Bradley, 1948). Kagalaska Strait, a strong linear tectonic feature, was established in preglacial time, for glacial valleys empty into it from Adak and Kagalaska Islands.

Mount Moffett, now highly dissected, was the center of glacial activity on northern Adak Island. Coats (1956a) and Bradley (1948) report till on the north end of the island and between Mount Moffett and the mountainous interior. Elsewhere on the island glacial deposits are rare (Bradley, 1948, fig. 11). Preliminary contouring of Kuluk Bay from detailed soundings shows a hummocky surface, probably in part the result of glacial deposition. Similar deposits may occur south of Adak Island, but detailed soundings are not available for that area.

The south boundary of Kuluk Bay (the northern coastline of eastern Adak and Kagalaska Islands) is a straight-line feature that abruptly truncates narrow fiords and headlands. The peripheral lowland is absent, and the offshore area is remarkably free of islands. On southern Adak and Kagalaska Islands, however, there is a dissected lowland and the shoreline is characterized by broad bays and many islands. The Adak fault (p. 398) may be the reason for this contrast. Some movement on this fault probably occurred after wave planation, but presence of hanging valleys on northern Adak Island cannot be used as positive evidence for postglacial faulting (Bradley, 1948, p. 230).

GEOLOGIC HISTORY

Earliest known events in the geologic history are recorded in the Paleozoic volcanic-derived sandstone beds of northern Adak Island and in the Finger Bay volcanics of probable Tertiary age. This complex sequence of pyroclastic deposits, lava flows, and sedimentary rocks started to accumulate in and near the sea in late Paleozoic time. A period representing most of Mesozoic time is probably missing from the record. A deposition basin, known to extend from Attu Island to the Alaska Peninsula, received some of its load in late Mesozoic time, but most of the deposition probably occurred during early and mid-Tertiary time. There is no evidence for assuming a major stage of deformation between the beginnings of Paleozoic deposition (known only from northern Adak Island) and the middle to late Tertiary intrusion and uplift, which marked a major change in conditions.

The mass of rocks deposited in this geosyncline are andesitic and basaltic. Albitized, chloritized, and epidotized pyroclastic deposits, massive and pillow lavas, argillite, and graywacke are characteristic. The deposits were buried, regionally altered by hydrothermal solutions, and then invaded by granodiorite plutons, which thermally metamorphosed small border zones and locally caused additional hydrothermal alteration in and near the plutonic borders. The major intrusive episode, probably middle to late Tertiary, was not accompanied by dynamic metamorphism at the relatively shallow level now exposed by erosion. Here the old volcanic rocks were gently folded; and a well-defined fracture pattern formed in the plutons and wall rock alike. This fracture pattern developed after intrusion of the granodiorite and before deposition of late Tertiary and Quaternary volcanic rocks. The presence of abundant dikes and conspicuous joints, normal faults, and the absence of positive evidence for compression indicate that extension, probably on an arch or arched wedge, may have been a controlling factor in the deformation.

During undated epochs, before and after the major intrusions, small, andesitics dikes and sills penetrated the Finger Bay volcanics. Similar dikes penetrated the plutons, possibly after some uplift and erosion.

A period of uplift and erosion, which removed an unknown thickness of Finger Bay volcanics and exposed portions of the plutons, preceded the subaerial volcanism recorded in the composite cones on northern Adak Island. Contributions to this later volcanic sequence came from three distinct centers. These deposits thus contrast sharply with the Finger Bay volcanics, which are believed to be largely submarine without discernible centers of origin. This last volcanic episode began in latest Tertiary time and ended on Adak Island before completion of the last major glaciation. A few small hot springs are active on the east side of Andrew Bay, and volcanoes are still active on adjacent Kanaga and Great Sitkin Islands.

A peripheral surface of low relief, probably a series of shore platforms, was developed in preglacial or interglacial time. Glaciers, moving outward from a central highland, cut through and overrode this surface.

Subsequent to the latest major glaciation a surficial blanket of volcanic ash was deposited. Ash layers are separated at intervals by humic zones, and peat, with a questionable radiocarbon date of about 3,300 years, has been found near the top of the series of ash-soil layers, indicating that most of the surficial blanket accumulated before this date.

The shape of Adak and Kagalaska Islands is still being modified by erosion and possibly by tectonic movement. Current seismicity may indicate movement along some of the old fractures in response to isostatic adjustment, or renewed pulses in the tectonic-magmatic continuum. Islands have existed intermittently since Paleozoic time, but the present island arc and series of volcanoes appear to have been established in late Tertiary or Quaternary time.

ECONOMIC GEOLOGY

The Aleutian Islands have proved remarkably barren of economic mineral deposits. Brecciated fault zones as much as 50 yards wide containing disseminated pyrite and quartz were discovered in the Blind Cove area; a similar zone 100 yards wide was found on the west shore of Beyer Bay; and secondary copper minerals were found associated with a quartz-pyrite mineralized zone upstream from the head of Bay of Islands. Small iron-stained fault zones occur in many places on Adak Island and in a few places on Kagalaska Island; disseminated pyrite is common in the Finger Bay volcanics, especially near the contacts with plutons. No metallic deposits of economic grade have been found on Adak and Kagalaska Islands or any of the other Aleutian Islands.

VOLCANO AND EARTHQUAKE HAZARD

The volcanoes on northern Adak Island have been inactive since prehistoric time, and the possibility of reactivation seems remote. However, three volcanoes in the same chain (Mount Katmai, 1912; Trident, 1953; and Mount Spurr, 1953) have erupted from vents regarded as extinct. Great Sitkin Volcano, 27 miles northeast of the base at Adak Island; and Kanaga Volcano, 22 miles northwest, are quite active, and their explosive products could reach Adak Island. Seismographs on Adak Island have recorded many earthquakes originating within a few miles of the island. Volcanic and seismic activity in the Andreanof Islands should continue for some time. Though there is little probability that catastrophic eruptions will endanger the base at Adak Island in the near future, some earthquake damage is possible.

Tsunamis associated with submarine earthquakes and volcanic activity are a potential hazard at Adak Island. Fortunately Kuluk Bay is on the north side of the Aleutian chain and is therefore less vulnerable to the rather common tsunamis originating south of the islands in the Aleutian Trench. The tsunami of April 1, 1946, which destroyed the Scotch Cap lighthouse on Unimak Island and caused the water there to rise 115 feet, did not affect Kuluk Bay (Shepard and others, 1950, p. 443). Kuluk Bay was likewise in the lee from another tsunami that originated off Kamchatka Peninsula on November 4, 1952. Several waves did cause the water to rise about 8 feet, but no damage resulted.

Conceivably, a major eruption of Great Sitkin Volcano could originate a seiche or tsunami in Kuluk Bay which might damage harbor installations and, especially in the case of a tsunami, the Adak base as well. Some evidence that two such waves inundated an Aleut village site about 3,000 years ago is found on the north end of the tombolo bounding Clam Lagoon (H. A. Powers, oral communication). More recent tsunamis, if they occurred, have left no record in the usually uninhabited Kuluk Bay area. Tsunamis cannot be predicted nor prevented, but installations should be located as high as possible, especially on the south sides of islands. The seismic warning net, now in operation, should prove of great benefit in saving life and property if the tsunami originates far enough away to allow adequate warning time (Zerbe, 1953, p. 9).

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