Geology of Umnak and Bogoslof Islands Aleutian Islands Alaska

By F. M. BYERS, JR.

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. Field studies under general direction of G. D. Robinson, were begun as soon as weather permitted in the spring of 1946. The results of the first year's field, laboratory, and library work were assembled as two administrative reports. Part of the data was published in 1950 in Geological Survey Bulletin 974–B, "Volcanic Activity in the Aleutian Arc", by Robert R. Coats. The rest of the data has been included in 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. The Geological Survey is indebted to that Office for its early recognition of the value of geologic studies in the Aleutian region, which made this report possible, and for its continuing support.

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INVESTIGATIONS OF ALASKAN VOLCANOES

GEOLOGY OF UMNAK AND BOGOSLOF ISLANDS, ALEUTIAN ISLANDS, ALASKA

By F. M. Byers, Jr.

ABSTRACT

Umnak and Bogoslof Islands are in the eastern part of the Aleutian Island arc, a geanticlinal uplift paralleled on the southerly (convex) side by the Aleutian Trench. Umnak Island, 675 square miles in area, is separated into northeastern and southwestern parts by a constriction in the central portion. The rocks consist of late Tertiary and Quaternary volcanic rocks that rest on a basement complex of probable early to middle Tertiary plutonic and low-grade metamorphic rocks. Bogoslof, 25 miles north of Umnak, is composed almost entirely of historic lavas.

The oldest geologic unit, an albitized sedimentary and igneous complex probably largely of early to middle Tertiary age, is exposed near sea level on southwestern Umnak and includes folded argillite and tuff, keratophyre flows, and albitized intrusive rocks. Post-Oligocene plutonic rocks, largely quartz diorite, intrude the albitized sedimentary and igneous complex. Granophyre dikes cut the larger body of quartz diorite and are associated with a wide aureole of potassium feldspathized quartz diorite. The volcanic rocks of central Umnak include both potassium feldspathized volcanic rocks that are probably prepluton in age and unaltered lavas of probable late Tertiary to early Quaternary age. The unaltered lavas rest unconformably on the albitized sedimentary and igneous complex.

Two Quaternary volcanoes, Mount Recheschnoi and Mount Vsevidof, overlie with an erosional unconformity the older rocks on southwestern Umnak. Mount Recheschnoi is a deeply dissected ridge remnant of a composite stratovolcanic cone composed largely of hypersthene andesite. Satellitic lavas of Mount Recheschnoi comprise mafic phenocryst basalt, extruded early in the history of the volcano, rhyolite domes, and a quartz-olivine basalt flow of early Recent age. Mount Vsevidof is composed of an older sequence of basaltic andesite and sparsely hypersthene-bearing andesite flows, an intermediate sequence of pyroclastic rhyodacite pumice and andesite scoria beds of a culminating summit eruption, and younger andesite and basaltic andesite flows, including a historic(?) latite flow.

Okmok Volcano on northeastern Umnak, in contrast to the andesitic stratovolcanoes of southwestern Umnak, consists largely of basalt flows and has a central caldera, Okmok Caldera, 6 miles in diameter. The rocks of Okmok Volcano are conveniently divided into precaldera rocks, Okmok volcanics, the deposits associated with the caldera-forming eruption, and postcaldera rocks. The precaldera rocks include the Ashishik basalt of latest Tertiary and Quaternary age and volcanic rocks of minor vents, including vitreous andesite, rhyolite,

and plagioclase-olivine basalt of satellitic vents. The youngest precaldera unit is the Crater Creek basalt of latest Pleistocene or early Recent age. The Okmok volcanics of early Recent age are composed of a few very thick beds of unsorted andesitic agglomerate, welded in the middle parts of beds, and an overlying unit, consisting of sorted ash, bomb, and lapilli beds. Postcaldera rocks within Okmok Caldera include early postcaldera pyroclastic rocks, plagioclase basalt flows of cones C and D, and bedded volcanic sediments. Subaerial basaltic flows later than the caldera lake include those from several vents within the caldera, the latest flow having been extruded as recently as 1945. The undissected condition of several cones and flows outside Okmok Caldera suggests that they are also postcaldera in age.

The structure of Okmok Volcano is chiefly that of a low shield volcano with gentle outward dips. A fault is exposed for a short distance at the periphery of Okmok Caldera, and the measurable displacement is toward the caldera. The steep infacing cliff of Okmok Caldera is therefore inferred to be the scarp of a caldera ring fault. A few faults are radial to Okmok Caldera. The north and the east arcuate ridges may have originated in any one of three ways; they may be receded fault scarps of an older caldera ring fault, they may have formed concomitantly with the collapse of Okmok Caldera, though there are several objections to this hypothesis, or they may represent accumulations of volcanic debris erupted from vents localized along a fissure beneath the arcuate ridges themselves with little or no fault movement. The first hypothesis, modified by the third, seems most plausible.

Regardless of which of two extreme assumptions is made in regard to size and shape of the missing summit of Okmok Volcano, the total volume of lithic fragments in the Okmok volcanics is not nearly sufficient to account for the missing summit. Hence, the missing portion of the summit must have collapsed inward to form Okmok Caldera.

Surficial deposits of Umnak comprise older till, younger till, glacier ice, glacial outwash, alluvium, talus, beach deposits, and dune sand. Older till of latest Wisconsin or early Recent age forms a series of end moraines several miles in front of the present glaciers. Younger till is confined to moraines within a mile of the present glaciers and probably records the most recent glacial advance, 100 to 300 years ago. Beach deposits are in as many as 20 concentric beach ridges parallel to the present beach. The older till is covered in part by these beach ridges, which are believed to date from the high, 3-meter stand of sea level, generally ascribed to the post-Wisconsin thermal maximum.

Hornblende andesite and basalt exposed in 1947 on Bogoslof Island are all of historic age. The oldest rock, representing the explosive phase of the 1796 eruption, is an andesitic vent agglomerate in fault contact with the hornblende andesite dome also extruded in 1796. The hornblende basalt dome of Fire Island was extruded in 1883 following a violent eruption. Domes were erupted in 1906, 1907, 1910, but no specimens of these domes were available for study, owing to explosive disruption of the domes soon after they formed. Basaltic agglomeratic ash erupted in 1926 and a basalt dome extruded in early 1927 formed most of the area of the island in 1947. From 1927 to 1953 Bogoslof was steadily reduced in size by marine erosion.

INTRODUCTION

In June 1945, a spectacular eruption of Okmok Volcano on the northeast part of Umnak Island in the Aleutian Islands (fig. 49) threatened a military base on the eastern slope of the volcano. Al-

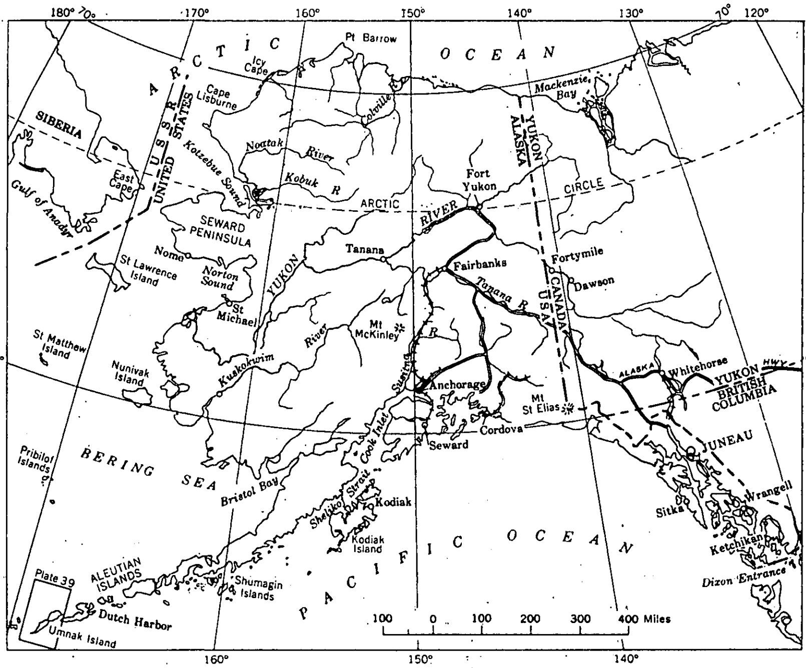

FIGURE 49.—Index map of Alaska showing location of Umnak and Bogoslof Islands.

though this eruption did no damage, military authorities were alerted to the fact that personnel and installations in the Aleutian region are constantly exposed to possible danger and damage from its many active volcanoes. In October 1945, the United States Geological Survey at the request of the Alaskan Defense Command, United States Army, began a program of systematic geological and geophysical investigation of the Aleutian Islands. As the site of a large base and of a currently erupting volcano, Umnak was one of the first islands investigated. A restricted report to the Department of Defense in 1947 emphasized the possibilities of damage by volcanic eruptions to the local military base. The present report deals primarily with the stratigraphy and petrography of rocks on Umnak and its tiny but famous neighbor, Bogoslof Island; the glaciers and glacial geology also are briefly discussed.

FIELDWORK AND ACKNOWLEDGMENTS

This report is based on fieldwork during the summers of 1946 and 1947. The writer was assisted in 1946 by D. M. Hopkins and Bernard Fisher, geologists. Hopkins mapped most of the area within Okmok Caldera, (pl. 39) and part of the description and interpretation of the postcaldera deposits is based on his work. Fisher and two Army men

were drowned in Umnak Pass on June 22, 1946, when they attempted to land their power dory on Ship Rock, a small island off the coast of Umnak. The loss of Fisher dealt a severe blow to the progress of the fieldwork. In 1946 the geologists were aided by Kenneth L. Wier, geophysicist, and by field assistants W. E. Hassman, O. L. Smith, G. A. Hill, and J. M. Borglum. Fieldwork in 1946 was confined to northeastern Umnak. In 1947, the writer, accompanied by W. S. Ogburn, field assistant, completed mapping of northeastern Umnak, made a 6-week reconnaissance of southwestern Umnak, and spent 1 day on Bogoslof. In 1948 the writer, accompanied by Howard A. Powers, supervising geologist, spent several days reexamining parts of northeastern Umnak.

Ray E. Wilcox, presently geologist of the Geological Survey, kindly made available specimens and information he had collected on Umnak during 1945, while serving in the Army.

Many officers and enlisted men, formerly stationed at Fort Glenn, cooperated fully in providing transportation and supplies. Maj. Jim McCall, commanding officer of Fort Glenn during the 1946 field season, Maj. Clarence J. Jackson, commanding officer during the 1947 field season, and Capt. Laverne E. Dye, adjutant during the 1947 season, were especially helpful. At Nikolski, H. Frank Barnett, and Harvey B. Bell gave material aid in August 1947, during two rainy periods. During 1947 and 1948, Harald Drewes gave valuable assistance in the office. The writer received many helpful suggestions in 1948 at the University of Chicago from Tom. F. W. Barth on optical study and chemical analysis of the lavas from Umnak.

HISTORY AND PREVIOUS GEOLOGIC WORK

RUSSIAN PERIOD, 1741–1867

Umnak Island was first sighted in 1741 by Capt. Alexei Chirikof of the *St. Paul,* a ship of Fleet-Captain Vitus Bering's expedition to North America. The name, Umnak, was the native name (Baker, 1906, p. 650). No Russian investigations were made on Umnak during the latter part of the 18th century, although Stephen Glottof and other Russian fur traders visited Umnak during this period (Baker, 1906, p. 36). William Coxe (1787, p. 141–142 and 173–181) gives interesting accounts of the early Russian traders and of the natives. The most complete descriptions of Umnak and Bogoslof during the Russian period are those of Veniaminof (1840) and Grewingk (1850). The first detailed map of Umnak appeared in the marine atlas of Capt. M. D. Tebenkoff (1852).

A rocky islet on the site of Bogoslof was first sighted in 1768 and named Sail Rock by the Russians; it was called Ship Rock by Captain Cook and other early navigators. The islet disappeared between

1884 and 1891. The name Ioánn Bogoslof (John the Apostle) was applied by the Russians to an island formed a little south of Ship Rock by an eruption of viscous lava in 1796 (Merriam, 1902, p. 291–294).

UNITED STATES TERRITORIAL PERIOD

In 1867, the United States purchased Alaska, but no survey or scientific study of Umnak by Americans was made until 1883, when the birth of a new volcanic dome, less than a mile north of Bogoslof Island, attracted interest. Dall (1884 and 1885) and Diller (1884 and 1885) used the names Grewingk and New Bogoslof, respectively, in describing the new dome, the remnant of which is now called Fire Island. Merrill (1885, p. 31–33) contributed petrographic descriptions and two analyses of specimens from Fire Island. Members of the Harriman Alaska Expedition stopped at Bogoslof in 1899 and collected specimens from Castle Rock. Merriam (1902), a member of that expedition, published the first complete paper in English on the history of Bogoslof during the period 1768–1900. Marcus Baker's Geographic Dictionary of Alaska (1906) is a valuable source of information, not only about origin of names but also about earlier workers and their publications, especially maps and charts.

Volcanic activity at Bogoslof was renewed during 1906–1907. Jaggar (1908) published a history of Bogoslof and an account of his landing of August 7, 1907. Robert Dunn visited both Bogoslof and northeastern Umnak and was the first (Dunn 1908) to publish the name Okmok, supposedly the native name for this volcano. Sidney Powers (1916) gave an account of the 1910 eruption of Bogoslof and the extrusion of the Taboma Peak dome and Jaggar (1930) gave an account of the 1926–27 Bogoslof activity. Lukens (1936) gave a description of Bogoslof Island as it was in 1935. Paul A. Smith (1937) using Coast and Geodetic Survey data, described the submarine canyons near Bogoslof.

On Umnak, Waldemar Jochelson, an anthropologist, made excavations at ancient village sites in connection with his studies on the origin of the Aleut (Jochelson, 1925, 1933). Hrdlička (1945) also visited Umnak in connection with his anthropological studies of the Aleut. Umnak Island was briefly visited in 1931 by S. R. Capps (1934) of the U. S. Geological Survey, and later Hultén (1937) made botanical collections near Nikolski. An eruption in Okmok Caldera in 1931 was reported by Jaggar (1932).

During World War II, from 1942 to 1945, Okmok Caldera became known to military personnel stationed at Fort Glenn. Dean Freiday (1945, p. 453–454) described Okmok Caldera by means of photographs and speculated on its origin. Ray E. Wilcox (1945 and 1946), while an officer at Fort Glenn, prepared file reports on the 1945 activity.

G. D. Robinson and Howel Williams as consultants to the U.S. Army also observed the 1945 eruption and advised the Alaskan Defense Command that Umnak Airbase was not threatened. Byers, Hopkins, Wier, and Fisher (1947) prepared an administrative progress report on volcano investigations begun in 1946 on northeastern Umnak. Byers and Brannock (1949) sampled hot springs and fumaroles and described volcanic activity on Umnak Island during the period 1946–48.

GEOGRAPHY

LOCATION, SETTLEMENTS, AND ACCESSIBILITY

Umnak and Bogoslof lie in the eastern Aleutian Islands, Alaska (fig. 49). Most of their area is enclosed by the meridians 168° and 169° W. and parallels 53° and 54° N. Umnak Island is bounded on the north by the Bering Sea and on the south by the Pacific Ocean. Bogoslof Island is entirely within the Bering Sea, 25 miles north of Umnak and slightly off the main trend of the eastern Aleutians. Umnak is 75 miles long and has an area of about 675 square miles. Bogoslof was only slightly more than a mile long in 1947 and had an area of less than a quarter of a square mile.

The chief settlements are Cape Air Force Base (Fort Glenn prior to 1947) on northeastern Umnak Island and the Aleut village of Nikolski on the southwestern part (pl. 39). In 1947 a group of about 12 U. S. Coast Guardsmen operated the Cape Starr Loran Station, 4 miles west of Nikolski, a village with a population of several score Aleuts, a school teacher, and the manager and a few employees of a livestock company. No one has lived on Bogoslof since 1945, when a World War II outpost was abandoned. Umnak Island can be reached by Government vessel in about 1 week's time from Seward, Alaska. The dock of Cape Air Force Base can accommodate small- to medium-sized vessels, but at Nikolski all supplies and passengers must be lightered ashore. Bogoslof Island is accessible only by small boat in calm weather.

Roads, in bad repair, encircle northeast Umnak Island except on the northwest side. Southwest Umnak has only wagon roads and trails in the vicinity of Nikolski.

HYDROGRAPHY AND TOPOGRAPHY

Umnak, like nearly all the islands of the Aleutian arc, rests on a flat-topped submarine ridge, the Aleutian Ridge (Studds, 1950, p. 787). Bogoslof is the top of a submarine volcano rising from oceanic depths, 25 miles north of the Aleutian Ridge (pl. 39). The general submarine features of the Bering Sea, the Aleutian Ridge, and the parallel Aleutian Trench to the south have been described by Murray (1945).

The Aleutian Ridge near Umnak Island reaches a maximum width of 35 miles along a line through northeastern Umnak but tapers to 22 miles opposite the southwestern end of Umnak; its upper surface is almost entirely at depths of less than 100 fathoms (pl. 39). The break in slope between the ridge or shelf area and the north wall of the Aleutian Trench is at about 100 fathoms, 12 to 30 miles south of the coast of Umnak. The north wall of the Aleutian Trench is dissected by short submarine canyons, which extend to depths ranging from 1,500 to 2,000 fathoms. The average gradient of the canyons is about 600 feet per mile. Below 2,000 fathoms the north wall of the Aleutian Trench has a more gradual slope. The bottom of the Aleutian Trench is 4,030 fathoms at about 100 miles south of Umnak (Murray, 1945, fig. 9) or about 50 miles south of the southern boundary of the area shown in plate 39.

Umnak Island is separated from Unalaska Island to the east by Umnak Pass, a strait 4 miles in minimum width and 26 fathoms in minimum depth. Samalga Pass, 20 miles wide and about 125 fathoms deep, separates Samalga Island off the southwestern tip of Umnak from Chuginadak, the nearest of the Islands of the Four Mountains, just west of the area shown in plate 39.

The submarine slope at a depth of about 100 fathoms (pl. 39) steepens off the northwest coast of Umnak within a few miles of the shoreline at the widest parts of the island. The gradient is about 600 feet per mile from 100 to about 600 fathoms and the submarine slope is incised by many steep V-shaped canyons as much as 1,000 feet deep. Below about the 600-fathom contour the submarine slope becomes less steep and also less regular. Submarine canyons separated by spurs extend northwesterly for several tens of miles to join a much larger submarine canyon with a westerly gradient (extreme top part of pl. 39). This canyon, 6,000 to 9,000 feet deep, is the largest submarine canyon of the eastern part of the Bering Sea (Murray, 1945, pl. 1; Smith, 1937). The largely submerged volcanic cone of Bogoslof rests on one of the northwest-trending intercanyon spurs.

Umnak Island is divided into northeastern and southwestern parts at the narrow isthmus where Inanudak Bay makes a deep reentrant into the northwest coast. The two parts of Umnak have marked differences in topography. Southwestern Umnak is much more rugged, with two large volcanic mountains rising to nearly 7,000 feet. Northeastern Umnak Island is almost wholly occupied by Okmok Volcano, a low shieldlike volcano, less than 3,500 feet in altitude.

Southwestern Umnak Island contains the glaciated volcanic mountains, Recheschnoi and Vsevidof, in the northern part and the Nikolski plain in the southern part (pls. 39 and 40). Mount Recheschnoi (altitude, 6,510 feet) is a deeply dissected ridge with radial flat-topped spurs separated by deep, glacier-filled valleys. Seven glaciers, 2 to 4 miles long, extended in 1947 from near the summit of the ridge to an altitude of a few hundred feet. Outwash plains in the valleys extend seaward from the glacier fronts. Mount Vsevidof, west of Mount Recheschnoi, is a symmetrical volcanic cone rising to about 7,000 feet above sea level. The crater of Mount Vsevidof, 0.8 mile across, is filled by a glacier with two distributaries, one north and the other east of the crater. The distributary glaciers have breached the crater wall and have incised gorges 200 to 400 feet deep. The larger, east distributary joins a glacier flowing southwest from Mount Recheschnoi. The composite glacier then flows southward 2 to 3 miles to a large end moraine at an altitude of about 1,000 feet. This glacier drains to the two forks of Black Creek, the largest stream on southwestern Umnak Island. The Nikolski plain southwest of Mount Recheschnoi and Mount Vsevidof is a rolling surface with a relief of a few hundred feet and about 300 feet in average altitude. Small lakes, less than a mile long, abound on the surface of the plain. Small islands, such as Ananiuliak, Samalga, and Vsevidof, off the coast of southwestern Umnak, are apparently remnants of the plain, which were isolated by marine erosion.

Okmok Volcano on northeastern Umnak is a shield-type volcano with a large central caldera, 6 miles in diameter. The rim of the caldera ranges in altitude from 1,600 to about 3,200 feet (pl. 39). Several cinder cones and craters, designated on plate 41 by letters A through H, are on the floor of Okmok Caldera. The caldera is drained toward the northeast by Crater Creek through a gorge 600 feet deep. North and east of Okmok Caldera, two arcuate ridges, roughly concentric to the walls of Okmok Caldera, are herein referred to as the north arcuate ridge and the east arcuate ridge, respectively. Radial spurs separated by broad short valleys are typical of the slopes of Okmok Volcano above altitudes of about 1,000 feet. At lower levels, slightly dissected plains slope 100 to 200 feet per mile seaward, except along the northwest coast between Fox and Aguliuk Points (pl. 39), where slopes are steeper and more dissected. The slopes on the lower flanks of Okmok Volcano have been incised with V-shaped gullies, as much as 200 feet deep. In exposed places where the plains intersect the coast, the sea cliffs are 100 to 250 feet high.

Northeast of Okmok Volcano, Mount Idak surmounts the southwestern end of a small lava plateau that slopes northward toward the Bering Sea. On the south flanks of Okmok Volcano are several parasitic cones in different stages of dissection. The largest of these, and also the highest peak on northeastern Umnak Island, is Mount Tulik, with an altitude of 4,111 feet. Low, rugged volcanic mountains, rising about 2,500 feet above sea level, occupy the narrow isthmus that joins the northeastern and southwestern parts of Umnak Island. This mountainous area is herein called the central Umnak area.

CLIMATE, VEGETATION, AND ANIMAL LIFE

The climate (U. S. Coast Pilot, 1947, p. 36–43) is marine subarctic, characterized by overcast skies, high winds, and small variations of diurnal temperature. Overcast skies and fog with considerable rain in the mountainous areas occur during the late spring and summer months, owing to warm southerly winds off the Pacific Ocean. Winds during the summer are usually accompanied by fog and drizzle and frequently exceed 30 miles per hour. Occasionally the winds reach velocities as high as 70 miles per hour, but winds of extreme velocity during the summer are probably williwaws, whose accelerated velocity is caused by local topographic conditions. Temperatures during the summer are cool, ranging from 46° to 68° F., on Umnak. After the September equinox, the average wind direction shifts from westerly to northwesterly, and winds of over 100 miles per hour are not uncommon. Fog and low overcast give way to broken overcast with occasional clear days. Drifting snow that blocks roads becomes a problem in winter. Winter temperatures at sea level in the vicinity of Umnak and Bogoslof Islands average slightly above freezing and the seas are ice-free throughout the year.

Table 1 summarizes climatological data at Cape Air Force Base and Nikolski from June 1942, to April 1948.

TABLE 1.—*Climatological data for two stations on Umnak Island, June 1942 to December 1948*

[Compiled from 11th Weather Squadron, 1950, Chart 19, and earlier files of U. S. Air Force]

	Cape Air Force Base	Nikolski [1]
Temperature (degrees Fahrenheit):		
Mean annual	39.0	39.2
Maximum annual	68.0	64.0
Minimum annual	9.0	11.0
Precipitation (inches):		
Mean annual	47.67	41.19
Annual snowfall, unmelted	64.5	49.9
Greatest depth on ground	8.0	13.0
Number of days with at least a trace of precipitation	318	307
Fog: Annual percentage of occurrence	28.72	13.0
Wind (miles per hour):		
Average velocity	18.8	19.4
Extreme velocity	135.0	72.0
Sky (condition in percent of hours):		
Clear	1.4	1.7
Scattered or broken	38.3	34.5
Overcast or obscured	60.3	63.8

[1] Data cover only a limited period from October 1942 to April 1945.

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A general desciiption of the vegetation of the Aleutian Islands is given by Walker (1945, p. 63–71). Grasses, sedges, and flowering plants cover the slopes below an altitude of 1,000 feet on northeastern Umnak. On southwestern Umnak, grasses and flowering plants grow in protected places at altitudes up to nearly 2,000 feet, and several types of edible berries grow at altitudes below 1,000 feet on the south-facing slopes of Mounts Recheschnoi and Vsevidof. In 1947, Bogoslof had very little vegetation other than a few grasses.

Umnak and Bogoslof, like other Aleutian Islands, are characterized by a profusion of marine mammals and birds. (See Clark, 1946, p. 31–61.) Fish and marine invertebrates likewise are abundant. By comparison the terrestrial fauna is insignificant. No reptiles or amphibians are known in the Aleutian Islands and the most common land mammal is the red fox. Reindeer, imported from Siberia, were stocked on Umnak about 1900 (Lantis, 1950, p. 28–29), and in 1946 several hundred of these animals, then in the wild state, inhabited the northeastern part of the island. Sheep are raised on southwestern Umnak, where they produce a premium crop of wool.

GENERAL GEOLOGIC SETTING

THE EASTERN ALEUTIAN ARC

Umnak and Bogoslof Islands are a small segment of the Aleutian Island arc, on the northern edge of the Pacific Ocean. Most Pacific island arcs (Umbgrove, 1947, p. 144–216; Hess, 1948, p. 417–445) are arcuate geanticlinal ridges with submarine trenches or downbuckles on their convex oceanward sides. Menard and Dietz (1951) provide hydrographic evidence that the Aleutian Trench has sunk, probably in late Tertiary and Quaternary time.

The Aleutian arc is a single island arc at Umnak and adjacent islands, but becomes a double arc to the northeast (Umbgrove, 1947, p. 189). In the Umnak portion of the arc, the geanticlinal ridge, marked by the line of Quaternary volcanoes, remains close to 100 miles from the axis of the Aleutian Trench (fig. 50). Bogoslof and Amak Islands are partly submerged volcanoes 30 miles north of the main Aleutian geanticlinal ridge and hence are exceptions to this general relationship. Northeast from Umnak, the line of Quaternary volcanoes diverges from the axis of the Aleutian Trench and is 200 miles away near Kodiak Island (fig. 50). The continental shelf south of the shoreline of the inner (northern) arc likewise widens from about 20 miles, south of Umnak, to 150 miles, southeast of the Alaska Peninsula near the Katmai Volcano. Where the shelf widens, an outer (southern) chain of nonvolcanic islands begins with Sanak, and extends northeastward.

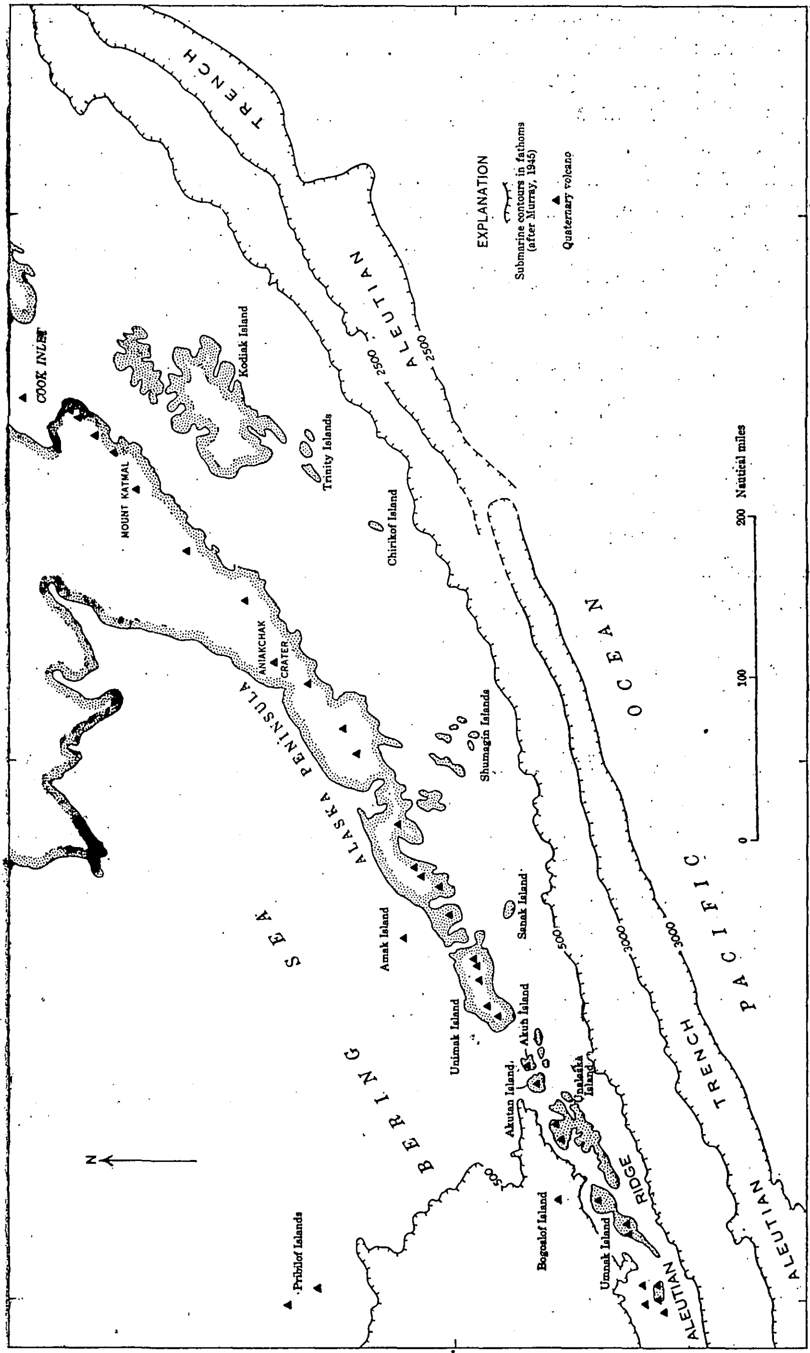


FIGURE 50.—Eastern part of Aleutian volcanic arc, showing positions of volcanoes and Aleutian Trench. Submarine contours selected to show positions of Aleutian Ridge and Aleutian Trench.

The geology of the outer, southeasterly islands of the double arc is known chiefly from the work of S. R. Capps (1937) on Kodiak Island. Capps (1937, pl. 2) has mapped sedimentary rocks of four ages: an early Mesozoic and older, a late Mesozoic, an early Tertiary, and a late Tertiary. The rocks are progressively more deformed with increasing age. In general the beds of Tertiary age crop out nearer the Aleutian Trench than the rocks of Mesozoic age. These sedimentary rocks strike northeast, parallel to the Aleutian Trench, and are generally separated by great, northwesterly-dipping faults running the entire length of Kodiak Island (Capps, 1937, p. 136).

The Alaska Peninsula, on the inner concave part of the Aleutian double arc, contains folded thick rocks of Mesozoic and Tertiary age (W. R. Smith, 1925, pl. 4; Atwood, 1911, p. 28; Knappen, 1929, pl. 6), which extend as far southwest as Pavlof Bay (P. S. Smith, 1939, pl. 1). Atwood (1911) mapped Jurassic to Tertiary sedimentary rocks, which have been bowed up into a broad anticlinorium. Thrust faults that strike northeast and dip northwest have been reported in the Aniakchak district (Knappen, 1929, p. 207).

Southwest of Pavlof Bay (fig. 50) the thick sedimentary formations of Mesozoic and Tertiary age are not exposed. Between Pavlof Bay and the end of the Alaska Peninsula (fig. 50) only minor thicknesses of late Tertiary sedimentary rocks interbedded with basic tuffs crop out at low altitude beneath the Quaternary volcanoes (Kennedy and Waldron, 1955, p. 6–7; H. H. Waldron, 1947, oral communication). The Tertiary and older rocks probably are mostly concealed beneath the Quaternary volcanoes of Unimak, the easternmost island of the single arc. The islands of Akun, Akutan, and Unalaska, west of Unimak, are composed almost entirely of volcanic rocks of Cenozoic age and their sedimentary derivatives. On Unalaska, the next island east of Umnak, lower Miocene tuffaceous sedimentary rocks and associated volcanic rocks are cut by quartz dioritic plutonic rocks.

AREA OF THIS REPORT

Umnak and Bogoslof Islands are composed almost entirely of igneous or altered igneous rocks of Cenozoic age. The 2 islands are divisible into 3 areas that with few exceptions differ significantly in geologic features and petrographic type. These areas are southwestern Umnak Island, northeastern Umnak Island, and Bogoslof Island (pl. 39), which are shown on separate geologic maps in plate 40, plate 41, and figure 53, respectively. Northeastern Umnak is arbitrarily separated from southwestern Umnak at the narrowest part of the island. Southwestern Umnak (pl. 40) contains the oldest rocks, a complex of albitized sedimentary and igneous rocks of possibly diverse geologic ages, mostly Tertiary, but possibly including still older rocks. Dioritic plutonic rocks, intrusive into this complex, were also found only on southwestern Umnak. Altered Tertiary volcanic rocks that crop out in the central part of Umnak underlie Quaternary volcanoes on both northeastern and southwestern Umnak. The petrography, composition, and physiographic expression of the volcanic rocks of Quaternary age in the northeastern part of Umnak differ from those of southwestern Umnak; the volcanic rocks of Bogoslof Island, which are entirely of historic age, differ somewhat in composition from those of either southwestern or northeastern Umnak.

Geologic dating of most of the rock units is uncertain and based chiefly on inferences from contact relationships, degrees of alteration, and, to less extent, degree of dissection of constructional surfaces. Tertiary fossils recently discovered on nearby Unalaska Island (pl. 39) have supplied some evidence, from which geologic ages of the older rocks may be inferred.

ROCK NAMES USED IN THIS REPORT

Names of volcanic rocks in the suite being investigated are based on the total content of silica in the rock, following in general (and extending to higher silica percentages), the system of Williams (1950 p. 234–235). As defined in this report, basalt contains less than 54 percent silica, equivalent to about 5 percent normative quartz; andesite contains more than 54 and less than 63 percent silica, approximately equivalent to the range 5 to 14 percent of normative quartz; latite contains between 63 and 65 percent of silica, approximately equivalent to the range 14 to 17 percent of normative quartz; rhyodacite contains about 65 percent of silica, equivalent to about 20 percent of normative quartz; and rhyolite contains more than 72 percent of silica, or more than 25 percent of normative quartz. (For chemical analyses of the rocks see table 2.)

Porphyritic rocks are named by applying the appropriate general rock name as determined by the silica content modified by mineral names, particularly those of mafic phenocrysts, to indicate the phenocrysts in the rock. The names applied to many of the porphyritic rocks on the maps and in stratigraphic descriptions are shortened versions of names based on chemical and petrographic analyses; that is, hypersthene andesite for hypersthene-bearing labradorite andesite. One term, mafic phenocryst basalt, found useful in the field mapping, is retained in the report as a map unit and general rock group. It includes porphyritic basalts that contain visible phenocrysts of olivine, augite, or both together in excess of about 2 percent by volume. Abundant plagioclase phenocrysts in association with mafic phenocrysts are not generally considered in naming the rock, especially if less than 10 percent, because plagioclase phenocrysts are abundant in many of the rocks described.

TABLE 2.—*Analyses of rocks from Umnak and Bogoslof Islands*

[Analyst indicated by initials: S. M. Berthold (SMB); W. W. Brannock (WWB); R. L. Hill (RLH), and Leonard M. Shapiro (LMS), of rapid-analysis laboratory (see Shapiro and Brannock, 1952), U. S. Geological Survey; W. W. Hommel (WWH), of Ledoux and Co.; M. K. Carron (MKC) and E. J. Tomasi (EJT) of U. S. Geological Survey; F. M. Byers, Jr. (FMB), of U. S. Geological Survey, on leave at University of Chicago laboratory; and Paul R. Barnett (PRB), Arthur Chodos (AC), K. J. Murata (KJM), A. T. Myers (ATM), spectrographers, U. S. Geological Survey.]

	Northeastern Umnak																		
	1	1A	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	SMB RLH LMS	EJT	WWH	SMB RLH LMS	MKC	WWB LMS	FMB WWH	FMB WWH	SMB RLH LMS	FMB WWH	WWH	WWH	WWB LMS	FMB WWH	FMB	FMB WWH	FMB WWH	SMB RLH LMS	SMB RLH LMS
Major oxides																			
SiO_2	45.7	48.07	48.43	48.7	48.97	50.1	50.52	50.60	51.4	52.23	52.43	52.58	53.1	54.35	54.41	54.80	57.40	63.5	65.6
Al_2O_3	12.9	15.61	18.94	14.9	16.27	23.0	19.71	18.06	14.4	17.04	15.27	14.97	18.4	16.38	15.77	14.90	15.49	16.1	14.1
Fe_2O_3	3.6	2.34	4.15	4.7	2.83	2.6	1.67	2.99	6.3	3.22	5.96	3.86	4.5	3.01	4.27	2.88	1.97	1.4	2.0
FeO	5.6	6.98	6.30	3.4	6.24	5.4	6.82	6.75	1.3	6.60	6.99	8.81	3.2	8.00	6.55	9.00	7.86	5.0	3.8
MgO	18.2	12.68	6.55	4.2	9.62	3.6	4.64	5.58	1.5	5.54	4.13	4.00	3.4	3.34	4.02	3.00	2.94	1.2	.49
CaO	9.6	10.76	11.04	7.8	12.86	11.6	11.96	11.46	8.4	10.39	8.70	8.64	9.3	8.08	8.29	7.15	6.74	3.8	2.8
Na_2O	1.7	1.86	2.51	2.1	2.00	2.4	[1] 2.71	2.73	4.4	2.97	3.50	3.47	2.8	[1] 3.66	3.50	3.83	3.96	4.6	4.3
K_2O	.52	.48	.52	.92	.54	.44	[1] .58	.53	1.1	.78	1.24	1.22	1.4	[1] 1.32	1.26	1.23	1.53	2.6	3.0
H_2O+		.09	.12		.09		[1] .08	.17		[1] .12	.20	.20	1.14	[1] .08	.09	[1] .18	[1] .20		
H_2O-	[3] —.16	.07	.11	[2] 10.1	.04	[3] —.13	[1] .01	.05	[2] 6.3	[1] .06	.11	.07	.54	[1] .04	.02	[1] .09	[1] .09	[3] —.08	[2] 3.4
CO_2		.01											.65						
TiO_2	.51	.73	1.20	1.2	.72	.74	.97	1.10	.93	1.24	1.48	1.80	1.0	1.25	1.56	2.48	1.54	.81	.64
P_2O_5	.10	.12	.27	.22	.13	.11	[1] .19	[1] .28	[1] 2.4	[1] .25	.36	.38	.30	[1] .33	.25	.65	[1] .32	.23	.16
MnO	.19	.17	.17	.20	.18	.13	[1] .18	[1] .16	.23	[1] .19	.17	.21	.14	[1] .15	.21	.25	[1] .18	.22	.18
Total	98.62	99.97	100.31	98.44	100.49	100.12	100.04	100.46	98.66	100.63	100.54	100.21	99.85	99.99	100.20	100.44	100.22	99.46	100.47
Powder sp. gr.	3.02		2.97	2.49	[4] 3.0	2.80	2.86	2.96	2.55	2.94	2.89	2.93	2.78	2.88	[4] 2.8	2.92	2.83	2.58	2.45
Minor elements [5]																			
		PRB			AC	ATM	KJM				KJM	KJM	ATM			KJM	KJM		
Zr		0.003			0.004	0.003	0.005				0.007	0.008	0.004			0.01	0.01		
Ga		.002			.0006	.0009	.0007				.0007	.001	.001			.001	.0007		
La																			
Sc					.004														
Y					.003	.002	.002				.005	.006	.002			.007	.007		
Yb					.0002														
B																			
Be																			

Sr		.08			.1	.05	.09				.1	.1	.05			.06	.1		
Ba		.06			.03	.01	.02				.03	.03	.05			.03	.05		
Pb																.001			
Mo																			
Cu		.004			.02	.003	.02				.03	.04	.007			.01	.008		
V		.03			.03	.02	.02				.03	.05	.02			.02	.02		
Cr		.07			.03	.004	.008				.004	.01	.007				.003		
Ni		.03			.01	.001	.004				.002	.004	.003				.001		
Co		.007			.004	.002	.002				.002	.003	.002			.002	.002		
Nb																			
Total		.286			.2358	.0959	.1717				.2107	.252	.146			.141	.2017		

Norms

Q				12.1		2.5		1.2	4.6	2.8	4.9	3.7	10.1	4.8	6.7	7.7	8.3	14.5	21.5
C																			
or	2.8	2.8	3.1	5.6	2.8	2.8	3.5	3.0	6.7	4.5	7.3	7.2	8.3	7.8	7.5	7.2	8.9	15.6	17.8
plag {ab	14.2	15.7	21.2	17.8	16.8	20.4	22.9	23.1	37.2	25.1	29.6	29.4	23.6	30.9	29.6	32.5	33.5	38.8	36.1
plag {an	26.1	32.8	38.9	28.4	34.2	50.3	39.9	35.5	16.1	30.8	22.3	21.7	33.4	24.7	23.6	19.7	20.0	15.6	10.3
ne																			
di {wo	8.6	8.2	5.9	3.6	12.1	2.7	7.6	8.1	4.2	7.9	7.7	7.8	3.0	5.5	6.6	4.7	4.8	1.0	1.2
di {en	6.6	5.7	3.9	2.9	8.3	1.4	4.0	4.8	3.6	4.8	4.7	3.7	2.4	2.4	3.9	1.9	1.9	.3	.3
di {fs	1.1	1.8	1.6	.3	2.8	1.2	3.4	2.8		2.7	2.6	3.9	.3	3.1	2.4	2.8	2.8	.8	.9
hy {en	1.7	8.7	10.6	7.6	6.6	7.6	7.5	9.0	.1	9.0	5.6	6.2	6.1	5.9	6.1	5.5	5.4	2.7	.9
hy {fs	.3	2.8	4.2	.5	2.2	5.9	6.4	5.6		5.1	3.2	6.6	.4	7.4	3.9	7.8	7.8	6.2	3.6
ol {fo	26.1	12.0	1.3		6.3		.1												
ol {fa	4.3	4.1	.5		2.4		.1												
mt	5.3	3.5	6.0	6.7	4.2	3.7	2.4	4.3	2.3	4.7	8.7	5.6	6.5	4.4	6.2	4.2	2.9	2.1	3.0
il	.9	1.4	2.3	2.3	1.4	1.4	1.8	2.1	1.7	2.4	2.8	3.4	2.0	2.4	2.9	4.7	2.9	1.5	1.2
hm									10.1										
ap	.3	.3	.6	.6	.3	.3	.4	.7	5.7	.6	.8	.9	.7	.8	.6	1.6	.8	.3	.3
cc													1.6						
Total	98.3	99.8	100.1	88.4	100.4	100.2	100.0	100.2	92.3	100.4	100.2	100.1	98.4	100.1	100.0	100.3	100.0	99.4	97.1

Niggli values

si	83	98	110	150	103	124	122	120	175	129	134	136	148	148	146	155	170	236	286
al	14	19	25	27	20	33	28	25	29	25	23	23	30	26	25	25	27	35	36
fm	64	54	42	39	46	29½	34	39	24	40½	42	42	32	38	40	41	37½	27	24½
c	19	23	27	26	29	31	31	29	31	27	24	24	28	24	24	22	21½	15	13
alk	3½	4	6	8	5	6½	7	7	17	7½	11	11	10	12	11	12	14	23	26½
k	.16	.16	.12	.23	.14	.11	.12	.11	.14	.15	.19	.19	.25	.19	.19	.17	.20	.27	.32
mg	.78	.72	.53	.49	.66	.45	.49	.51	.32	.50	.37	.36	.45	.35	.40	.31	.35	.25	.13
qz	−31	−18	−14	18	−17	−2	−6	−8	7	−1	−10	−8	8	0	2	7	14	44	80

See footnotes on page 284.

TABLE 2.—*Analyses of rocks from Umnak and Bogoslof Islands*—Continued

[Analyst indicated by initials: S. M. Berthold (SMB); W. W. Brannock (WWB); R. L. Hill (RLH), and Leonard M. Shapiro (LMS), of rapid-analysis laboratory (see Shapiro and Brannock, 1952), U. S. Geological Survey; W. W. Hommel (WWH), of Ledoux and Co.; M. K. Carron (MKC) and E. J. Tomasi (EJT) of U. S. Geological Survey; F. M. Byers, Jr., (FMB), of U. S. Geological Survey, on leave at University of Chicago laboratory; and Paul R. Barnett (PRB), Arthur Chodos (AC), K. J. Murata (KJM), A. T. Myers (ATM), spectrographers, U. S. Geological Survey.]

	Northeastern Umnak—Con.		Southwestern Umnak													Bogoslof	
	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
	FMB	MKC	WWB LMS	WWB LMS	WWB LMS	WWB LMS	WWB LMS	SMB RLH LMS	SMB RLH LMS	SMB RLH LMS	SMB RLH LMS	WWB LMS	SMB RLH LMS	WWB LMS	SMB RLH LMS	WWB LMS	WWB LMS
Major oxides—Continued																	
SiO_2	72.36	72.77	54.3	56.0	57.4	57.5	60.6	61.3	61.4	64.4	65.6	65.6	68.2	75.4	76.0	46.0	61.0
Al_2O_3	13.75	13.29	18.0	15.6	18.2	17.4	15.4	16.3	16.5	16.0	14.1	15.6	11.4	13.0	12.8	18.5	18.6
Fe_2O_3	.59	1.48	1.7	2.1	2.0	2.2	2.7	2.1	2.6	2.1	4.5	2.1	2.3	.5	.0	6.1	3.9
FeO	2.33	1.55	7.8	4.8	5.0	5.2	5.6	6.0	5.4	4.1	2.2	3.4	6.0	.8	1.3	5.0	1.2
MgO	.09	.08	3.8	8.8	4.0	3.8	2.0	1.6	2.2	1.2	2.0	.71	3.8	.22	.09	5.4	1.1
CaO	1.53	1.27	7.9	7.7	7.7	6.9	3.5	5.6	5.6	4.2	2.8	3.4	.94	1.2	.91	11.9	6.5
Na_2O	4.64	4.72	3.4	2.4	2.9	3.6	5.4	4.6	4.3	4.5	6.1	4.2	3.5	3.5	3.5	2.6	4.2
K_2O	4.16	4.06	1.0	1.6	1.4	1.7	2.2	1.7	1.6	2.6	1.5	2.8	.51	3.9	4.7	1.6	2.9
H_2O+	.27	.10					1.07					.81					
H_2O-	.03	.02	[3] —.20	[2] .03	[2] .20	[2] .24	.31	[3] —.51	[3] —.29	[3] —.11	[2] 1.4	.31	[2] 3.1	[2] 2.2	[2] .48	[3] —.29	[2] .08
CO_2	------	------					.07					.07					
TiO_2	.21	.21	1.2	.66	.90	1.2	1.0	1.0	1.1	.82	.75	.78	.72	.16	.18	1.4	.53
P_2O_5	.06	.06	.32	.17	.16	.4	.43	.42	.18	.23	.20	.27	.08	.06	.02	.36	.28
MnO	.09	.10	.18	.12	.10	.10	.15	.20	.17	.16	.11	.12	.24	.02	.02	.17	.16
Total	100.11	99.71	99.60	99.98	99.96	100.24	100.43	100.82	101.05	100.31	101.26	100.17	100.79	100.96	100.0	99.63	100.45
Powder sp. gr	[4] 2.4	[4] 2.4	2.79	2.88	2.81	2.84	2.76	2.59	2.67	2.59	2.71	2.48	2.71	2.46	2.61	2.86	2.60
Minor elements [5]—Continued																	
	KJM	------	ATM	------	ATM	AC	ATM	------	------	------	------	ATM	------	ATM	AC	ATM	AC
Zr	0.02	------	0.007	------	0.005	0.007	0.008	------	------	------	------	0.02	------	0.008	0.02	0.006	0.009
Ga	.001	------	.001	------	.0008	.002	.001	------	------	------	------	.001	------	.0008	.0009	.001	.002
La	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Sc	------	------	------	------	------	.002	------	------	------	------	------	------	------	------	.0003	------	.0002
Y	.01	------	.004	------	.002	.004	.004	------	------	------	------	.006	------	.002	.003	.004	.0009
Yb	------	------	------	------	------	.0003	------	------	------	------	------	------	------	------	.0003	------	.00009
B	.006	------	.002	------	.002	.002	------	------	------	------	------	.002	------	.008	------	------	.001
Be	.0005	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

Sr	.02		.05		.03	.06	.03					.03		.02	.01	.08	.07
Ba	.09		.02		.05	.02	.06					.06		.07	.05	.06	.1
Pb	.005																
Mo						.0006											.0002
Cu	.004		.009		.006	.005	.003					.003		.0008	.0008	.01	.0007
V	.001		.02		.01	.02	.02					.002			.002	.03	.008
Cr	.0003		.0007		.007	.01	.0003								.0001	.002	.0002
Ni			.001		.004	.003	.001								.0001	.003	.0001
Co			.002		.002	.003	.001					.0007			.0001	.002	.0008
Nb						.002											
Total	.1618		.1167		.1208	.1409	.1283					.1266		.1096	.0876	.1980	.1932
Norms—Continued																	
Q	25.2	27.0	5.1	6.0	11.3	9.2	9.5	12.6	14.0	16.5	17.2	21.3	35.2	37.5	35.0		12.4
C												.2	3.8	1.0	.5		
or	24.6	24.5	6.1	9.4	8.3	10.0	12.8	10.0	9.5	15.6	8.9	16.7	2.8	22.8	27.8	9.4	17.2
plag ab	39.3	39.8	28.8	20.4	24.6	30.4	45.6	38.8	36.2	38.3	51.4	35.6	29.3	29.3	29.3	18.7	35.6
plag an	4.4	2.8	30.6	27.0	32.3	26.4	11.4	18.9	21.1	15.6	6.7	14.7	3.9	5.6	4.2	33.9	23.1
ne																1.9	
di wo	1.2	1.2	2.9	4.4	2.2	2.1	1.2	2.6	2.4	1.6	2.7					9.6	3.0
di en	.1	.17	1.3	3.1	1.3	1.2	.5	.9	1.2	.7	2.3					7.4	2.6
di fs	1.2	1.1	1.6	.9	.8	.8	.7	1.7	1.2	.9						1.2	
hy en	.2	.03	8.2	18.9	8.7	8.3	4.5	3.1	4.3	2.3	2.7	1.8	9.5	.5	.2		.1
hy fs	2.4	.22	9.5	5.3	5.3	5.0	5.9	6.2	5.0	3.8		3.4	8.3	.8	2.0		
ol fo																4.3	
ol fa																.7	
mt	.9	2.1	2.6	3.0	3.0	3.3	3.9	3.0	3.7	3.0	5.3	3.0	3.3	.7		8.8	2.5
il	.4	.4	2.4	1.2	1.5	2.3	2.0	2.0	2.1	1.5	1.4	1.5	1.4	.3	.5	2.7	1.1
hm											.8						1.9
ap	.1	.1	.7	.3	.3	1.0	1.0	1.0	.3	.5	.4	.7	.3	.2	.07	.8	.7
cc												.2					
Total	100.0	99.42	99.8	99.9	99.6	100.0	99.0	100.8	101.0	100.3	99.8	99.1	97.8	98.7	99.57	99.4	100.2
Niggli values—Continued																	
si	372	384	148	141	167	169	207	203	200	240	248	270	286	471	473	105	204
al	42	42	29	23	31	30	31	32	31½	35	31½	38	28	48	47	24½	37
fm	13	13	37	47½	34	35	33½	30	32	26	31½	23	52½	8	7½	38	19
c	8	7	23	21	24	22	13	20	19½	17	11	15	4	8	6	29	24
alk	37	38	11	8½	11	13	22½	18	17	22	26	24	15½	36	39½	8½	20
k	.37	.37	.17	.30	.24	.24	.21	.20	.20	.28	.14	.31	.08	.42	.47	.29	.31
mg	.05	.05	.42	.70	.51	.48	.30	.26	.34	.26	.36	.18	.45	.23	.10	.48	.25
qz	124	134	4	7	23	17	17	27	32	50	44	74	124	227	215	−29	24

See footnotes on page 284.

[1] These constituents determined by W. W. Hommel (WWH), Ledoux and Co.
[2] Ignition. Includes gain due to oxidation of FeO.
[3] Gain due to oxidation of FeO greater than losses of volatile constituents; not included in totals.
[4] Inferred from bulk specific gravity.
[5] Also looked for but not found within the limits of spectrographic determination for the particular element: Ag (.0001), Cd (.005), Zn (.01), Sn (.002), As (.005), Sb (.01), Bi (.001), Ge (.001), In (.001), Tl (.005), and Re (.005).

1. Olivine-rich basalt flow (45-95) of Ashishik basalt at Cape Idak (lat 53°31.4′ N., long 167°47.8′ E.).
1A. Olivine-rich basalt flow (46 ABy 531) of Ashishik basalt 0.1 mile south of Cape Idak.
2. Plagioclase-olivine basalt flow (46 ABy 92) of Mount Tulik. Lat 53°22.4′ N., long 167°04.3′ E., 3,000 feet S. 80° W. of summit.
3. Palagonitized tuff cone (46 ABy 132) of early postcaldera pyroclastic rocks within Okmok caldera. Lat 53°26.4′ N., long 168°05.0′ E., 1 mile northeast of cone *D*. Specimen collected from palagonitized bed near summit.
4. Anorthite-augite-olivine basalt flow (46 AFr 28) of Ashishik basalt. Lat 53°25.7′ N., long 167°55.5′ E., 3 miles N. 25° W. of Umnak Airfield. Specimen collected from lower middle of flow.
5. Anorthite basalt flow (46 ABy 609) near Inanudak Bay. Specimen collected at lat 53°17.7′ N., long 168°21.3′ E., from sea cliff S. 25° E. of cinder cone.
6. Anorthite basalt flow (46 AHp 68) extruded in December 1945 from cone *A*. Lat 53°24.7′ N., long 168°11.0′ E., 6,000 feet northwest of cone.
7. Bytownite-augite-olivine basalt flow (46 ABy 29), a subaerial flow of cone *D*. Specimen collected at lat 53°25.6′ N., long 168°05.8′ E., on south-southeast slope, altitude 1,900 feet.
8. Palagonitized scoria bed (45-73) from Ashishik basalt. Lat 53°21.2′ N., long 168° 17.0′ E.
9. Augite basalt flow (46 ABy 70) of Ashishik basalt in lower part of Okmok caldera wall. Lat 53°27.3′ N., long 168°05.5′ E.
10. Flow no. 2 (46 ABy 45) of Crater Creek basalt. Lat 53°28.5′ N., long 168°05.0′ E. in northwest wall of Crater Creek gorge.
11. Flow no. 11 (46 ABy 54) of Crater Creek basalt. Lat 53°28.7′ N., long 168°04.6′ E. in northwest wall of Crater Creek gorge.
12. Hydrothermally altered plagioclase basalt (47 ABy 44) from volcanic rocks of central Umnak. From cliff (lat 53°17.1′ N., long 168°19.8′ E.) just south of Air Force hut near Inanudak Bay.
13. Lower welded andesitic agglomerate bed (46 ABy 13) in Okmok volcanics exposed in upper part of north wall (lat 53°28.3′ N., long 168°08′ E.) of Okmok caldera. Sample taken to exclude most xenolithic fragments.
14. Older basaltic andesite flow (46 ABy 6) from cone *B* in Okmok caldera. Near front of flow at lat 53°27.6′ N., long 168°07′ E.
15. Aphyric andesite pipe (46 ABy 63) of vitreous andesite. Near top of pipe (lat 53°28.0′ N., long 168°05.4′ E.) at intersection of southeast wall of Crater Creek gorge and Okmok caldera.
16. Upper welded andesitic agglomerate bed (46 ABy 15) in Okmok volcanics exposed in upper part of north wall (lat 53°28.3′ N., long 168°08′ E.) of Okmok caldera. Sample taken to exclude most xenolithic fragments.
17. Vitreous latite fragment (46 AFr 2) in Okmok volcanics. From bank of Crater Creek (lat 53°32.6′ N., long 167°59.2′ E.) near Cape Tanak.
18. Rhyodacite pumice lapilli bed (47 ABy 26) near base of Okmok pyroclastics. Sea cliff (lat 53°33.5′ N., long 168°04.9′ E.) 0.6 mile S. 10° E. of Ashishik Point.
19. Rhyolite obsidian band (46 ABy 30a) in rhyolite from northeastern Umnak (lat 53°29.5′ N., long 168°10.3′ E.).
20. Felsitic rhyolite facies (48 Um 11) in east end of rhyolite from northeastern Umnak (lat 53°29.4′ N., long 168°09′ E.).
21. Basaltic andesite flow (47 ABy 73) of Mount Vsevidof from Twin Lava Point (lat 53°11.1′ N., long 168°47.7′ E.)
22. Quartz-bearing olivine andesite flow (47 ABy 10). North-facing cliff (lat 53°13.6′ N., long 168°21.9′ E.), south of Hot Springs Cove.
23. Hypersthene-bearing labradorite andesite flow (47 ABy 9) of Mount Recheschnoi. lat 53°13.8′ N., long 168°22.0′ E., south of Hot Springs Cove.
24. Quartz diorite (47 ABy 41) facies of plutonic rocks (lat 53°16.1′ N., long 168°34.9′ E.), 1¼ miles S. 70° E. of Cape Ilmalianuk.
25. Albitized diorite (47 ABy 34) in albitized sedimentary and igneous complex. Specimen collected from shoreline (lat 52°51.8′ N., long 169°00.1′ E.) south of Elbow Hill.
26. Andesitic glass clot (47 ABy 72) in dark scoria bed of Mount Vsevidof cone. Specimen collected at an altitude of 4,000 feet on north slope of cone (lat 53°07.7′ N., long 168°41.3′ E.).
27. Hypersthene-bearing andesite flow (47 ABy 57) of Mount Recheschnoi. South slope at lat 53°05.3′ N., long 168°28.5′ E.
28. Historic(?) latite flow (47 ABy 36) of Mount Vsevidof. Front of flow (lat 53°07.7′ N., long 168°46.6′ E.) on west slope of Mount Vsevidof.
29. Quartz keratophyre (47 ABy 29) in albitized sedimentary and igneous complex. From headland (lat 53°02.4′ N., long 168°30.0′ E.) east of Amos Bay.
30. Rhyodacite pumice bed (47 ABy 67) that forms uppermost bed of Mount Vsevidof cone. Altitude, 1,700 feet on north slope of cone (lat 53°09.7′ N., long 168°41.7′ E.).
31. Argillite bed (47 ABy 54) in albitized sedimentary and igneous complex. From bedded sequence (lat 53°07.7′ N., long 168°22.4′ E.), 1 mile southwest of Russian Bay.
32. Rhyolite dome (47 ABy 28). From middle dome (lat 53°10.2′ N., long 168°25.1′ E.) on west side of valley that drains into Russian Bay.
33. Granophyre dike (47 ABy 39A) that cuts plutonic rocks. From sea cliff (lat 53°16.2′ N., long 168°36.9′ E.) ¾ mile southwest of Cape Ilmalianuk.
34. Bytownite-salite-hornblende basalt dome (47 ABy 100) extruded in 1927. Specimen collected at lat 53°56.1′ N., long 168°02.5′ E.
35. Andesine-hornblende andesite dome (47 ABy 103) (Old Bogoslof) extruded in 1796. Specimen collected in saddle of Castle Rock (lat 53°55.8′ N., long 163°02.3′ E.) at an altitude of 100 feet.

GEOLOGY OF UMNAK

GENERAL FEATURES

The oldest rocks of the island, exposed only in the southwest part (pls. 39 and 40), include an albitized sedimentary and igneous complex intruded by plutonic rocks. These rocks have been deformed, and deeply eroded. The age of the sedimentary rocks of the complex is middle Tertiary or older; the plutonic rocks are post-Oligocene. Upon a basement of these rocks, volcanic edifices have been built around four main centers of activity. The oldest of the centers is in the isthmus region of Umnak; the rocks are called the volcanic rocks of central Umnak. The initial forms of the volcanoes have been completely destroyed by erosion. The volcanic rocks of central Umnak probably include lavas that range in age from middle Tertiary to early Quaternary. The hypersthene andesite of Mount Recheschnoi, of probable Quaternary age, overlies the volcanic rocks of central Umnak on the southwest. The largely Recent symmetrical cone of Mount Vsevidof, consisting of basaltic andesite, andesite, and rhyodacite, buries the hypersthene andesite on the western slope of Mount Recheschnoi. Mount Vsevidof has been active in historic time. Okmok Volcano (pls. 39 and 41) lies northeast of the isthmus, and its rocks make up almost all of northeastern Umnak. Most lavas of Okmok Volcano are porphyritic to aphyric feldspathic basalts. The early activity of Okmok Volcano probably was simultaneous in part with that at Mount Recheschnoi but has persisted to the present.

ALBITIZED SEDIMENTARY AND IGNEOUS COMPLEX

DISTRIBUTION AND THICKNESS

The oldest rocks of Umnak Island include bedded argillite and tuff, keratophyre flows, albitized diabase sills, and irregular intrusive bodies exposed near sea level in the southwest tip and along the south-central coast of the island (pl. 40). In contrast to the younger rocks of the island, these rocks are deformed and characteristically show the effects of low grade metamorphic alteration. West and southwest of Kigul Island, the lake-studded rolling plain of southernmost Umnak is underlain by gently dipping flows of keratophyre, subordinate beds of argillite and tuff, and albitized gabbro or diorite. Sections of bedded argillite and tuff are exposed along the east shore of Nikolski Bay, in the north and east shore of Driftwood Bay, and in a small coastal outcrop 1½ miles northeast of Lookout Point. Albitized intrusive rock is exposed in two small headlands at 2 and 3 miles southwest of Russian Bay, and bedded argillite and tuff with minor sills and dikes of albitized diabase crop out along the coast from the west shore of Russian Bay to the north shore of Partov Cove.

The total thickness of the complex is unknown. About 5,000 feet of northeasterly dipping argillite, tuff, and albitized diabase sills are exposed along the shore northeast of Partov Cove, but parts of this sequence may be repeated by faulting.

STRUCTURE

The little that is known about the structure of the albitized sedimentary and igneous complex is included here with the stratigraphic descriptions, mainly because the structural features described below are confined to these oldest rocks and in part define them. The general strike of the sedimentary rocks is northwest in the largest area of their exposure near Russian Bay and Partov Cove (pl. 40), and dips range from 13° NE to vertical. Near Lookout Point, the sedimentary rocks dip 15° SE. Dips at the head of Driftwood Bay suggest an anticline plunging southeast. The sedimentary rocks north of Nikolski village, and the extensive keratophyre flows near Amos Bay, are nearly horizontal. No major faults were mapped in the field, but a few inferred faults in areas underlain by the albitized sedimentary and igneous complex have been mapped from well-defined alinements of swales, gullies, and lakes seen on the air photographs. The northwesterly strike of the sedimentary rocks suggests that axes of folds in these rocks cut across the northeasterly trend of the Aleutian arc, whereas the lineaments mapped from air photographs and the general elongation of the island parallel the trend of the arc.

RELATION TO YOUNGER ROCKS

In the few good exposures, the contact between albitized sedimentary and igneous complex and the other extrusive and sedimentary rocks of the island is one of angular erosional unconformity. That this relationship is general is indicated by the fact that major deformation is confined to the older rocks, and that the replacement of primary intermediate plagioclase by albite is confined to these rocks.

PETROGRAPHY

ARGILLITE

The argillite varies from massive dark-gray bands 1 to 3 inches thick, to laminated argillite made up of randomly alternating thin beds of light-gray siltstone and laminae of medium-dark-gray argillite as much as one-eighth of an inch thick. The massive bands of argillite have small joints that form a crude rectangular pattern, parallel and perpendicular to the major fold axes. Thin calcite veinlets as much as one-sixteenth of an inch thick are found along many of the joints. The laminated argillite has a shaly parting, along which many dark carbonaceous patches suggestive of leaf fragments are found. One specimen of argillite collected southwest of Russian Bay (pl. 40) contains a few small angular detrital fragments of plagioclase crystals and rare fragments of quartz in a fine-grained groundmass of cherty and feldspathic material whose index of refraction is near that of albite. Patches and veinlets of calcite are common. The chemical analysis of this specimen is given in column 31, table 2.

TUFF

Greenish water-laid tuff interbedded with the argillite ranges from moderate yellow green to slightly different shades of greenish gray. The grain size ranges from fine to coarse with a few grains as much as 1 millimeter. Three specimens from near Partov Cove are highly altered crystal tuffs in which fragments of the former pyroxene and plagioclase have been largely replaced by chlorite and albite respectively. A specimen from Driftwood Bay (pl. 40), however, contains fragments of unaltered pyroxene and labradorite, as well as fragments of quartz crystals. Calcite is common in scattered patches in all specimens. The groundmass is an aggregate of chlorite, calcite, albite, an unidentified zeolite mineral, and other unidentifiable light-colored, cloudy material. Pyrite is rare in the specimens from near Partov Cove, but absent from the Driftwood Bay specimen.

ALBITIZED INTRUSIVE ROCK

Three varieties of albitized intrusive rock include albitized diorite or gabbro, an albitized porphyritic rock, and albitized diabase. The albitized diorite is exposed near the southwestern tip of Umnak, chiefly at Elbow Hill (pl. 40). The albitized porphyritic rock is from a thick sill or flow near Amos Bay, and the albitized diabase occurs as sills, 2 to 10 feet thick, in the sedimentary rocks at Russian Bay and Partov Cove. Each is altered to a different degree from a rock probably of original gabbroic or dioritic composition.

The albitized diorite near the southwest end of Umnak is the least altered of the three rocks. The plagioclase is mostly unzoned albite, but includes a few irregular-shaped relics of andesine (pl. 42*A*). Apatite needles are in both the andesine and the albite. The albite is clouded with aggregates of fibrous rosettes of sericite. A few small (less than 0.5 mm), clear crystals of plagioclase are zoned normally from a center of andesine-oligoclase to a rim of albite. Some of these are veined with albite, potassium feldspar, and a zeolite mineral. A few larger areas intersertal to the plagioclase contain cloudy potassium feldspar intergrown with quartz. The mafic minerals are largely intersertal to the feldspars. Anhedral patches of augite in places are intergrown with or replaced by green amphibole and greenish biotite dusted with opaque oxides. Chemical and petrographic analyses of this rock are given in column 25, tables 2 (p. 282 to 284) and 3 (in pocket), respectively.

The albitized porphyritic rock near Amos Bay contains albite that has entirely replaced the former plagioclase of both phenocrysts and groundmass. Patches of quartz and potassium feldspar are similar to the Elbow Hill rock. Many subhedral and anhedral pyroxene grains are unaltered, but some augite is intergrown with, or replaced by, greenish biotite and high-iron chlorite. Small albite laths, shreds of green biotite and chlorite, and anhedral quartz and potassium feldspar, all dusted with opaque oxides, make up the groundmass. Chemical and petrographic analyses of the rock are listed in column 29, tables 2 and 3, respectively.

The diabasic sills at Partov Cove show evidence of both albitization and potassium feldspathization, as might be expected from their proximity to areas of intensely potassium feldspathized rock near the narrow part of Umnak. The feldspar in the most altered specimen is all clouded albite, in places cut by veinlets of chlorite and calcite. No pyroxene is present, but the space interstitial to the plagioclase is entirely occupied by calcite, chlorite, opaque oxides including some hematite, rare epidote, and pyrite. A few veinlets of quartz cut through all minerals. Optical data on the chlorite (alpha, 1.612, colorless; gamma, 1.618, light green) are indicative of high iron, suggesting prochlorite or ripidolite (Winchell, 1933, pt. 2, p. 284).

KERATOPHYRE

The keratophyre lava flows exposed between Amos and Driftwood Bays are greenish gray, specked with dark grains of opaque oxide, and more abundant, larger white phenocrysts of albite, 1 to 3 mm long. Some contain a few clear colorless calcite crystals of the same size and shape. Two specimens described in detail are representative of these flows.

A specimen of fine-grained, greenish-gray keratophyre near Black Cape (pl. 40) is specked with grains of opaque oxide and mottled with white phenocrysts of albite and sparse clear, colorless crystals of calcite. In thin section, the phenocrysts are seen to be unzoned albite, flecked with wisps of sericite and minute rods of apatite. The groundmass is largely albite crystals (0.05 mm), patches and shreds of chlorite, opaque oxide euhedra, and rare anhedral potassium feldspar. Quartz and calcite are associated in patches and veinlets.

A specimen of hydrothermally altered (potassium feldspathized) keratophyre collected east of Partov Cove contains evidence of two periods of alteration. The former plagioclase phenocrysts are now albite remnants largely replaced by calcite, sericite, and quartz (pl. 42 *B*). The groundmass is an aggregate of chlorite, sericite, quartz, adularia(?), a low index zeolite and an opaque white mineral. The later type of alteration that has occurred is completely different from the regional albitization and is typical of later, locally intense hydrothermal alteration of the volcanic rocks of central Umnak in the Inanudak Bay area (see p. 295 to 296).

AGE AND CORRELATION

Carbonized impressions suggestive of leaf fragments have been seen on bedding planes of the argillite. Botanist Eric Hultén (1937, p. 22) also reports fragments of coal in what he calls slate, presumably the bedded argillite of this investigation. Carbonaceous, coaly argillite or mudstone deposits that have yielded plant fossils elsewhere in the Aleutian Islands and the Alaska Peninsula, have generally, though not always, proved to be early Tertiary. Bedded argillite and tuffaceous graywacke, similar in degree of metamorphism and deformation to the rocks of Umnak, are late Paleozoic in age on Adak Island (Coats, 1956) and early Tertiary on the Alaska Peninsula (Knappen, 1929, p. 182–198), Kodiak Island, and the Kenai Peninsula (Capps, 1937, p. 138–153). A sequence of bedded argillite and tuff similar to that on Umnak has also been mapped by members of the Geological Survey party along the south coast of Unalaska about 30 miles to the northeast; carbonized remains were likewise found in these rocks but were unidentifiable (G. D. Fraser, oral communication, 1955). Vertebrate-fossil remains, chiefly teeth, have been found in greenish volcanic graywacke exposed in a quarry on the north side of Unalaska. These teeth were identified by G. Edward Lewis (written communication, 1954) as those of *Cornwallius* sp., a marine mammal of early Miocene age. Both the fossiliferous graywacke and the argillite of Unalaska, like the argillite of Umnak, are intruded by plutonic rocks. The albitized sedimentary and igneous complex of Umnak is therefore probably early to middle Tertiary, but may possibly include older rocks.

PLUTONIC ROCKS

GEOLOGIC RELATIONS

Coarse-grained dioritic rock is found in five small, widely separated areas around the margins of Mount Recheschnoi and Mount Vsevidof (pl. 40). The lava flows of these two volcanoes and the unaltered flows of the volcanic rocks of central Umnak rest on eroded surfaces in the dioritic rock. It intrudes the bedded argillite and tuff sequence and contains blocky xenoliths of these sediments in the area on the southeast slope of Mount Recheschnoi. Most of the rock is quartz diorite, but the composition ranges from diorite to quartz monzonite. Dikes and stringers of granophyre cut altered plutonic rock on the west side of Cape Ilmalianuk. The coarse, even grain of the quartz diorite and its similarity to that of batholithic quartz diorite on Unalaska indicate a rather large plutonic body. The distribution of its few outcrops suggests that it may underlie much of the area of the two younger volcanoes.

The plutonic rocks on Umnak and Unalaska are so similar petrographically and so closely parallel in range of composition and in geologic relations that they must certainly belong to the same intrusive episode. The plutonic rocks on Unalaska are intrusive into beds that, as noted above, are now known to be of early Miocene age. Thus the plutonic rocks can be no older than early Miocene. An upper age limit may be inferred from the fact that large areas of the plutonic rocks have been laid bare by erosion and subsequently covered by unaltered lava flows of central Umnak, which are probably early Pleistocene but may be as old as Pliocene. The erosion of the plutonic rock, prior to extrusion of the Pliocene and Pleistocene lavas, must have taken part of the Pliocene epoch so that the youngest possible age of the plutonic rocks would be mid-Pliocene. On the basis of present evidence, the plutonic rocks were most likely intruded sometime during middle to late Tertiary time.

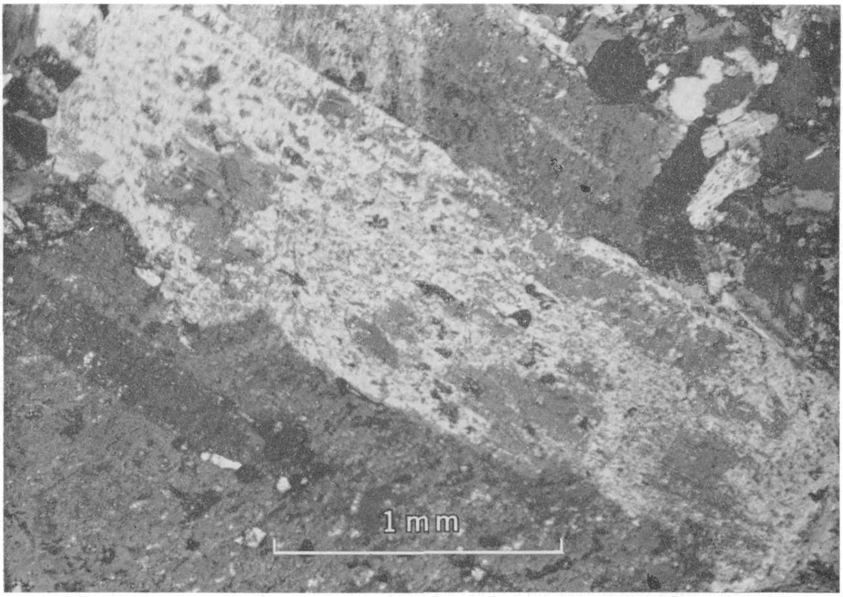
PETROGRAPHY

DIORITE

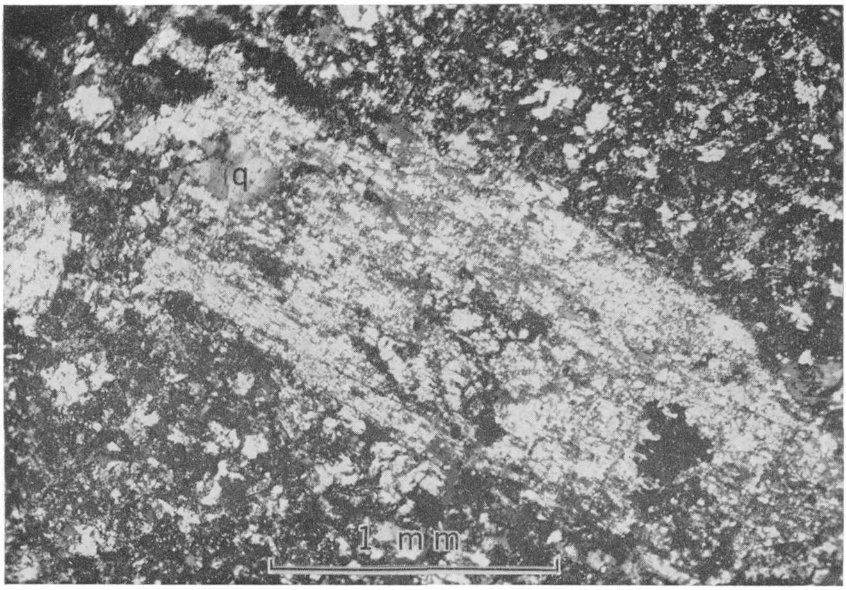
A specimen of gray diorite from the small knob 4½ miles south of Mount Vsevidof has an average grain size of about 1 mm. A few veinlets of light-gray granophyre cut the diorite, which is slightly altered adjacent to the veinlets. As seen in thin section the texture of the diorite (column 1, table 4) is hypidiomorphic granular except for a little interstitial micrographic intergrowth of quartz and orthoclase. A few plagioclase grains are veined with orthoclase and to less extent with biotite. Orthoclase appears as rare irregular wisps in the plagioclase. Dusty fragments of biotite and sericite are common, and radiating sheaflike aggregates with the birefringence and relief of prehnite are rare as inclusions in the feldspar. Augite remnants are enclosed by the hornblende and biotite, and hornblende remnants in turn are enclosed and apparently replaced by biotite. Apatite is found as sparse tiny needlelike laths, as larger euhedra up to 0.3 mm long, and as anhedral grains 0.2 mm in diameter.

QUARTZ DIORITE

Fresh, granular quartz diorite is the most common plutonic rock type on southwestern Umnak. It is similar to the quartz diorite that forms the large intrusive body on nearby Unalaska Island (Becker, 1898, p. 42). The quartz diorite of southwestern Umnak has an



A. Photomicrograph of composite plagioclase crystal in albitized diorite (column 25, table 2). Discontinuous, low birefringent (darker in picture) "islands" are andesine remnants surrounded by albite that replaced original andesine of rock. Crossed nicols.

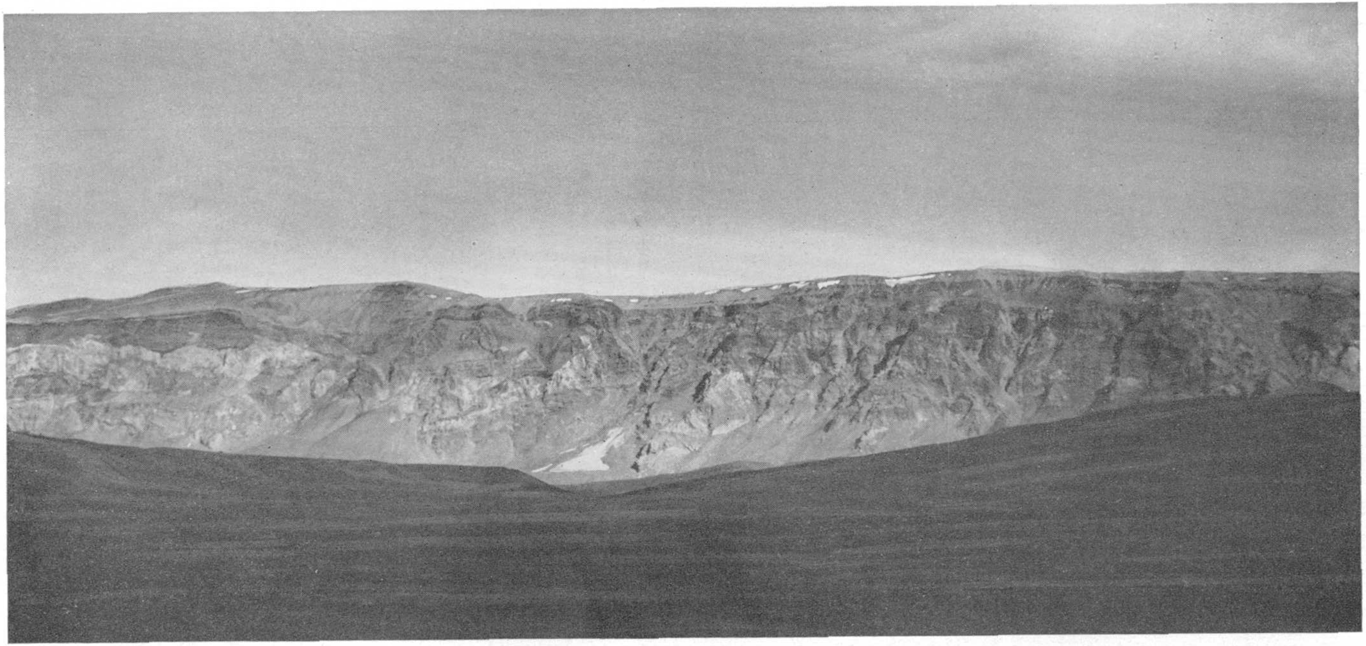


B. Photomicrograph of partly replaced albite phenocryst in hydrothermally altered (potassium feldspathized) keratophyre. Quartz (*q*) and calcite-service (*light aggregates*) have replaced earlier albite. Crossed nicols.

Photomicrograph of plagioclase crystals veined and corroded by orthoclase in altered quartz diorite (specimen no. 47ABy39) bordering granophyre dikes. Crossed nicols.

Mount Vsevidof from the south

Steep-sided pyroclastic cone and flows forming moderate slope at the base. Drained lava channels in center middle background apparently formed when lava flowed over a now-buried, eroded cliff of older rocks. Glacial-outwash plain in foreground.



View of east wall of Okmok Caldera, showing precaldera rocks, largely palagonitized rocks of Ashishik basalt, overlain by bedded Okmok volcanics.

TABLE 4.—*Petrographic analyses of plutonic rocks*

[Modal analyses in volume percent]

	1	2	3	4
Chemical analysis number (table 2)	----------	24	----------	33
Mode in volume percent:				
Quartz	4.0	10.2	15.8	28.6
Potassium feldspar (cloudy)	9.7	5.9	28.1	43.7
Plagioclase	64.5	64.9	44.5	24.7
Biotite (includes sparse chlorite)	7.4	8.4	[1] 4.7	.3
Hornblende	4.4	3.2	5.6	.0
Augite	4.1	5.4	.4	[3] 2.6
Hypersthene	.0	.2	.0	.0
Apatite	.8	.3	.1	.01
Opaque oxides	2.0	1.5	.8	.1
Micropegmatite	3.0	[4] .1	----------	([2])
Range in composition of plagioclase	An_{5-50}	An_{27-59}	An_{6-46}	An_{6-16}
Bulk specific gravity of rock	2.7	2.82	2.72	2.58

[1] Includes considerable chlorite, some epidote, and rare prehnite(?).
[2] Rock largely micrographic intergrowth of quartz and potassium feldspar; minerals listed separately above.
[3] Epidote.
[4] Myrmekite.

1. Diorite from small knob surrounded by recent flow, 4½ miles south of Mount Vsevidof.
2. Quartz diorite from sea cliff, 1⅛ miles southeast of Cape Ilmalianuk.
3. Quartz monzonite from sea cliff, Cape Ilmalianuk.
4. Granophyre, from sea cliff, three-fourths of a mile, southwest of Cape Ilmalianuk.

average grain size of about 2 mm and consists of dominant, medium-dark-gray plagioclase as much as 8 mm long, minor light-gray to light-pinkish-gray orthoclase, inconspicuous quartz, and mafic minerals, of which biotite is most abundant and easily recognizable (column 2, table 4). Quartz and orthoclase occur interstitially to the subhedral to euhedral plagioclase. Myrmekite occurs on lobate ends of several large plagioclase crystals and also on irregular borders along the 010 face, where islands of myrmekitic plagioclase surrounded by orthoclase extinguish in sequence with the nearby mainland plagioclase. The plagioclase of the myrmekite is calcic oligoclase. Augite and rare hypersthene occur as corroded remnants enclosed by hornblende and biotite. Biotite occurs as individual grains ranging down to submicroscopic size, as an interstitial mineral with quartz and orthoclase, as reaction rims around pyroxene and hornblende, and as veinlets cutting pyroxene. Opaque oxides are chiefly associated with biotite and in part appear to replace it. A minor amount of chlorite has replaced biotite, and sericite(?) is rare as tiny wisps in the feldspar. Apatite is scattered as rod-shaped inclusions in the other minerals. The chemical analysis of this specimen is given in table 2, column 24.

QUARTZ MONZONITE

The quartz monzonite is a facies of the quartz diorite and was observed only on Cape Ilmalianuk. In hand specimen the rock differs from the quartz diorite in the greater abundance of pink orthoclase and light-gray oligoclase. The hornblende and biotite are stained green with chlorite and epidote. The hand specimen appears distinctly granitoid, although quartz is not conspicuous. The quartz monzonite (column 3, table 4) as seen in thin section resembles the quartz diorite except for differing proportions of the minerals. Quartz and orthoclase appear interstitial, but show only a very slight tendency toward graphic intergrowth. Some oligoclase crystals are veined and contain irregular wisps of orthoclase as well as specks of calcite(?) and tiny flakes of sericite(?). A little of the orthoclase is perthitic. Augite remnants are sparse and contain reaction rims of hornblende and biotite. About half the biotite has altered to chlorite. Anhedral opaque oxides are associated with hornblende and biotite and appear to replace them. Minor epidote and rare prehnite(?) also appear as alteration products of the biotite.

GRANOPHYRE

Pinkish-gray granophyre (column 4, table 4), as dikes and narrow stringers, cuts the quartz diorite on the west side of Cape Ilmalianuk headland. The texture of the rock is largely micrographic superposed on an allotriomorphic texture. Each larger granular unit contains uniformly oriented quartz grains that differ in orientation from grains in a neighboring unit. A few larger grains of quartz, orthoclase and albite-oligoclase are not micrographically intergrown. Epidote is in aggregates interstitial to the other minerals. The biotite is largely altered to chlorite. Rare needlelike inclusions of apatite are in the quartz and feldspar. Actinolite also occurs as sparse aggregates. The chemical analysis of this specimen is listed in column 33, table 2.

ALTERED CONTACT ROCK

An altered monzonitic rock borders the granophyre dikes and extends for some distance on either side. The altered rock is invaded by smaller stringers of granophyre at closely spaced intervals. The contact with the granophyre is gradational, and the alteration within the monzonitic contact rock is variable. Streaks of pinkish-gray rock with spots of mafic minerals alternate with streaks of mottled light-greenish-gray epidotized feldspar and pinkish-gray orthoclase. The streakiness in general parallels the approximate border of the granophyre dike. Dark-greenish actinolitic hornblende as much as 3 mm in length shows slight segregation in bands parallel to the feldspathic streaks but shows no visible lineation. As seen in thin section, the rock has a variable texture. An allotriomorphic texture involves chiefly quartz and orthoclase with minor albite-oligoclase and grades into a micrographic intergrowth of quartz and potassium feldspar and also into poikilitic intergrowths of small quartz grains in potassium feldspar. A few formerly euhedral andesine and calcic oligoclase crystals have relict outlines and are veined and corroded by potassium feldspar and albite-oligoclase (pl. 43). Much of the plagioclase contains fine to coarse aggregates of epidote, probably derived from the decomposition of the more calcic plagioclase.

VOLCANIC ROCKS OF CENTRAL UMNAK

GEOLOGIC RELATIONS

Lava flows, vent breccias and associated irregular shallow intrusive bodies crop out over a large area in the narrow central part of Umnak Island. These rocks are herein grouped together as the volcanic rocks of central Umnak. The original constructional surface form of these volcanic rocks have been destroyed by erosion. Their original areal extent is not known because they are covered both to the northeast and to the southwest by Quaternary lavas of Okmok Volcano and Mount Recheschnoi, respectively. The volcanic rocks of central Umnak were in part erupted from several vents northeast of Hot Springs Cove (pl. 41).

These rocks include both hydrothermally altered and fresh unaltered volcanic rocks in each of the two map units: bedded volcanic rocks (QTv) and vent and intrusive complex (QTvp), as shown on plates 40 and 41. No contacts between altered and fresh unaltered volcanic rocks within the units were seen. The intensely silicified, potassium feldspathized rocks included as map unit QTvq, (pls. 40 and 41), consists of rocks so completely replaced by silica, potassium feldspar, and in places tourmaline, that the original rock type cannot be identified in hand specimen or thin section, though field relations indicate that most grades into rock included in the map unit, QTv.

Altered lava flows and vent complexes make up most of the isthmus terrain east and north of Hot Springs Cove (pl. 41). Breccias and irregular intrusive rocks, interpreted as old vent complexes, are found at several places in the isthmus. Volcanic necks of hydrothermally altered basaltic porphyry at Thumb Point (pl. 40), and High Hill, 2½ miles north of Nikolski, are included here. Areas of most intense alteration, mapped under the symbol, QTvq, are along the coastline just west of Hot Springs Cove and in the southwest wall of Bottleneck Pass (pl. 41). The base of the altered volcanic rocks has not been observed.

Unaltered hypersthene andesite flows considered part of this unit are found in several localities south and west of Hot Springs Cove (pl. 40). South of Hot Springs Cove these unaltered flows dip about 5° SW. under the similarly appearing hypersthene andesite flows from Mount Recheschnoi, which dip northeast and lie on an erosion surface cut on the volcanic rocks of central Umnak. Similar relations between unaltered lava flows of central Umnak and those of Recheschnoi are found at Broken Point, Geyser Bight, Partov Cove, Russian Bay, and in the west wall of the canyon 4 miles due south of the summit of Mount Recheschnoi. Along the Pacific coast at Partov Cove and Russian Bay, unaltered lava flows of this unit lie on an erosion surface cut on the albitized sedimentary rocks; on the Bering Sea coast at Broken Point and the west shore of Geyser Bight they lie on a plane erosion surface, possibly a raised marine bench, cut on the plutonic rocks; and west of Hot Springs Cove and along the south shore of Inanudak Bay they overlie hydrothermally altered lava flows and diorite in an irregular contact that was concealed or inaccessible for study in the field.

The nature of the contact between the altered and unaltered lavas of the volcanic rocks of central Umnak is unknown. Near the head of the easternmost fork of Geyser Creek (pl. 40), a patch of intensely altered rock, about 0.1 square mile in area, is just upstream from an area of borate-bearing hot springs, geysers, and fumaroles (Byers and Brannock, 1949, p. 728). This altered rock consists of a very fine-grained aggregate of quartz, chlorite, pyrite, and colorless minerals, possibly including adularia. The altered rock may here be related to hot-spring activity in the recent geologic past. Elsewhere, however, as near the isthmus of Umnak, larger areas of tourmalinized, silicified, potassium-feldspathized rock are not associated with hot springs and are also somewhat coarser grained than the altered rocks on Geyser Creek. The relation between the unaltered and altered volcanic rocks may be gradational, inasmuch as gradation was observed in the field and confirmed by the laboratory study of specimens from the southeast wall of Bottleneck Pass (pl. 41). On the west side of Hot Springs Cove (pl. 40), however, intensely altered rock is overlain by fresh, unaltered hypersthene andesite flows. The overlying fresh lava could hardly have escaped some alteration during the intense silicification and potassium feldspathization of the lower unit; hence, it is believed that a sharp contact, representing a significant period of geologic time, may be concealed between the altered and unaltered lavas at this place. Possibly the alteration is locally associated with buried plutonic rocks of the same age as those that now crop out at the surface.

AGE AND CORRELATION

The volcanic rocks of central Umnak, as shown on plates 40 and 41, include rocks that are probably older and unaltered lavas that are younger than the plutonic rocks. The altered volcanic rocks in many places on Umnak closely resemble rocks on Unalaska known to be intruded by the post-Oligocene plutonic rocks. The relations between the altered volcanic rocks and the albitized sedimentary and igneous complex are unknown, but from the petrographic evidence, the potash feldspathization of the altered volcanic rocks occurred later than the albitization of the complex; how much later remains an open question. The altered volcanic rocks therefore may range in age from early to middle Tertiary, though a still earlier age cannot be ruled out on present evidence. The unaltered lavas rest on the post-Oligocene plutonic rocks and are overlain by the Quaternary lavas of Recheschnoi and Okmok volcanoes; hence, the unaltered lavas of the volcanic rocks of central Umnak are late Tertiary or early Quaternary in age.

PETROGRAPHY AND CHEMICAL COMPOSITION

A volcanic neck at Thumb Point intrudes the albitized rock of the basement. Examination of a specimen from the basement rock adjacent to the neck indicates that it was first albitized and later potassium feldspathized (see p. 288). The rock of the neck, however, shows only potassium feldspathization. The rock is a dense, medium-dark-gray, sparsely porphyritic lava with greenish-gray spots resembling amygdules, but as seen in thin section former labradorite phenocrysts are much altered to chlorite and a zeolite. Former olivine phenocrysts are replaced by antigorite(?) and magnetite. The groundmass consists of andesine, magnetite, quartz veinlets (secondary), chlorite, and a cloudy white feldspar (index of about 1.52), probably adularia.

Fine-grained potassium feldspar was identified in several thin sections of the hydrothermally altered volcanic rocks of central Umnak. Partial chemical analyses were made of three specimens, progressively more altered, from the southwest wall of Bottleneck Pass (see pl. 41). The least altered specimen (column 12, tables 2 and 3) is representative of most of the hydrothermally altered lavas. Quartz, magnetite, chlorite, and serpentine in various proportions have replaced former olivine phenocrysts and portions of the groundmass glass. The chlorite is penninite. The serpentine mineral, more abundant than chlorite, is probably antigorite (α, colorless to faint yellowish green; γ pale green and parallel to fibers; birefringence, 0.015–0.020; indices variable, ranging from about 1.53 to 1.58). Zeolites, potassium feldspar, and calcite embay the primary plagioclase. The introduced zeolite minerals, identified on the basis of optical properties, are heulandite(?), chabazite(?), and natrolite. Amygdaloidal fillings of quartz and natrolite(?) are common.

A second specimen (12–A) collected about 0.7 mile southeast from the locality of the first specimen (column 12, table 2) and from apparently the same lavas, was originally a porphyritic lava. Secondary amphiboles, epidote, and sparse tourmaline have developed in addition to potassium feldspar, quartz, and zeolites. A fibrous actinolitic amphibole (uralite) like that in the granophyre replaces augite. A second amphibole fills druses with acicular crystals distinctly pleochroic from light green to bluish green. Epidote is common apparently in part as an alteration product of augite. Tourmaline, with strong greenish-blue absorption, has replaced plagioclase phenocrysts.

A third specimen (12-B) collected about 50 feet from the second, probably represents nearly the end stage of the potassium feldspathization. The original rock is no longer recognizable, but in the field it is gradational with rock whose relic texture indicates porphyritic lava. This rock is light colored, brown stained in weathered outcrop, and veined with quartz. Minute cubes of pyrite, 0.1–0.5 mm, are sparsely distributed. Small rosettes of black tourmaline, 1 to 2 mm long, appear to have preferentially replaced the former ferromagnesian minerals. All the secondary minerals observed in the less altered rocks are present, but quartz and potassium feldspar (adularia?) are much more abundant. Portions of the rock are completely replaced by potassium feldspar and vuggy vein quartz. The more compact, massive portions of the rock consist of dense cryptocrystalline aggregates of quartz, potassium feldspar, and zeolites.

Partial chemical analyses of the three specimens (table 5) show that potash has greatly increased in the most altered rock at the expense of soda, iron oxide, magnesia and lime. The abundance of quartz observed in the completely altered rock indicates that silica was likewise introduced, despite the slight drop in bulk specific gravity with progressive alteration. Sulfur, boron, and carbon dioxide have been fixed in the hydrothermally altered rocks in pyrite, tourmaline, and calcite, respectively.

TABLE 5.—*Partial analyses of hydrothermally altered (potassium feldspathized) volcanic rocks near Bottleneck Pass*

[Analyses of oxides in weight percent. For complete analysis of No. 12, see column 12, table 2. Alkalis of 12A and 12B, analyzed by E. J. Benton, Petrographic Laboratory, U. S. Bureau of Reclamation; total iron, lime, and magnesia of 12A and 12B, analyzed by Herbert M. Ochs, Denver, Colo.]

	12	12A	12B
Total Fe as FeO	7.3	5.5	3.2
MgO	3.4	3.0	.31
CaO	9.3	5.0	.45
Na_2O	2.8	2.3	1.9
K_2O	1.4	2.9	5.8
Bulk specific gravity	2.67	2.43	2.26

12. Slightly altered plagioclase basalt (47ABy44) collected just south of Bottleneck Pass (lat. 53°17.1′ N., long 168°19.8′ E).
12A. Moderately altered porphyritic lava (47ABy43A) from south side of Bottleneck Pass (lat. 53°16.7′ N, long 168°19.3′ E) about 0.7 mile southeast of No. 12. Outcrop areas occur as "islands" in 12B.
12B. Completely altered rock (47ABy43B) collected about 50 feet from 12A. Predominant rock of locality.

VOLCANIC ROCKS OF MOUNT RECHESCHNOI

GENERAL GEOLOGIC FEATURES

The volcanic rocks of Mount Recheschnoi occupy most of the width of the island west of the isthmus (pl. 40). The summit of Mount Recheschnoi is an east-west ridge of rugged aretes and divides, between cirques occupied by small glaciers. Most of the original surface of the summit area has been destroyed, but at lower altitudes large areas of original surface remain between the glaciated valleys. Projection of the slopes suggests that two major vents, separated by about 2 miles, were active in the construction of the volcano. The western part of the mountain is less cut up by glaciated valleys; possibly major activity at the western vent continued longer than at the eastern vent. Some glaciated valleys have been partly filled by lavas from the central vents, then reexcavated by continued glacial action. Products of a satellitic basaltic vent occupy about 6 square miles on the northwest flank of Recheschnoi. These lavas have been glaciated. Products of later volcanic vents, including cones, domes, and flows retain their constructional surfaces and rest on the glaciated surfaces of the older erupted rocks.

The volcanic rocks of Mount Recheschnoi are divided into five map units: hypersthene andesite, mafic phenocryst basalt of Kshaliuk Point, youngest hypersthene andesite flows, rhyolite domes, and quartz-olivine andesite flow (pl. 40). The hypersthene andesite that forms the main mass of the Mount Recheschnoi volcanic pile is the principal map unit. The mafic phenocryst basalt of Kshaliuk Point on the northwest slope is distinguished only by its petrographic character; its contact with the main body of hypersthene andesite is not exposed and the stratigraphic relations are not known. The youngest hypersthene andesite comprises flows, including a pyroclastic flow, separated from the main mass of hypersthene andesite because of their youthful land forms. The rhyolite domes and the quartz-olivine andesite flow are distinguished from the older hypersthene andesite by both land form and petrographic type.

HYPERSTHENE ANDESITE

The hypersthene andesite in the main volcanic pile of Mount Recheschnoi occurs mostly in thick, widespread flows and interstratified pyroclastic material. Most of the rock is strongly porphyritic andesite, containing phenocrysts of plagioclase and pyroxene, both having two different ranges in composition. Some flows in the western part are less porphyritic. The volume of these porphyritic rocks is estimated at more than 16 cubic miles. The basal hypersthene andesite flows lie on surfaces eroded on the dioritic plutonic rocks, the albitized sedimentary and igneous complex, and the volcanic rocks of central Umnak. The upper flows are overlapped by the volcanic rocks of Mount Vsevidof.

MAFIC PHENOCRYST BASALT OF KSHALIUK POINT

A vent complex and associated lava flows of basalt containing plagioclase and mafic minerals as phenocrysts underlies an area of about 6 square miles at Kshaliuk Point on the northwest slope of Mount Recheschnoi (pl. 40). The area is surrounded by hypersthene andesite from Mount Recheschnoi, but no contacts were seen that expose the relations between the two rock types. Both terrains show similar erosion and have been glaciated. The basalt has not been altered nor deformed, so it must be considered younger than the basement rocks.

The basalt contains phenocrysts of gray, translucent bytownite (20 percent; as much as 2 mm in size), green augite (4 percent; as much as 8 mm in size), and lemon-yellow olivine (5 percent; as much as 3 mm in size) in a purplish-gray crystalline groundmass. The phenocrystic augite has optical constants that indicate an average composition (Hess, 1949, pl. 1) of $Ca_{45}Mg_{38}Fe_{17}$. Olivine phenocrysts range in composition from Fo_{88} to Fo_{84}. The average composition of the groundmass plagioclase is about An_{75}.

YOUNGEST HYPERSTHENE ANDESITE FLOWS

PYROCLASTIC FLOW

A flow of pyroclastic material fans out from one of the glaciated valleys on the east slope of Mount Recheschnoi. Its source was not seen, but is probably buried beneath the youngest hypersthene andesite lava that flowed down the same valley and overlies part of it. Older till of the earlier glaciation overlaps the pyroclastic flow along part of its western edge. The pyroclastic flow is made up of angular blocks embedded in a relatively small amount of matrix. Blocks range in size from 10 feet in diameter to fragments of microscopic size. Most of the rock fragments are hypersthene andesite similar to that of the lava flows, but a few represent altered sedimentary basement rocks. The matrix is light brownish to light purplish gray, dotted with grayish-black grains and intricately transected with thin (as much as 1 mm thick) seams of clayey, grayish-orange-pink material. The matrix includes fragments of plagioclase, hypersthene, augite, and opaque oxide crystals, but is largely glass with an index of refraction of 1.542. Some of the glass is free of all fragments and appears to cut through the matrix as veinlets. The deposit is believed to be a mudflow of brecciated lava that was still somewhat hot, rather than any sort of ash flow associated with a nuée ardente type of explosive eruption.

LAVA FLOWS

Three cinder cones and lava flows of the youngest hypersthene andesite of Mount Recheschnoi are preserved essentially uneroded. Two of the lava flows, one of which flowed down a glacial valley almost to the Pacific Ocean, rest on the glaciated southeastern slope of Mount Recheschnoi (see pl. 40). The third cone and lava flow is in the saddle between Mounts Recheschnoi and Vsevidof. These flows are petrographically similar to the hypersthene andesite that forms the major part of Mount Recheschnoi.

RHYOLITE DOMES

Three small domes of rhyolite west of the head of Russian Bay (pl. 40) are younger than the glaciated topography, and appear to have been formed as parts of a single episode of extrusion. The domes are partly buried in their own talus.

QUARTZ-OLIVINE ANDESITE FLOW

A quartz-olivine andesite flow lies on the glaciated surface of hypersthene andesite of Mount Recheschnoi just southwest of the isthmus (pl. 40) and covers somewhat more than 1 square mile. It is probably about 450 feet thick at the lava dome in the western part of the flow and averages perhaps 300 feet. The flow spreads in all directions from the dome, chiefly eastward to form a small plateau about 1,600 feet above the sea. The surface is a series of arcuate ridges about 50 feet high and 400 feet from crest to crest, eccentric to the dome.

AGE OF LAVAS OF MOUNT RECHESCHNOI

The major cone-building activity of Mount Recheschnoi may have begun as early as late Tertiary, but available evidence suggests that the main pile of hypersthene andesite is mostly if not entirely Pleistocene in age. The basal contact of the Mount Recheschnoi pile is well exposed and rests on a marine(?) erosion surface of low relief carved on a basement complex that includes fresh unaltered lavas that may be as young as Pleistocene. The exposed lavas of Mount Recheschnoi resting on this surface have been deeply dissected by glacial erosion probably during late Pleistocene and early Recent time. The relations of the basalt at Kshaliuk Point to the hypersthene andesite are not known; hence this basalt may be as old as Pliocene. The essentially uneroded satellitic flows and domes, excepting possibly the pyroclastic flow beneath older till, are postglacial and therefore probably Recent in age.

PETROGRAPHY

All 12 specimens of volcanic rocks of Mount Recheschnoi examined microscopically are characterized by one or more minerals apparently not in equilibrium with the groundmass minerals. The hypersthene andesite comprising the bulk of the volcano, though similar from outcrop to outcrop, appears to be a hybrid rock formed either by incomplete fusion and assimilation of country rock, by mixing of partly crystallized melts, or a combination of these processes.

HYPERSTHENE ANDESITE

The dominant rock type is hypersthene-bearing labradorite andesite with varying amounts of plagioclase, augite, hypersthene and olivine as phenocrysts. Petrographic analyses of several specimens of this rock type are given in table 6. In each rock, crystals of plagioclase, whose relations are not simple zoning, occur in two separate ranges of composition.

TABLE 6.—*Petrographic analyses of specimens of hypersthene andesite of Mount Recheschnoi*

	1a	1b	1c	2	3	4	5
Mode in volume percent:							
Phenocrysts >0.2 mm:							
Plagioclase	33.1	32.9	28.9	31.3	28.4	1.9	13.5
Augite	3.1	[1] 7.7	[1] 7.7	2.9	2.9	1.2	1.2
Hypersthene	2.1	[1] 3.1	[1] 3.5	1.8	3.0	.2	.6
Olivine	.1	[1] .2	[1] .5	.2	.1	.01	.4
Opaque oxides	.1	.1	.1	.2	.2	.2	.1
Groundmass	61.5	56.0	59.3	63.6	65.4	96.5	84.3
Composition of more calcic plagioclase >0.2 mm.	------	An_{88-92}	--------	------	------	An_{78-88}	An_{80-85}
Composition of less calcic plagioclase >0.2 mm.	------	An_{60-68}	--------	------	------	An_{58-62}	An_{55-63}
Approximate composition, groundmass plagioclase.	------	An_{65}	--------	------	------	An_{45}	An_{60}
Augite crystals >0.2 mm, β index	------	1.708	--------	------	------	----------	1.707
Composition of hypersthene crystals >0.2 mm	------	En_{60-64}	--------	------	------	----------	En_{54-60}
Composition of olivine crystals >0.2 mm	------	Fo_{68-78}	--------	------	------	Fo_{67-72}	Fo_{70-72}
Groundmass glass, refractive index	------	----------	--------	------	------	1.505	1.53

[1] Mafic minerals somewhat higher than other sections owing to mafic inclusions.
1a, 1b, 1c. Three mutually perpendicular thin sections, hypersthene-bearing labradorite andesite of hypersthene andesite of Mount Recheschnoi, altitude of 1,400 feet (lat 53°13.8′ N., long 168°22.0′ E.), 1.8 miles south of Hot Springs Cove (chemical analysis 23, table 2).
2. Hypersthene-bearing labradorite andesite near base of hypersthene andesite of Mount Recheschnoi at altitude of 850 feet on east side of valley (lat 53°12.5′ N., long 168°25.2′ E.) that drains into Geyser Bight.
3. Hypersthene-bearing labradorite andesite near base of hypersthene andesite of Mount Recheschnoi collected at altitude of 200 feet in sea cliff (lat 53°10′ N., long 168°20.7′ E.) east of Russian Bay.
4. Hypersthene-bearing aphyric andesite of hypersthene andesite of Mount Recheschnoi, at altitude of about 500 feet (lat 53°05.3′ N., long 168°28.5′ E.), 3.2 miles N. 60° E. of Amos Bay (chemical analysis 27, table 2).
5. Hypersthene-bearing labradorite andesite of youngest hypersthene andesite flow of Mount Recheschnoi, collected at lat 53°08.8′ N., long 168°28′ E., 7.3 miles N. 75° E. of Amos Bay.

After crushing and sieving 50 grams of the chemically analyzed specimen (columns 1a, 1b, and 1c), the ratio of anorthite-bytownite to calcic labradorite was determined to be 1:9 by counting grains in two size ranges: between U. S. Standard sieves no. 80 and no. 120 and between sieves no. 150 and no. 200. The anorthite-bytownite is in separate crystals and irregularly shaped cores within wide rims of the calcic labradorite. There is no zone of the composition intermediate between calcic bytownite and calcic labradorite. The more abundant phenocrysts of calcic labradorite commonly show a clear core and a surrounding zone of slightly more sodic labradorite clouded with dust inclusions. The borders of this clouded zone are rounded and enclosed in still another shell of clear, slightly more calcic labradorite with a composition of about An_{65}, which is the composition of the groundmass plagioclase. This type of plagioclase phenocryst is believed to be comparable to those described by Kuno (1950, p. 968) and suggests that the part of the crystal including the clear core and the dust-bearing zone was xenocrystic in the liquid and partly resorbed before the outer shell of plagioclase was precipitated.

In specimen 5 (table 6), from one of the recent flows, most of the plagioclase crystals contain a core of andesine, showing normal and slightly oscillatory zoning with dust inclusions in the outer zone. The inner core is separated by a rounded outline from an outermost shell of clear labradorite of composition An_{60}. A few phenocrysts have an inner core of bytownite, rounded and enclosed in a thick zone averaging about An_{50}. This zone is embayed and encased in an outermost rim of plagioclase of composition An_{60}, which is the same composition as the plagioclase microlites of the groundmass. Mafic phenocrysts include augite, hypersthene, and olivine. The rare olivine grains all show evidence of resorption, and are rimmed with monoclinic pyroxene. Hypersthene in euhedral crystals as much as 3 mm long is commonly rimmed with monoclinic pyroxene, and some hypersthene forms ragged cores in relatively thick aggregates of monoclinic pyroxene. Augite or ferroaugite phenocrysts reach a maximum length of 2 mm. The groundmass consists of fine microlites of plagioclase, clinopyroxene, and opaque oxides in a dusty, grayish-brown glass.

Inclusions composed of hypersthene, augite, and minor bytownite-labradorite are in part mutually intergrown, suggestive of an original gabbroic texture (specimen 1, table 6). Minor, opaque oxide-charged dark-brown glass occurs interstitially within them, suggesting their partial resorption. The plagioclase of the xenoliths is normally zoned with bytownite cores and a thick shell of clear labradorite. In one clump only augite crystals are clustered together. All the xenoliths are more mafic than the average of the rock, and they are abundant enough to make the rock somewhat heterogeneous on a small scale.

RHYOLITE

The rhyolite contains sparse, small euhedral phenocrysts of bluish-gray quartz, feldspar, biotite, hornblende, and rare hypersthene in a light-purplish-gray felsitic groundmass. The rock weathers light brownish gray. Flow banding is conspicuous and the quartz is moderately concentrated in certain thin bands. Hence, the thin-section analysis given in table 3 may be low in quartz phenocrysts.

A few plagioclase phenocrysts seen in thin section contain labradorite as small mottled cores inside a thick outer shell of sodic andesine. The other plagioclase phenocrysts and microphenocrysts down to 0.05 mm are sodic andesine. All the plagioclase is normally zoned. Small inclusions of hornblende are associated with a few labradorite cores within andesine phenocrysts, and one xenolith consisting of hornblende and normally zoned labradorite-andesine was also observed.

The biotite phenocrysts show certain optical anomalies common in extrusive rhyolite. The optic angle of different biotite phenocrysts ranges from about 5° to 32°; the larger angles are in general measured on smaller phenocrysts. A few contain opaque oxides, probably magnetite, parallel to the lamellae. The deep color and high refractive index may be due to a high Fe_2O_3: FeO ratio, which can be caused by heating at atmospheric pressure. A. Jean Hall (1941b, p. 35) has shown that the refractive indices are raised considerably with increase in the oxidation of the iron but that no effect of oxidation of iron on the color (Hall, 1941a, p. 32) has been demonstrated.

The groundmass of the rhyolite consists of colorless glass, apatite needles, crystallites, and abundant spherulites amounting to more than half the volume of the groundmass. In certain bands the glass is lightly charged with red hematite(?) dust. The spherulites are of two main types, clear radiating low birefringent laths (*n*. about 1.53) in nearly perfect sperulites reaching a maximum diameter of about 0.1 mm, and white, cloudy, partly opaque, fine spherulitic aggregates that commonly contain a hollow cavity. These aggregates reach a maximum diameter of about 0.5 mm; and have an index considerably lower than balsam. A few vesicles are filled with a weakly birefringent zeolite with an index of 1.484.

QUARTZ-BEARING OLIVINE ANDESITE

This rock is unusual in that it contains phenocrysts of both quartz and olivine, which are incompatible under equilibrium conditions. Lemon-yellow olivine, pyroxene laths, dark-gray glassy andesine, minor amounts of white bytownite, and quartz occur as phenocrysts in a medium-light-gray to medium-gray groundmass that weathers light to medium olive gray on exposed surfaces. Petrographic analyses of three mutually perpendicular thin sections are given in table 7. The quartz occurs as rounded and embayed xenocrysts up to 0.5 mm, encased by a thin shell of radial fibers of clinopyroxene, probably augite. The abundant plagioclase phenocrysts consist of normally zoned cores, ranging from sodic labradorite to sodic andesine. The outer zones contain a dust inclusion band that parallels the rounded outlines of the phenocrysts rather than the pseudorectangular pattern of zoning. A relatively thin, outermost shell of about An_{60}, essentially the same composition as the groundmass plagioclase, encloses the phenocrysts and follows the rounded edges into embayments as well. Normally zoned bytownite occurs in a few separate phenocrysts and anhedral inclusions in the andesine-labradorite phenocrysts.

TABLE 7.—*Petrographic analyses (modes in volume percent) of three mutually perpendicular thin sections of quartz-bearing olivine andesite*

[Chemical analysis of the rock is given in column 22, table 2]

	1	2	3
Phenocrysts, microphenocrysts, and irregular masses > 0.2 mm:			
Quartz	0.7	1.6	1.2
Andesine-labradorite (An_{35-55}; avg. An_{50})	[1]7.0	[1]9.9	[1]6.0
Bytownite (An_{78-84}; avg. An_{80})	[1]1.2	[1]1.7	[1]1.1
Ferroaugite and augite	1.9	3.1	3.1
Hypersthene (En_{54-64}; avg. En_{57})	.1	.5	.6
Olivine (Fo_{84-88})	8.2	5.2	9.3
Hornblende(?) "ghosts" (opaque oxide-clinopyroxene aggregate)	.8	.9	.4
Opaque oxides (irregular masses)	.2	.4	.3
Groundmass (plagioclase-An_{60}, orthoclase(?), clinopyroxene, opaque oxides, and sparse glass (1.54)	79.9	76.8	78.0

[1] Plagioclase ratios computed by crushing rock sample on sieves nos. 150/200, counting plagioclase grains in oil immersion, and then recomputing to total plagioclase percentage determined by Chayes point counter.

Both bytownite and andesine-labradorite also occur separately in xenoliths. The bytownite is associated with diopsidic augite and the andesine-labradorite with ferroaugite, some of which contains hypersthene cores. Brown glass containing apatite needles is interstitial to the larger (1 to 3 mm) plagioclase and pyroxene grains.

Mafic phenocrysts are more abundant than plagioclase. The ferroaugite generally contains tiny grains of opaque oxide and appears faintly pleochroic in brownish green. Its diagnostic optical properties (beta index, 1.710; 2V, 50°), though slightly variable, indicate a composition of about $Ca_{38}Mg_{28}Fe_{34}$ (Hess, 1949, pl. 1). Sparse augite (beta index, 1.698; 2V, 53°), corresponding in composition to $Ca_{43}Mg_{35}Fe_{22}$ also occurs. The hypersthene invariably occurs as deeply corroded, opaque oxide-charged remnants surrounded by ferroaugite. Hornblende(?) "ghosts" are a fine aggregate of opaque oxides and augite. Olivine occurs both as euhedral and deeply embayed crystals and is generally enclosed by a reaction rim of clinopyroxene.

The groundmass consists of a very fine (0.005–0.01 mm) microlitic aggregate of labradorite, clinopyroxene, opaque oxides, orthoclase, and sparse glass. The presence of orthoclase in the groundmass is not surprising in view of the moderate potash content (1.6 percent) of the lava.

VOLCANIC ROCKS OF MOUNT VSEVIDOF

GENERAL GEOLOGIC FEATURES

Mount Vsevidof is a single stratovolcano south of Mount Recheschnoi (pl. 40). A crater three quarters of a mile in diameter occupies the summit and is filled with snow and ice. The cone is steep above an altitude of 3,000 feet, approaching 30° near the 6,920-foot summit; below 3,000 feet the slope gradually decreases to about 15° at an altitude of 1,000 feet. A few narrow canyons as much as 400 feet deep have been incised by glaciers, but most of the surface of the mountain is uneroded and represents the constructional surface of the uppermost lava flow or pyroclastic bed (pl. 44). The drained lava channels illustrated on plate 44 resemble stream gullies, but their location on the higher spurs at the flanks of the volcano and the "natural levees" of lava on the sides of these features demonstrate that they formed at the time of extrusion and not as products of stream erosion.

The rocks exposed are mostly lava flows of aphyric basaltic andesite and andesite. Near the summit, the surface is blanketed with pyroclastic beds. A sequence exposed in an inacessible cliff in the east slope gives the impression of four distinct beds of pyroclastic rocks. Only two beds are exposed in accessible places: an underlying layer of consolidated grayish-orange rhyodacite pumice and a surface layer of dark-gray andesitic scoria. Three of the most recent lava flows, apparently younger than the pyroclastic beds, have been outlined on plate 40. The most recent (possibly historic) flow on the west flank of Mount Vsevidof has the composition of latite.

The andesitic scoria and rhyodacitic pumice thin markedly down the slope of the cone and essentially disappear between 1,000 to 2,500 feet above sea level. In the north crater wall, the pumice and scoria beds are each about 50 feet thick. At an altitude of 4,000 feet on the north side of the cone an exposed thickness of 40 feet of pumice is overlain by 30 feet of scoria, whereas at 2,000 feet, 40 feet of pumice with scattered clots of scoria in the upper few feet rest on at least 40 feet of mixed loose ash, older scoria fragments and talus blocks. Below an altitude of 1,000 feet, both the scoria and pumice are missing. The gullies on the north lower slopes below 1,000 feet contain abundant, rounded pumice fragments.

AGE AND CORRELATION

The lavas of Mount Vsevidof lie on glaciated hypersthene andesite of Pleistocene Mount Recheschnoi but the older till, of latest Wisconsin or early Recent age, rests on some of the oldest andesite flows of Mount Vsevidof; these flows are older than the pyroclastic beds of the summit cone. The geologic relations and the youthful state of dissection of the volcano, indicate that the cone is latest Pleistocene and Recent in age; probably most of the cone is Recent, although the beginning of activity may date from late Pleistocene. The uppermost pyroclastic beds of the composite summit cone were probably deposited within the last few thousand years and possibly by one of the earlier historic eruptions. Mount Vsevidof was reported active in 1830, and a minor explosive eruption occurred in 1878 (Coats, 1950, table 2). "Smoke" was also reported from the summit of Mount Vsevidof in 1784, 1790, and 1880. An eruption of steam and "smoke" (volcanic ash) from Mount Vsevidof occurred March 11–12, 1957, during earthquakes on southwestern Umnak. This eruption, probably from the west rift (pl. 40), was observed by local inhabitants at Nikolski, according to The Anchorage Times, Anchorage, Alaska.

Three beds of pumice ash are interbedded with windblown sand and silt in an archeological excavation near Nikolski. The middle bed, which contains charcoal, has a carbon-14 age of 3,018±230 years (William S. Laughlin, written communication, 1951; Arnold and Libby, 1951, p. 118). Material in the three pumice beds is compared with dacite pumice from the north slope of Mount Vsevidof in table 8. The three beds appear to be made up of similar pumice, which differs petrographically from the sample from the slope of Mount Vsevidof. These ash beds were probably derived either from an older Vsevidof eruption or from one of the volcanoes in the Islands of the Four Mountains, 35 to 50 miles west of Nikolski (see fig. 50).

TABLE 8.—*Comparative petrographic data: rhyodacite pumice of Mount Vsevidof and pumice fragments in ash beds of archeological profile, Nikolski*

[Samples of ash from Nikolski archeological profile were furnished by William S. Laughlin]

Locality	Approximate percentage of pumice (and phenocrysts)	Refractive index of pumice glass	Composition of plagioclase	Composition of hypersthene	Index of augite
Mount Vsevidof cone	100	1.514	An_{48-55}	En_{57-61}	1.705
3.75-meter level	80	1.520–1.522	An_{56-62}	En_{62-64}	1.705
4.33-meter level	40	1.521–1.526	An_{53-62}	En_{63}	1.704
4.50-meter level	65	1.520–1.521	An_{56-64}	En_{62-64}	Not determined

PETROGRAPHY

BASALTIC ANDESITE FLOWS

The basaltic andesite is a medium-dark-gray lava with sparse lath-shaped plagioclase phenocrysts about 2 mm in length. Thin section analyses of basaltic andesite flows are given in columns 1 and 2 of table 9 (see also column 21, table 3). All the plagioclase phenocrysts are normally zoned. Subparallel plagioclase laths, whose

TABLE 9.—*Petrographic analyses of basaltic andesite, andesite, and latite flows of Mount Vsevidof*

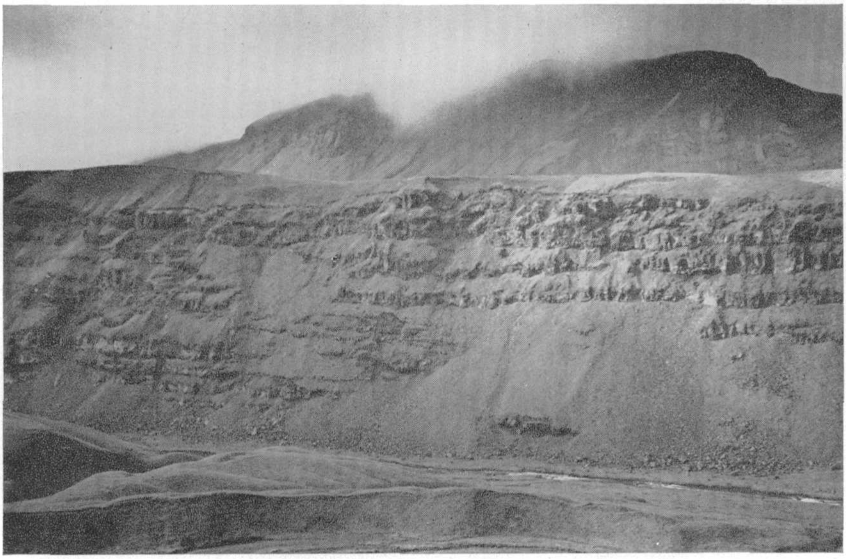
	1	2	3	4
Mode in volume percent:				
Phenocrysts>0.1 or 0.2 mm (see notes):				
Plagioclase	1.2	2.2	3.7	3.8
Augite		.2	.3	.1
Hypersthene			.2	.5
Olivine	.1	.1		
Opaque oxides			.5	.3
Groundmass	98.7	97.5	95.3	95.3
Range of composition of plagioclase phenocrysts	An_{78-84}	An_{74-87}	An_{56-60}	An_{48-60}
Average composition of groundmass plagioclase	An_{75}	An_{75}	An_{50}	An_{40}(?)

1. Basaltic andesite flow at Twinlava Point older than pyroclastic beds. Chemical analysis, column 21, table 2. Crystals >0.2 mm are considered phenocrysts.
2. Youngest basaltic andesite flow on north slope of Mount Vsevidof; specimen from an altitude of 1,500 feet. Crystals >0.2 mm are considered phenocrysts.
3. Youngest andesite flow on south slope of Mount Vsevidof; specimen from flow front on Black Creek outwash plain. Crystals >0.1 mm are considered phenocrysts.
4. Latite flow, possibly historic in age, on west slope of Mount Vsevidof; specimen collected from flow front at altitude of 650 feet. Chemical analysis, column 28 ,table 2. Crystals >0.1 mm are considered phenocrysts.

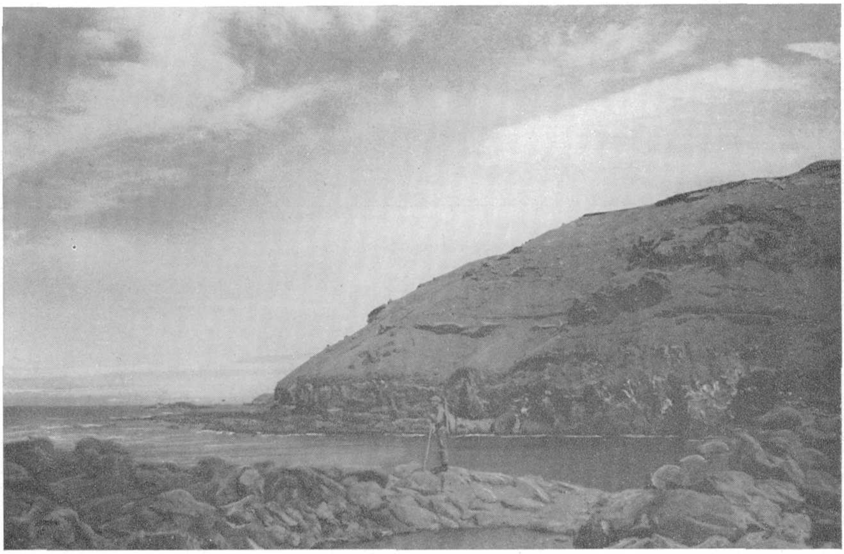
average size is about 0.1 mm, comprise the bulk of the groundmass as defined in table 9, though a few, whose average size approaches 0.2 mm, have lengths as much as 0.4 mm parallel to axis *a*. The tabular plagioclase crystals grade downward to tiny microlites, about 0.02 mm long, that compare in size with microlites of clinopyroxene and opaque oxide. Olivine occurs as rare microphenocrysts as much as 0.4 mm and as rare microlites grading downward to 0.05 mm. Euhedral olivine is enclosed by a thin shell of clinopyroxene and ranges in forsterite content from Fo_{68} to Fo_{77}.

ANDESITE AND LATITE FLOWS

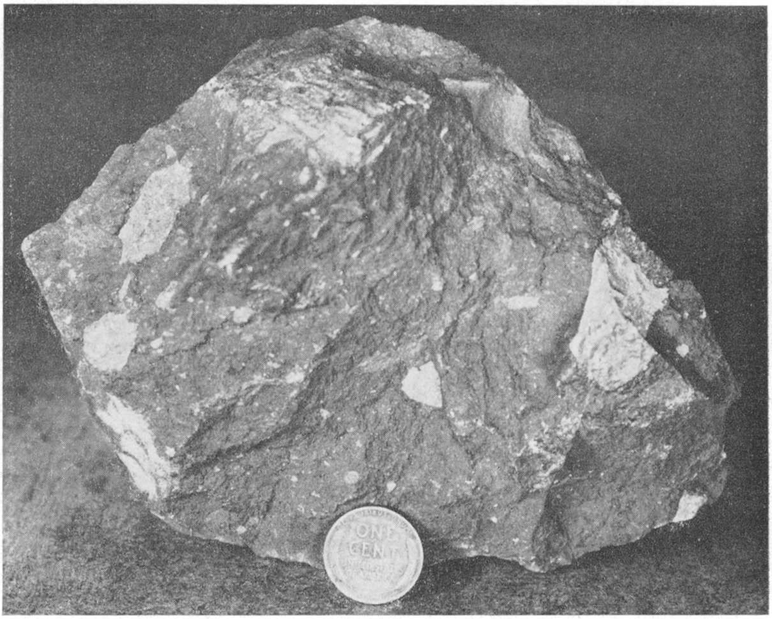
The andesite flows and the historic(?) latite flow contain light-gray plagioclase phenocrysts in a dark-gray groundmass; the groundmass of the latite is somewhat more glassy and darker in hand specimen than those of the andesites. Thin section analyses are presented in columns 3 and 4, respectively, table 9 (see also column 28, table 3). A size cutoff of 0.1 mm between phenocrysts and groundmass was assumed, because microphenocrysts, ranging in size upward from 0.1 mm, are set in a hyalopilitic groundmass. The microlites in the groundmass, with the exception of orthoclase, average from 0.002 to 0.005 mm. Plagioclase phenocrysts are normally zoned through the slight range indicated in the andesite (column 3, table 9). The plagioclase of the latite has a slight tendency toward oscillatory zoning with a reverse zoning associated with glass in the inner shells. A few of the plagioclase phenocrysts of the latite contain a small core of sodic andesine. Hypersthene occurs as small laths ranging from 0.2 to 0.5 mm and has a thin shell of augite or ferroaugite. Augite occurs as microphenocrysts ranging from 0.1 to 0.3 mm in average dimension. Opaque oxide euhedra average slightly over 0.1 mm in diameter.



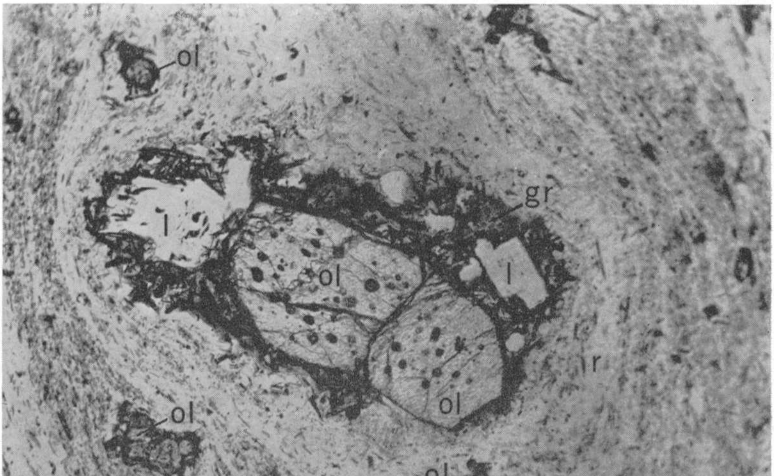
A. Nearly flat-lying undisturbed Crater Creek basalt flows exposed in the northwest wall of Crater Creek gorge. Uppermost thin resistant bed is lower welded agglomerate bed near base of Okmok volcanics. Arcuate ridge north of caldera is partly shrouded in cloud bank.



B. View northeast toward sea cliff northeast of Cape Chagak. About 250 feet of Okmok volcanics rests on precaldera feldspathic basalt flows of Ashishik basalt (vertical sea cliff and foreground). Note welded palagonitized agglomerate beds in lower third of exposure. Middle part of Okmok volcanics is eroded into grotesque forms.



A. Hand specimen of dark-gray welded andesitic agglomerate with fragments of medium-gray aphyric and plagioclase basalt. Collected from headwaters of New Jersey Creek (lat. 53°29′, long. 168°05′).



B. Photomicrograph of small mass of basaltic andesite enclosed by rhyolite (column 19, table 2). Olivine (*ol*), labradorite (*l*), andesitic groundmass (*gr*), contains microlites of plagioclase, clinopyroxene and opaque oxides in glass. Note flow banding in rhyolite (*r*). Plane-polarized light.

The groundmass consists of very fine microlites of ferroaugite(?), andesine and sparse opaque oxide enclosed by glass and orthoclase. Orthoclase occurs in minor amounts in the groundmass of the andesite but is common in the latite groundmass. Part of the orthoclase in the latite occurs in euhedra, a few of which reach 0.2 mm in length but are considered part of the groundmass, because the fine microlites are poikilitically enclosed by the larger orthoclase euhedra. Orthoclase thus crystallized slightly later than the microlites or at about the same time as the associated interstitial liquid was cooled to a glass. The glass in the latite groundmass (column 28, table 3) has an index of refraction comparable to glass of the analyzed rhyolites from Umnak.

ANDESITIC AND RHYODACITIC PYROCLASTIC BEDS

The beds that form the uppermost part of the cone consist of an underlying solid, welded, grayish-orange rhyodacite pumice bed (column 30, table 3), gradational with and overlain by a streakily banded, medium to dark-gray scoria bed. This contains minor solid clots of black andesitic glass (column 26, table 3) gradational in texture with andesitic scoria. Both the pumice and the scoria contain 10 to 15 percent of accessory blocks of andesitic lava and dioritic intrusive rock.

Petrographic analyses of the nonvesicular andesite glass, the vesicular scoria, and a xenolith in the glass are presented in table 10. The plagioclase and augite of the limonite-stained xenolith average about 0.5 mm and are mutually intergrown, as in an intrusive rock. Euhedral opaque oxide grains average slightly larger than 0.1 mm.

TABLE 10.—*Petrographic analyses of rocks in dark andesitic scoria bed of Mount Vsevidof cone*

	1	2	3
Mode in volume percent (not determined in column 2):			
Crystals larger than 0.1 mm:			
Orthoclase(?)	<0.1	----------	(1)
Plagioclase	.3	----------	43
Augite	.1	----------	16
Hypersthene	< .1	----------	----------
Opaque oxides	.0	----------	11
Groundmass (glass: 1,2) or mesostasis (3)	99.5	----------	[1] 22
Hydrated iron oxides (limonite?)	.0	----------	8
Range of composition of low-An plagioclase	An_{30-35}	An_{30-35}	An_{30-34}
Range of composition of high-An plagioclase	An_{48-55}	An_{48-56}	An_{50-56}
β index of augite	[2] 1.710	[2] 1.710	1.705
Range of composition of hypersthene	En_{55-58}	En_{55-58}	----------
Refractive index of groundmass glass	1.543	1.545	----------

[1] Cloudy orthoclase(?) is the dominant constituent of the mesostasis.
[2] *Minor augite with β=1.703-05, probably from altered xenoliths?*

1. Black andesitic glass clot (chemical analysis, column 26, table 2) within and gradational into dark andesitic scoria erupted after rhyodacitic pumice during last major eruption of Mount Vsevidof. Collected at 4,000 feet on N. Slope of cone (lat 53°07.7′ N, long 168°41.3′ E).
2. Dark andesitic scoria that forms nearly all of bed. Same location as 1.
3. Limonite-stained dioritic xenolith in black andesitic glass. Same location as 1.

The interstitial material is largely cloudy, limonite-stained potassium feldspar with abundant apatite needles. Sodic andesine occurs in the outermost shells of all the plagioclase of the xenolith, in some grains of the andesitic scoria and glass, and as mottled, irregular grains in all three rocks. The apatite-charged orthoclase(?) and mottled sodic andesine grains in the scoria and andesitic glass suggest that they are xenocrysts from the disaggregation of diorite xenoliths.

VOLCANIC ROCKS OF OKMOK VOLCANO

Erupted rocks of Okmok Volcano and satellitic vents occupy most of northeastern Umnak Island (pl. 41). The main cone of the central volcano is truncated by Okmok Caldera, an approximately circular depression 6 miles in diameter and 1,500 feet in maximum depth. Mount Tulik, Mount Idak, and Jag Peak are the most prominent secondary volcanic piles superimposed on the outer slopes of the main cone. The lava plateau northeast of Mount Idak and the ridge west of New Jersey Creek are made up of bedded volcanic rock with gentle dip away from the main center of Okmok Volcano and are probably faulted parts of the outer slopes.

The rocks are divided into three stratigraphic groupings: precaldera rocks erupted prior to the formation of the caldera, pyroclastic rocks associated with the caldera-forming eruption, and postcaldera rocks erupted after the caldera-forming eruption. The precaldera rocks are mostly of basaltic composition and are by far in greatest volume. They include lava flows and pyroclastic beds and range from aphyric to porphyritic in texture. The pyroclastic rocks associated with the caldera-forming eruption consist of agglomerate, welded agglomerate, ash, and tuff-breccia. Basalt cones, plug-domes, and flows occur outside Okmok Caldera and cannot be dated precisely with respect to its formation. The known postcaldera deposits within Okmok Caldera include volcanic material erupted from different vents and also a sedimentary unit containing bedded volcanic material deposited in a caldera lake, which has now almost completely vanished.

Several formal stratigraphic names were proposed in the 1947 administrative report describing Okmok Volcano (Byers, Hopkins, Wier, and Fisher, 1947, p. 19–53). These names in approximate order of age were: Ashishik basalt, Crater Creek basalt, Idak basalt, Tulik basalt, Tanak volcanics, and Okmok ash. The names, Ashishik basalt and Crater Creek basalt, are used but redefined in this report; Okmok ash is changed to Okmok volcanics and redefined in this report to include both the Tanak volcanics and Okmok ash, which are herewith abandoned. The names, Idak basalt and Tulik basalt are also abandoned and replaced by informal names.

ROCKS OF PRECALDERA AGE

The precaldera rocks are subdivided on plate 41 into three main categories based on geologic and geomorphic relations. These categories in order of relative age are the Ashishik basalt, volcanic rocks of minor vents, and the Crater Creek basalt. The three categories may in part overlap in time, but generally their ages are believed to be as indicated on the map explanation of plate 41.

ASHISHIK BASALT

The oldest precaldera rock of Okmok Volcano is named the Ashishik basalt after exposures in the east-facing cliff, 2 to 3 miles south of Ashishik Point, at the northernmost part of Umnak Island (pl. 41). The formation as redefined in this report includes most of the bulk of Okmok Volcano and comprises the Ashishik basalt of the 1947 administrative report (Byers, Hopkins, Wier, and Fisher, 1947, p. 25), tuff-breccia and tuff, that part of the Crater Creek basalt on the outer flanks of Okmok Volcano, Idak basalt, excepting the mass of Mount Idak, and the "basalt flows of Hill 1200" (Byers and others, 1947, pl. 3). The Ashishik basalt is here subdivided into three lithologic units, mafic phenocryst basalt, consisting of porphyritic basalt with more than 2 percent of mafic megaphenocrysts, palagonitized pyroclastic rocks, and aphyric (nonporphyritic) and feldspathic basalt, made up mostly of aphyric basalt flows but with some porphyritic flows that contain phenocrysts of plagioclase and less than 2 percent of mafic phenocrysts. These units are listed in general order of age, although they complexly intertongue.

The Ashishik basalt must rest on the volcanic rocks of central Umnak, although the contact is concealed by the extensive blanket of Okmok volcanics. The hydrothermal alteration, the topographically low position, and the great amount of dissection of the volcanic rocks of central Umnak, in contrast to the constructional surfaces yet remaining on the Ashishik basalt, leaves little room for doubt that the Ashishik basalt is a generally younger pile of lavas superposed on the volcanic rocks of central Umnak. The volcanic rocks of minor vents intrude or overlie the Ashishik basalt.

MAFIC PHENOCRYST BASALT

At the type locality of the Ashishik basalt in the prominent ridge west of New Jersey Creek (pl. 41), mafic phenocryst basalt flows dip gently northward. The sequence is several hundred feet thick, with the base not exposed, and is overlain by approximately conformable aphyric and feldspathic basalt flows. A thickness of 500 feet of these flows was measured on the cliff, 1½ miles upstream from the mouth of New Jersey Creek. Individual flows range from 20 to 60 feet in thickness. Most are massive without flow banding, but horizontal sheeting possibly representing flow structure, is conspicuous in a few. The upper 2 to 5 feet of many flows is reddish oxidized flow-breccia. The rocks are chiefly light to dark purplish gray, and range from aphanitic to coarsely porphyritic. Phenocrysts are in order of abundance calcic plagioclase, olivine, and monoclinic pyroxene.

A group of six superimposed, nearly horizontal flows of porphyritic basalt with mafic phenocrysts is exposed in the base of the northeast wall of Okmok Caldera (pl. 41). The outcrop is about 1,000 feet long and 300 feet high. The lowest outcrops are about 1,100 feet above sea level, and do not expose the base. The rock is overlain by palagonitized pyroclastic rock, with intervening lenses of bedded conglomerate as much as 15 feet thick.

Mafic phenocryst basalt underlies or intertongues with aphyric and feldspathic basalt flows at several scattered places on the eastern outer slope of Okmok Volcano, but the base is nowhere exposed. Mafic phenocryst basalt flows, dipping gently northeast, are the oldest rocks exposed in the east face of the lava plateau east of Mount Idak. Similar flows crop out higher in the cliff section and intertongue with both feldspathic basalt flows and palagonitized pyroclastic rock. In part of the ridge, mafic phenocryst basalt is the uppermost rock in the section and directly underlies the Okmok volcanics.

PALAGONITIZED PYROCLASTIC ROCKS

The palagonitized pyroclastic rocks of the Ashishik basalt include bedded tuff, poorly bedded tuff-breccia, which crops out beneath the Okmok volcanics on the lower slopes of Okmok Volcano (pl. 41), and unbedded vent agglomerate exposed mainly in the walls of Okmok Caldera. These rocks were included in the tuff-breccia and tuff unit of the preliminary report (Byers and others, 1947, pl. 3). The color ranges from dull yellowish brown to bright yellowish orange; the breccias and agglomerates are mottled by darker lithic fragments against the bright-colored matrix of palagonitized tuff. Xenolithic fragments range in size from microscopic grains to 3-foot blocks, and are similar to the mafic phenocryst basalts and to the aphyric and feldspathic basalts exposed on the flanks of the volcano and in the caldera walls.

These rocks are most abundant near the caldera, particularly in the east wall (pl. 45), where yellowish-orange agglomerate is exposed through a vertical distance of 1,000 feet. Comparable agglomerates more than 800 feet thick appear to make up a large part of the high cliff that truncates the north arcuate ridge on the east. Many small dikes and irregular bodies of intrusive rock cut the agglomerate here. At the southwest end of this same ridge, the caldera fault scarp exposes 1,000 feet of palagonitized pyroclastic rocks cut by several vertical lava pipes or dikes as much as 300 feet wide. Many dikes are similarly associated with the palagonitized agglomerate elsewhere in the caldera wall.

Palagonitized pyroclastic rocks are exposed in many places on the flanks of Okmok Volcano. In some places, chaotic dips and associated irregular dikes suggest that they occupy old vents, as near the headwaters of Bering Creek east of the caldera. Most of the outcrops are of tuff-breccia or agglomerate with no well-defined bedding, but on the southwest flank of Okmok Volcano at the base of three of the satellitic mountains, bedded palagonitized tuff is exposed as part of the main mountain mass under the edges of plagioclase-olivine basalt flows of satellitic vents.

Beds of the palagonitized pyroclastic rocks are exposed in the southeast face of the plateau northeast of Mount Idak: one bed between the lower mafic phenocryst basalt flow and the overlying aphyric and feldspathic basalt flows, and the other between the aphyric and feldspathic basalt flows and the upper mafic phenocryst basalt flow that tops the plateau.

APHYRIC AND FELDSPATHIC BASALT

The aphyric and feldspathic basalt unit of the Ashishik basalt includes abundant flows of aphyric basalt and less common feldspathic basalt rich in phenocrysts of calcic plagioclase. Phenocrysts of mafic minerals are rare. Aphyric and feldspathic basalt flows form much of the constructional surface of the flanks of Okmok Volcano and are exposed in the caldera walls, in the shallow stream cuts, and in much of the sea cliff around the periphery of Okmok. A thick unit of these rocks forms the middle of the sequence exposed in the lava plateau northeast of Mount Idak. These rocks cap the isolated ridge west of New Jersey Creek and form the bulk of Magazine Ridge south of Mount Idak. Except for those on the plateau northeast of Mount Idak, they were included in the Crater Creek basalt in the preliminary report (Byers, and others, 1947).

Individual flows of these rocks are from 10 to 70 feet thick, and tops and bottoms commonly are reddish oxidized breccia and scoria from 5 to 20 feet thick. Columnar jointing is not well developed. The aphyric rocks are generally gray to light gray and commonly contain closely spaced joints, about one-eighth of an inch apart, parallel to the top or bottom. Parallel orientation of minute plagioclase tablets gives a satinlike sheen to the joint surfaces. The porphyritic rocks are gray and conspicuously speckled with light-gray or white plagioclase phenocrysts. Flows have an irregular jointing which yields blocks with partly conchoidal surfaces.

VOLCANIC ROCKS OF MINOR VENTS

The volcanic rocks of minor vents are subdivided into three units: vitreous andesite in plugs, domes, and flows; rhyolite in the form of a dome, and the plagioclase-olivine basalt of satellitic vents. These rocks either rest on the Ashishik basalt or intrude it. They were emplaced after the major upbuilding of Okmok Volcano and yet were dissected prior to deposition of the Okmok volcanics. Because of similar geologic relations with the older Ashishik basalt, the three units are assumed to be about the same age, although nowhere are they in exposed contact. The mass of Mount Tulik may be slightly younger than the other plagioclase-olivine basalts, for it is little dissected.

VITREOUS ANDESITE

In the caldera wall, in Crater Creek gorge, and on the outer slopes of Okmok near the caldera (pl. 41) several pipes, plug-domes and necks, and a few thick stubby flows are of dense, vitreous andesitic rock. In the field, these rocks were distinguished from the more common aphyric basalts by vitreous lustre, darker color, and almost complete absence of vesicles. The largest exposed body is a neck in the northeast wall of Okmok Caldera about 500 feet across and exposed 1,700 feet vertically. The total volume of these rocks is insignificant compared to that of the Ashishik basalt.

RHYOLITE

Rhyolitic rocks crop out for a mile along the north side of the north arcuate ridge and also form a ridge that extends a mile northwest from the north arcuate ridge (pl. 41). The rhyolite of the ridge is made up of randomly alternating bands ranging from a fraction of an inch to several inches in thickness and consisting of dense black obsidian, vesicular gray and black obsidian, and light-gray felsitic rhyolite. The banding strikes parallel to the ridge and dips inward from each margin, suggesting that the ridge is an elongated narrow extrusion or dome from a fracture rather than an elongated flow. The eastern part of the mass along the north base of the north arcuate ridge contains black obsidian but is made up of gray vesicular glass and light-gray felsitic rhyolite in crude bands that dip southward into the ridge. The rhyolite presumably rests on the Ashishik basalt, although the contact is covered by talus from the dome. It is overlain by the Okmok volcanics, and a Recent basaltic flow overlies it to the east.

PLAGIOCLASE-OLIVINE BASALT OF SATELLITIC VENTS

Flows of plagioclase-olivine basalt make up the bulk of satellitic piles on the outer slope of Okmok Volcano. These include volcanic rocks at the satellitic vents of Mount Idak on the east slope, Mount

Tulik on the southeast slope (pl. 41), and Jag Peak and three other volcanic mountains on the southwest slope. These satellitic mountains rise 1,000 to 2,000 feet above the adjacent slope of Okmok Volcano. The flows have quaquaversal dips as great as 30° away from their summits. Vent breccia or intrusive plug material is exposed at some of the summits. Thick ash and, in places, agglomerate of the Okmok volcanics blanket the eroded flanks of the satellitic mountains.

CRATER CREEK BASALT

The Crater Creek basalt, the youngest precaldera unit, was originally defined in the 1947 administrative report (Byers, Hopkins, Wier, and Fisher, 1947, p. 25–26) to include the uppermost aphyric basalt flows on the outer slopes of Okmok Volcano, but it is restricted herein to the sequence of basalt flows exposed in Crater Creek gorge and in the north wall of Okmok Caldera to the west (pl. 46*A*). A fault separates the Crater Creek basalt in the north wall from the Ashishik basalt where the north arcuate ridge intersects Okmok Caldera. The Crater Creek basalt is separated from the Ashishik basalt by an erosional surface. The unit was mapped separately because it occupies a topographically low position between the arcuate ridges, composed largely of the older Ashishik basalt, and because it rests unconformably on the Ashishik basalt and vitreous andesite in the lower part of Crater Creek gorge (pl. 41); otherwise, the rocks are petrographically indistinguishable from the feldspathic basalts of the Ashishik basalt. The depression in which flows of the Crater Creek basalt lie may have included part of an earlier caldera on the concave side of the arcuate ridges.

The Crater Creek basalt consists of at least 15 separate flows with a total exposed thickness of 500 feet. The north wall of Okmok Caldera exposes several with easterly dip components of 1° to 2° toward Crater Creek gorge. The base is not exposed, but the gorge of Crater Creek is cut through into older palagonitized pyroclastic rocks, vitreous andesite, and associated dikes. The dikes are truncated by an eroded surface upon which the basal basalt flows were extruded. The Crater Creek basalt is thickest in the northwest wall of Crater Creek gorge, appreciably thinner and less continuous in the southeast wall, and does not crop out at all in the east wall of the caldera south of the gorge.

The basalt rocks are dark to light gray, range from aphanitic to porphyritic, and are rich in plagioclase phenocrysts. One to 10 feet of red ash or scoria separates several of the flows. Wherever this red scoria can be examined, it is seen to be the oxidized rubbly, scoriaceous surface facies of the underlying flow. Two specimens, whose chemical analyses are shown in columns 10 and 11, table 2, were taken from flows 2 and 11 (numbered from base) of the 15-flow sequence exposed in the northwest wall of Crater Creek gorge. The chemical analyses of these two flows are as closely alike, except for oxidation of the iron, as two replicate analyses of the same specimen (Michael Fleischer, written communication, 1948).

AGE OF PRECALDERA ROCKS

The precaldera rocks are probably mostly of Quaternary age, though some of the lowermost flows may be late Tertiary in age. None of the precaldera rocks show general hydrothermal alteration. This lack of alteration suggests a latest Tertiary and Quaternary age. Erosional features on these rocks are also youthful. Several moderately developed cirques are high on Mount Idak, the satellitic mountains, and the outer slopes of Okmok Volcano. Glacial striae were found as much as 2 miles downslope from some of these depressions. Of equal importance, much of the major slope surface is clearly only slightly modified from the original surface of the uppermost lava flow. Construction of the main volcanic structures was apparently keeping ahead of the destructive processes of erosion at the time of the latest glaciation, and some of the uppermost flows of the Crater Creek basalt probably were later than the last major glaciation, presumably at the end of the Pleistocene epoch. The precaldera rocks of Okmok Volcano are therefore considered to be mainly Pleistocene to early Recent in age though some of the oldest flows are possibly latest Tertiary.

OKMOK VOLCANICS OF CALDERA AGE

The thick deposit of pyroclastic material that covers much of the outer slopes of Okmok Volcano is herein named the Okmok volcanics. It includes the Tanak volcanics and the Okmok ash of the preliminary report (Byers and others, 1947), a subdivision abandoned herein, because it was based mainly on degree of sorting, consolidation and other field characteristics that are gradational both vertically and laterally and cannot be mapped consistently throughout the area.

The Okmok volcanics reach their maximum thickness of about 400 feet at the type locality on the north rim of Okmok Caldera and thins outward to as little as 20 feet. It has smoothed irregularities of the pre-Okmok surface, filling valleys to depths of several hundred feet and covering thinly most bedrock spurs between valleys. Erosion has cut many V-shaped gullies in the formation, and has removed it entirely from some of the ridge areas. The amount removed by erosion appears negligible compared to the probable original amount of material—not less than 7 cubic miles. An average thickness of 300 feet around the caldera rim and of 100 feet at the coast (an average of 6 miles distant from the rim) was used in this approximation.

The Okmok volcanics consist of thick deposits of unsorted agglomerate in the lower part and beds of moderately sorted bombs and well sorted ash in the upper part. A few thin lava flows, seen in transverse lenticular section, are interbedded in the agglomerate near the caldera rim. Bedding and sorting are irregular in detail. Generally speaking, however, unsorted agglomerate predominates in the lower part at the caldera rim and persists to the seacoast, whereas agglomeratic beds of sorted ash predominate in the upper part at the rim and grade outward into thinner, well-sorted ash at the seacoast. A measured geologic section is given below.

Measured section at type locality of Okmok volcanics in north wall, Okmok Caldera (lat 53°28.2′N., long 168°08.1′E.)

	Feet
Okmok volcanics:	
Ash, loosely consolidated, bedded; contains spatter, teardrop bombs, dark scoria fragments, and very minor lithic fragments; beds appear nearly black from a distance	120
Ash, loosely consolidated; contains scoria and bombs with many large angular blocks of basalt as much as several feet in diameter; beds appear medium light gray from a distance; gradational contact with unit below	160
Agglomerate, dense, medium-gray, andesitic; streaky appearance; contains common angular basalt fragments; forms upper welded bed; gradational contact with unit below	20
Agglomerate, medium-dark-gray, moderately consolidated; consists of spatter, bombs, and basaltic blocks as much as several feet in diameter, all in fine friable ash matrix; gradational contact with unit below	40
Agglomerate, andesitic, welded, moderate- to dark-red; appears streaky; contains common angular basalt fragments; forms lower welded bed; gradational contact with unit below	30
Agglomerate, moderately consolidated, medium-dark-gray; contains spatter, bombs, and large blocks; upper 10 feet oxidized to moderate red; unit rests disconformably on Crater Creek basalt filling V-shaped gullies	40
Total	410
Crater Creek basalt	270+

AGGLOMERATE DEPOSITS

The deposits of unsorted agglomerate in the lower part of the Okmok volcanics are in very thick beds as much as 100 feet in thickness. Two agglomerate beds are so completely indurated, or welded, that they were first mistaken for lava flows. No sorting of fragments by size was seen either vertically or horizontally. Around the caldera rim the agglomerate is locally more than 200 feet thick but is missing from radial ridges. Near Cape Chagak the agglomerate deposits are more than 200 feet thick (pl. 46 *B*), but just east of Ashishik Point they are only 20 feet thick. A short distance eastward at Cape Tanak they pass below sea level with an unknown thickness greater than 20 feet. Fragments of precaldera rock of all types commonly make up about 5 percent of the agglomerate but in places as much as 20 percent, and the agglomerate grades into tuff-breccia. Most of the material is juvenile lapilli and ash of very fine grained, partly glassy, erratically vesicular andesitic scoria. Fresh surfaces of the juvenile matrix are neutral gray, mottled with both lighter and darker colored lithic fragments, but at distances greater than about 2 miles from the caldera rim the fine-grained juvenile matrix is brownish gray, approaching but not duplicating the yellowish brown to bright yellowish orange of the palagonitized pyroclastic rocks of the Ashishik basalt. In places a rhyodacite ash bed is interbedded within the agglomerate.

WELDED AGGLOMERATE BEDS

Near the rim of the caldera, the agglomerate contains two welded agglomerate beds that are nonvesicular and as completely indurated as dense lava flows. These two beds are exposed in nearly continuous outcrop for 4 miles along the upper part of the north and east walls of the caldera (see pl. 45); one continues along the upper part of the walls of Crater Creek gorge. The two welded agglomerate beds range from 5 to 30 feet in thickness; the variation is apparently related to undulations of the underlying surface. These beds grade vertically into partly indurated agglomerate; one grades laterally into brownish-gray partly indurated (palagonitized) agglomerate, 2 to 3 miles from the edge of Okmok Caldera.

The constituent juvenile lava particles of the welded beds were apparently welded at the time of their emplacement. Fine, streaky banding parallel to bedding, common in outcrops of the completely welded agglomerate, apparently is due to flattening of juvenile bombs that now differ in crystallinity. Dark streaks are extremely fine-grained and are charged with opaque oxides; lighter streaks are composed of pyroxene, plagioclase, and opaque oxide grains, whose average size is about 0.01 mm. Aside from these differences, nothing in the groundmass of the completely indurated rock suggests boundaries between masses of the juvenile material. The xenolithic fragments are enclosed by the welded juvenile material (pl. 47*A*). A few coarser grained fragments grade into the predominantly fine-grained surrounding groundmass and some patches appear to be ghosts of xenolithic fragments, whose ragged outlines suggest that the fragments have been partly assimilated into the matrix material. Though the microscopic texture of the completely indurated layers could be that of a rapidly cooled lava flow charged with xenoliths, the texture was more likely a result of complete welding of the juvenile lava masses, for these indurated layers grade vertically and laterally into unsorted agglomerates clearly composed of discrete bombs, lapilli, and xenolithic fragments.

Two welded agglomerate beds are also exposed in less extensive outcrops in the north and east arcuate ridges. The following geologic section on the south slope of the north arcuate ridge includes these two welded agglomerate beds. This section differs in detail from the one at the type locality (page 315), in that the upper welded bed is basaltic, rather than andesitic in composition.

Measured section of Okmok Volcanics on south slope, north arcuate ridge (lat 53°29.3′ N., long 168°06.3′ E.)

[Measured with altimeter and tape]

	Feet
Vent agglomerate, oxidized, medium-red, scoriaceous; contains many fragments of mafic phenocryst basalt; weathers grayish red purple; lower 20 ft strongly indurated.	
Okmok volcanics:	
Agglomerate, pale- to medium-yellowish-brown; contains reddish scoria fragments; possible vent agglomerate	60
Agglomerate, basaltic, welded, medium-gray; contains many fragments of aphyric basalt; gradational with agglomerates above and below	10
Agglomerate, dark-yellowish-brown; contains large blocks of vitreous andesite as much as 10 ft thick and smaller angular fragments of basalt. Partly covered	100
Agglomerate, andesitic, welded, medium-gray; stained with medium-red iron oxide; has streaky (eutaxitic) texture; gradational with beds above and below	15
Ash, pumiceous lapilli, bedded, yellowish-gray; gradational with ash below	3
Ash, rhyodacitic, grayish-yellow; sharp contact with agglomerate below	.5
Agglomerate, dark-yellowish-brown, partly covered	40
Total	228.5
Vitreous andesite flow	100+

The welded agglomerate beds were intensively studied both petrographically and chemically in the hope that they could be identified elsewhere, and thus be used as marker beds in structural studies of Okmok Volcano. Petrographic analyses (table 11) and silica analyses

TABLE 11.—*Petrographic analyses of agglomerate and ash marker beds of the Okmok volcanics*

[Modal analyses in volume percent]

	1	2	3	4	5	6	7	8
Chemical analysis number (table 2)	13	16					18	
Mode in volume percent:								
Crystals larger than 0.2 mm:								
Plagioclase	1.8	2.6	2.1	5.2	0.7	0.8	±0.5	±3
Augite	1.1	1.6	.2	<.1	<.1	.2	.2	.1
Hypersthene	.0	sparse (?)	<.1	.0	<.1	.0	.0	<.01
Olivine	.1	<.1	<.1	.2	.1	.0	<.1	<.1
Opaque oxide aggregates	.2	.1	.2	.0	.1	.0	<.1	.1
Zeolites (largely chabazite)	.1	.1	.0	.0	<.1	.1	.0	.0
Lithic fragments (largely basalt)	1.1	.6	.3	1.6	15	20	.0	.0
Groundmass	95.6	95.0	97.1	93.0	84	79	99	97
Range in composition of higher An plagioclase > 0.2 mm	An_{72}(?)$_{-90}$	An_{81-87}	(sparse)	An_{78-87}	An_{78-86} An_{65}	(sparse)	(rare)	(rare)
Range in composition of lower An plagioclase >0.2 mm	An_{42-50}	An_{43-60}	An_{43-57}		An_{41-44}	An_{65}	An_{50}	An_{47-52}
β index, higher Fe augite (phenocrysts?)		1.710					1.705	1.706
β index, lower Fe augite (xenocrysts?)	1.698	1.696	1.698–1.702					
Range in composition of high Fo olivine crystals	Fo_{68-73}	Fo_{53-81}	Fo_{66-74}	Fo_{64-72}			$Fo_{72-?}$	
Range in composition of low Fo olivine crystals		Fo_{23-29}						$Fo_{47-?}$
Refractive index of groundmass glass					1.566; 1.525	1.565	1.520	1.525

1. Lower welded agglomerate bed of type locality (p. 315) at north wall, Okmok caldera (lat 53°28.3′ N., long 168°08.1′E.).
2. Upper welded agglomerate bed of type locality (p. 315).
3. Lower welded agglomerate bed of section (p. 317) at south slope, north arcuate ridge (lat 53°29.2′ N., long 168°06.5′ E.). Composition of hypersthene: En_{55-60}.
4. Upper welded agglomerate bed of section (p. 317) at same locality as 3.
5. Partly palagonitized agglomerate from bed at road cut; 300 feet east of bridge across Crater Creek (lat 53°32.8′ N., long 167°59.1′ E.).
6. Partly palagonitized agglomerate from bed at bottom of New Jersey Creek gorge (lat. 53°31.8′ N., long 168°04.5′ E.).
7. Pumice lapilli bed in northeast-facing sea cliff (lat 53°33.5′ N., long 168°04.9′ E.), 0.6 mile south 10° E. of Ashishik Point.
8. Pumiceous ash bed in north side Camp Creek gully (lat 53°23.6′ N., long 167°59.1′ E.).

(see below) suggest that the lower welded bed of the type locality is correlative with similar beds exposed several miles distant on the north slope.

Silica analyses and bulk specific gravity determinations on welded agglomerate beds of the Okmok volcanics

[Analysts: Leonard Shapiro, 3-8; author 1-2. Bulk specific gravity determinations by author]

	SiO_2 (weight percent)	Bulk specific gravity
Okmok Caldera (lat 53°28.3′ N., long 168°08.1′ E.):		
1. Lower welded agglomerate bed of type section (p. 315) at north wall	54.35	-------
2. Upper welded agglomerate bed of type section (p. 315)	57.40	-------
North arcuate ridge (lat 53°29.2′ N., long 168°06.5′ E.):		
3. Lower welded agglomerate bed of section (p. 317) at south slope	56.7	-------
4. Upper welded agglomerate bed of section (p. 317) at same locality as 3	n.d.	2.86
Crater Creek gorge (lat 53°28.0′ N., long 168°5.2′ E.):		
5. Dense aphyric lava of welded bed near top of southeast wall	54.0	2.80
6. Dark finely scoriaceous lava of welded bed, 2½ mi. northeast of 5, in upper part of southeast wall	54.0	-------
Crater Creek (lat 53°32.5′ N., long 167°59.2′ E.), a few hundred feet south of road bridge:		
7. Black, scoria fragment in palagonite agglomerate bed, possibly equivalent to lower welded bed of type section	53.7	-------
East arcuate ridge (lat 53°27.0′ N., long 168°2.8′ E.) at north end:		
8. Welded, dense aphyric agglomerate bed at top of section	52.6	2.84

The composition of the phenocrysts (column 4, table 11) and the bulk specific gravity of the upper welded bed exposed in the north arcuate ridge section indicate a basaltic composition. The 2 welded beds of the section at the type locality and the 2 in the north arcuate ridge section are not correlative from their petrographic and chemical character, although the upper welded bed (column 2) at the type locality may possibly correlate with the lower welded bed (column 3) of the north arcuate ridge section. The welded basaltic beds (Nos. 4 and 8) are limited to the upper parts of the two stratigraphic sections at the north and east arcuate ridges. The present work does not demonstrate whether the section at the north arcuate ridge is partly correlative with that at the type locality. Possibly, the pyroclastic beds exposed in the north and east arcuate ridges were deposited by an earlier caldera-forming eruption related to the origin of the arcuate ridges.

PARTLY PALAGONITIZED AGGLOMERATIC TUFF-BRECCIA

No beds completely welded over a large area are found along the seacoast; there they vary from loosely consolidated to moderately indurated. On the plain south of Cape Tanak, the brownish-gray agglomeratic tuff-breccia lies in huge remnant blocks over 2 square miles. These blocks are associated with old channel scars of Crater Creek and appear to have been undermined by removal of a loosely consolidated agglomerate bed from beneath a thick bed of moderately indurated tuff-breccia.

This tuff-breccia south of Cape Tanak contains as much as 20 percent of xenolithic fragments, which include medium- to dark-gray basalt, dark-gray to black vitreous andesite or latite, and yellowish-brown palagonite tuff. Abundant masses of juvenile grayish-black scoria are also enclosed in the palagonitic matrix which is light olive gray to dark yellowish brown. The vitreous latite (see column 17, table 2) is more siliceous than any known precaldera vitreous andesite and possibly represents chilled, unvesiculated juvenile lava of the Okmok volcanics. Less than 1 percent of euhedral to subhedral crystals of plagioclase, monoclinic pyroxene, and olivine are scattered through the grayish-black scoria clots and the matrix. The scoria clots include cryptocrystalline, nearly opaque amorphous material and clear, light-yellow to light-brown glass (see columns 5 and 6, table 11). The groundmass or matrix material enclosing the scoria clots consists mostly of a partly opaque, cellular cryptocrystalline aggregate that ranges from light to dark brown, less commonly greenish, in transmitted light. The refractive index of the aggregate is mostly slightly lower than that of balsam.

Though this aggregate was not chemically analyzed it closely resembles the groundmass of the palagonite tuffs of the Ashishik basalt both in outcrop and in thin section and is therefore presumed to be hydrated basaltic glass or palagonite.

RHYODACITE PUMICE BEDS

Light-yellowish-gray, unconsolidated pumice and pumiceous ash is associated in three places with agglomerate of the Okmok volcanics. On the south in-facing slope of the north arcuate ridge, 3½ feet of gray ash rests in sharp contact on 40 feet of partly indurated agglomerate, and is overlain by a 15-foot layer of welded agglomerate (see section, p. 317). In a sea cliff 0.6 mile southeast of Ashishik Point, 1½ feet of pumice lapilli ash rests on Ashishik basalt and is overlain by 20 feet of partly indurated agglomerate. On the east slope at an altitude of 1,000 feet, 2½ feet of gray pumice ash in the north wall of Camp Creek gully rests on partly indurated agglomerate and is overlain by loosely consolidated agglomerate. A few fragments of gray pumice were found in the partly palagonitized agglomerate at an altitude of 100 feet along Crater Creek near Cape Tanak. Petrographic analyses of two rhyodacitic pumice specimens are shown in columns 7 and 8, table 11.

BEDDED ASH

Massive, poorly sorted ash and bedded, sorted, unconsolidated ash in general forms the upper part of the Okmok volcanics. In the caldera walls, the thickness ranges from a few feet to more than 300 feet and averages about 170. (See page 315.) On the outer slopes the ash becomes distinctly sorted and thins rapidly with increasing distance from the caldera; less than 5 feet is exposed in the cliffs of the Bering Sea coast.

The bedded deposits consist mostly of 1 to 10 foot beds of well-sorted ash, lapilli, and fragments of accessory materials. A consolidated bomb bed, from 5 to 20 feet thick, is exposed near the bottom of the ash deposits in gullies on the upper slopes of the volcano and in places in the walls of the caldera. Abundant juvenile bombs, 1 to 2 feet long, consist of dark fine-grained aphyric lava, and xenolithic fragments of precaldera basaltic rocks locally as much as 3 feet in median diameter. Angular blocks, 1 to 3 feet across, litter the surface of the ash near the caldera wall and consist of fragments of Ashishik basalt, including palagonite tuff. With increasing distance from the caldera rim the xenolithic fragments become progressively smaller, and at the seacoast they average only about 1 inch in diameter.

ORIGIN AND EMPLACEMENT OF OKMOK VOLCANICS

The Okmok volcanics are thickest around the rim of Okmok Caldera, yet no recognizable deposits assignable to them are found within the caldera. The thick blanket of Okmok volcanics must therefore be related to the formation of the caldera itself, as Williams (1941) has demonstrated for many calderas throughout the world. The unsorted agglomerate and welded agglomerate beds of the lower part of the Okmok volcanics certainly must have been emplaced as a catastrophic eruption. The lack of bedding and poor sorting of the agglomerate clearly indicate that little if any winnowing of material took place. Furthermore, the presence of welded agglomerate beds also suggests that heat loss due to air transport was at a minimum. The deposits are therefore believed to have been emplaced as a red-hot emulsion of volcanic gases, molten juvenile particles, and minor lithic fragments—the glowing avalanche or *nuée ardente* (glowing cloud) type of eruption. The absence of the unsorted agglomerate from most of the higher ridges radial to Okmok Caldera further supports this hypothesis of origin.

The partly palagonitized agglomeratic tuff-breccia is not found within 2 to 3 miles of the rim of Okmok Caldera but occurs on the lower slopes of Okmok Volcano, where these partly palagonitized rocks occupy the same stratigraphic position as the nonpalagonitized agglomerate closer to the caldera. The change, moreover, from nonpalagonitized agglomerate to palagonitized agglomerate is gradational through a distance of about a mile. Xenolithic fragments are also more abundant in the partly palagonitized agglomerate, which with increasing abundance of xenolithic fragments grades into tuff-breccia. These features of the partly palagonitized deposits suggest that as the glowing avalanche reached the lower slopes, farther from the source vents, considerable water from melting snow and ice became admixed with the primary constituents of the glowing avalanche so that when the mass finally came to rest the juvenile particles were hydrated to palagonite. The texture of the partly palagonitized tuff-breccia in many exposures superficially resembles glacial till or, more likely, a mudflow deposit. This general impression suggests that some of the partly palagonitized deposits may have been emplaced as hot mudflows.

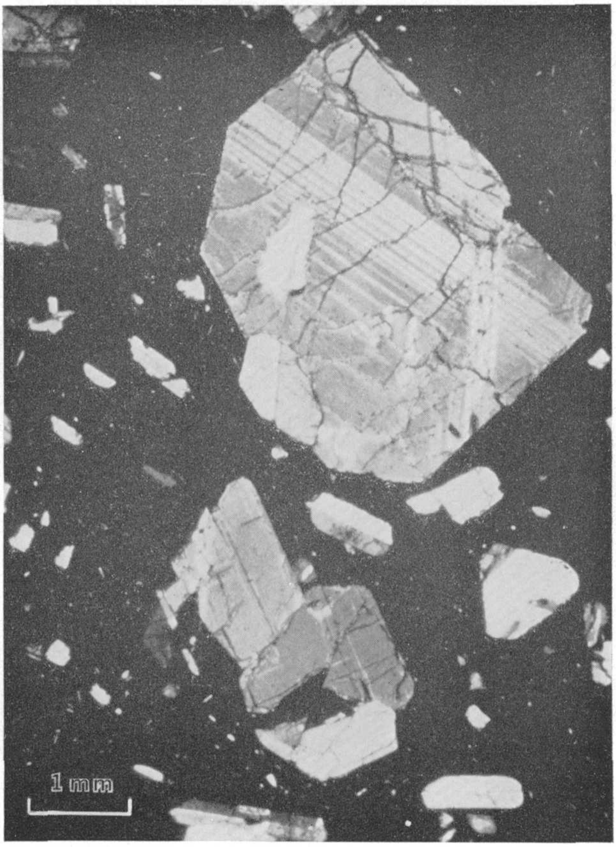
The greater abundance of xenolithic fragments in the partly palagonitized deposits may be due in part to the glowing avalanche picking up boulders enroute and in part to solidification of molten juvenile fragments with cooling. Part or all of the vitreous andesite-latite fragments in the tuff-breccia may actually represent chilled, unvesiculated juvenile lava. This same material closer to the source vents may have cooled more slowly into the finely microlitic lava of the welded agglomerate beds.

The bedded ash and lapilli in the upper part of the Okmok volcanics were emplaced as ash falls from explosive or vulcanian eruptions, in part associated with the caldera-forming eviscerating eruptions but in part subsequent to them. Generally, the bedded deposits are the product of the caldera-forming eruptions but include in the upper part an indeterminate amount of ash from postcaldera eruptions.

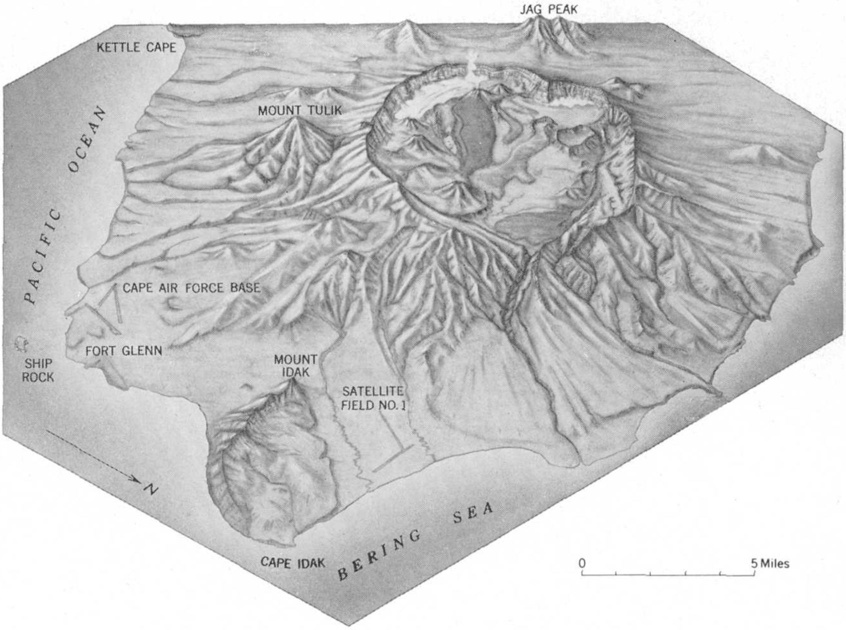
The part of the Okmok volcanics in the north and east arcuate ridges may possibly have been deposited as the result of an eruption earlier than that which deposited the pyroclastic material around the present caldera (see p. 319), but such deposits from an earlier caldera-forming eruption have not been recognized during the present study.

AGE OF THE OKMOK VOLCANICS

The Okmok volcanics postdate the last major glaciation of Okmok Volcano as neither they nor the wall of Okmok Caldera have been significantly glaciated. However, the carving of Crater Creek gorge 500 feet deep into basalt flows is all later than the Okmok volcanics.



Photomicrograph of anorthite phenocrysts in anorthite basalt flow (column 5, table 2). Crossed nicols.



Perspective diagram of Okmok Volcano viewed from the northeast.

Hence, the Okmok volcanics were probably emplaced shortly after the waning of the last main glacial epoch on Umnak Island and are therefore considered early Recent in age.

BASALT FLOWS OUTSIDE OKMOK CALDERA

Many slightly dissected flows, plugs, and cones of basaltic composition are outside Okmok Caldera and hence cannot be dated with respect to its formation. Vent lavas, such as plugs and cinder cone deposits, are discussed, where appropriate, with the flows with which the vent lavas are associated, though they are grouped together on plate 41 to reduce the number of color patterns. The relations of these youthful volcanic features to the Okmok volcanics could not always be ascertained, because ash from postcaldera eruptions has obscured critical contacts close to the caldera. At least one cone and its associated flow on the caldera rim are known to be precaldera in age. Some flows appear to be interbedded in the Okmok volcanics and are probably contemporaneous; two are shown on plate 41. One is in Missouri Creek about 2 miles north of Satellite field no. 2, and the other is near the mouth of Vermont Creek about 2 miles south of Satellite field no. 2. The unconsolidated pyroclastic debris of most cinder cones on the upper slopes of Okmok Volcano appears to grade laterally into bedded ash in the upper part of the Okmok volcanics, whereas some of the lava flows associated with the same cones pass under the bedded ash of the Okmok volcanics. Some of the cones and flows may predate the Okmok volcanics, but if the bedded ash in the upper part of the Okmok volcanics is actually postcaldera in age, some of these cones and flows may likewise be postcaldera in age.

MAFIC PHENOCRYST BASALT ON CALDERA RIM

Mafic phenocryst basalt dikes are exposed in the wall of the caldera southeast of cone *C*. The dikes connect with a cinder cone and small lava flow on the caldera rim. The rough flow surface is barren of ash, suggesting that the flow may be younger than most ash eruptions in the vicinity, yet the dikes, cinder cone, and the upper edge of the flow are all truncated by the wall of Okmok Caldera, thereby proving that they are precaldera in age. The basalt is porphyritic with phenocrysts of calcic plagioclase, augite, and olivine.

BASALT FLOWS ON THE ARCUATE RIDGES

A number of small plug-domes, cinder cones, and associated small lava flows with surfaces barren of ash form part of the crest of the north arcuate ridge and the east arcuate ridge. A line of similar extrusive rocks branches from about the middle of the east arcuate ridge and extends southeast down the outer slope of the volcano.

The rock in all these cinder cones and lava flows is dense, medium-gray, aphyric basalt. The volume is estimated at less than 0.1 cubic mile.

BASALT FLOW ON CAPE ASLIK

A large cinder cone, which has been slightly dissected by erosion, and an associated lava flow cover about 4 square miles of the lower western slope at Cape Aslik. The lava flow, which is 100 feet thick in the present sea cliff, extended a 3-mile section of the coastline nearly a mile seaward. There is no ash cover on most of the flow. The rock is aphyric basalt and its volume is estimated to be about 0.1 cubic mile.

BASALT FLOW NEAR CAPE IDAK

Two small cinder cones and one very small lava flow, with a surface barren of ash, overlie the ash deposit of the Okmok volcanics, which mantles most of the plateau between Mount Idak and Cape Idak. The rock is dark-gray dense basalt with a few small phenocrysts of plagioclase. These volcanic rocks are almost certainly of postcaldera age, for they rest on the Okmok volcanics.

ANORTHITE BASALT FLOWS NEAR INANUDAK BAY

Five cinder cones are alined easterly from Cinder Point in the head of Inanudak Bay. Anorthite basalt flows are associated with four of the cones. For convenience, these lavas are considered with those of Okmok Volcano even though these anorthite basalt flows near Inanudak Bay came from a separate alinement of vents closer to much earlier vents that extruded the volcanic rocks of central Umnak. The basalt flow at Cinder Point forms the shoreline including Cinder Point, and covers an area of about 0.6 square mile. Two miles inland, a narrow flow extends 1⅛ miles northwest from the second cone. Lava from the third and fourth cones to the east flowed south and coalesced to form a lava field half a mile wide and over a mile long. No lava flow was extruded at the fifth and eastermost cone. No ash covers the surface of the flows, and the cones and flows have not been modified by erosion, although the basal contact at the lower end of the eastermost flow is covered by alluvium. The rock in the cones and flows is porphyritic anorthite basalt with common to abundant phenocrysts of translucent sodic anorthite with a maximum length of 6 mm. The total volume of anorthite basalt is estimated at 0.04 cubic mile.

ROCKS OF POSTCALDERA AGE WITHIN OKMOK CALDERA

All the rocks within the caldera are obviously younger than the caldera. The most recent deposits are subaerial, and therefore younger than the shrinkage of a lake which temporarily filled the caldera to a depth of 500 feet above the present low point of the floor. Other deposits, contemporaneous with or older than the lake, show evidence of subaqueous eruption and are overlapped by lake beds or show erosional features associated with the changes of level of the lake. Major relations between some of these early deposits are shown in the diagrammatic profile (pl. 48 in pocket) taken approximately north through cones *C* and *D* in the southeastern part of the caldera. The oldest material in the profile is a chaotic assemblage of pyroclastic material that shows no systematic structure; elsewhere in the caldera the oldest deposits are relatively deeply eroded pyroclastic cones. Prominent benches ringing cones *C* and *D* are underlain by subaerial flows, which are between 1,350 and 1,400 feet in altitude. Below 1,350 feet they grade abruptly downward into brecciated pillow lavas, which were emplaced under water. The level of change at an altitude of 1,350 feet is consistent around both cones and indicates the altitude of the lake surface at the time of extrusion of the lava flows of cones *C* and *D*. The lake level rose subsequently to its highest altitude at 1,560 feet, which is marked by wave-cut scars on cones *C* and *D* and by the top of sediments deposited at or near the shore of the lake. This altitude is also the top of hard Crater Creek basalt at the low point of the caldera rim, into which the gorge of Crater Creek has been entrenched. Temporary halts in the lowering of the lake level, as the outlet stream deepened its gorge, are indicated by wave-cut scars nicked in cone *D* at altitudes of 1,140, 1,120, and 1,100 feet and by a prominent graded surface at 1,120 feet on lake sediments just north of cone *D*. A small, shallow remnant of the lake remains north of cone *D* at an altitude of about 1,075 feet.

ROCKS CONTEMPORANEOUS WITH CALDERA LAKE

EARLY POSTCALDERA PYROCLASTIC ROCKS

This unit includes bedded deposits of cones *G* and *H* in the northwest floor of Okmok Caldera (pl. 41), the material that comprises an unnamed cone older than and due east of cone *C* in the southeastern part of the caldera floor, and deposits of pyroclastic material whose source vents could not be determined. The pyroclastic debris not identified with recognized source vents may be part of a breccia that presumably formed the original floor of Okmok Caldera when it first subsided. The cones have very wide low craters with narrow serrate rims. The outer slopes consist of many radial ridges, fluted by gullies, and have the general appearance of badlands. The pyroclastic material of the cones is well sorted, fine-bedded unconsolidated ash and lapilli, randomly interbedded with layers of consolidated palagonitized tuff. Many xenolithic fragments ranging from a small fraction of an inch to blocks as much as 10 feet in diameter are randomly strewn through the sediments; most of them are of aphyric basalt but a few are of palagonitized tuff, similar to palagonitized tuffs of the Ashishik basalt. The juvenile material is fragmented cryptocrystalline scoria, shards of vesicular glass and palagonite, and broken crystals of plagioclase and pyroxene. Some shards consist of a core of clear, unaltered glass surrounded by a green to yellow to dark-brown palagonitic aggregate of microcrystalline altered material; other shards are entirely the palagonitic aggregate.

The eroded, wide-mouthed cones, containing as they do, bedded, well-sorted pyroclastic debris with a large amount of accessory xenolithic fragments, resemble Diamond Head on Oahu, Hawaiian Islands (Wentworth, 1926; Stearns, 1935), and are believed to be the products of phreatomagmatic eruptions caused when rising hot magma entered the water-saturated breccia beneath the caldera lake.

PLAGIOCLASE BASALT FLOWS OF CONES C AND D

Cones *C* and *D* are similar to each other but differ in form and rock type from all other cones in the caldera. Each consists of a cinder cone surmounting a terrace. The terrace is underlain by a lava flow that has structures and textures normal in subaerial flows in the upper part and pillow structures embedded in brecciated glass in the lower part (pl. 48). The physiographic form consisting of the cone, subaerial lava bench, and underlying pillow lava has been called a "tuya" by Mathews (1947) after Mount Tuya, a similar feature in northern British Columbia. Cone *D* is symmetrical with a single crater at the summit, exposing a vent plug of coarse crystalline basalt. Cone *C* is less symmetrical and near the summit has remnants of 5 different vents, one of which contains a plug of coarse-grained basalt. A line of active fumaroles crosses the lip of an asymmetric crater on the south flank, a hundred feet below the summit (Byers and Brannock, 1949, p. 724). Bedded palagonite tuff is exposed locally at one of the subsidiary vents. Most of the pyroclastic material of both cones *C* and *D* is dark ash and scoria, locally oxidized to brick red. The rock is porphyritic basalt, containing up to 25 percent of bytownite plagioclase phenocrysts, and about 1 percent each of olivine and monoclinic pyroxene phenocrysts, all less than 2 mm in greatest dimension. The abundance of phenocrysts is about the same, whether in the chilled margin of the pillows with glass groundmass, in the subaerial flows with aphanitic but crystalline groundmass, or in the plugs with ganular, gabbroid groundmass. The volume of material extruded from cones *C* and *D* is estimated at about 0.1 cubic mile.

BEDDED VOLCANIC SEDIMENTS

Bedded volcanic sediments are composed mainly of water-laid volcanic ash and silt and subordinate older dissected alluvium, graded to the surface of the caldera lake. They are scattered in small areas over all except the southernmost part of the caldera floor. The beds range in altitude from nearly 1,900 feet along the wall of the caldera to about 1,140 feet in the northeastern part, where Crater Creek leaves the caldera (pl. 41). The greatest exposed thickness is about 300 feet with the base not exposed. The older dissected alluvium stands highest west of cones *G* and *H* and is largely younger than these. The true lakebeds are of greatest extent in the center and southeastern part of the caldera floor below 1,560 feet, the altitude of a lakeshore scar on the flanks of cones *C* and *D* and the topmost horizontal beds in the lake terrace east of cone *D*. The lakebeds near the head of Crater Creek gorge are below about 1,120 feet, the altitude of a lakeshore scar in the pillow lavas of cone *D*.

The bedded volcanic sediments contain well-bedded silt, sand, fine gravel and lapilli; the silt beds are as thin as a fraction of an inch and the coarser material is in beds as much as several feet in thickness. Light-gray to light-yellowish-gray silt beds form as much as 60 percent of the lakebed section in the northeastern part of the caldera, but coarser materials form most of the deposits, near cones *G* and *H*, which may have contributed coarse debris to them. Blocks as much as several feet across constitute nearly 10 percent of the deposits near the caldera walls, but are less abundant away from the walls.

BASALTIC FLOWS LATER THAN CALDERA LAKE

BASALT FLOWS FROM CONE F

Cone *F*, a symmetrical cinder cone, and its associated lava flow of aphyric basalt are southwest of cone *C* (pl. 41), almost against the south wall of the caldera. The lava flowed northward from the cinder cone, apparently following a shallow valley cut in lake beds and material from cone *C* after the lake shore had withdrawn to a lower level. A modern glacier encroaches on the south flank of the cinder cone, and the lower end of the lava flow has been covered by more recent alluvium.

BASALT FLOWS FROM CONE E

Cone *E* is a composite cone in the west-central part of the caldera floor. One of its youngest lava flows reaches over 2 miles eastward beyond the center of the caldera floor, beneath flows of cone *A*. The cone contains a pit crater, 3,000 feet in diameter at the rim. The lowest part is concealed by a crater lake 500 feet below the rim. Interbedded pyroclastic rocks and lava flows are exposed in the crater walls down to lake level. Part of the lower outcrops consist of yellowish indurated palagonite tuffs, which may be older or contemporaneous with the caldera lake. The uppermost flows and pyroclastic material from cone *E* lie on a surface cut on lakebeds almost continuous with the present graded surface of the adjacent caldera floor. All the flows and most of the pyroclastic material from cone *E* are therefore considered younger than the lake of Okmok Caldera, although some pyroclastic material may be older. Pyroclastic material and the basalt flows are sparsely porphyritic, and their volume may be as much as 0.2 cubic mile.

WALL-FISSURE FLOWS

In the north wall of Okmok Caldera, just west of cone *B*, several steep-sided agglutinate cones are alined on a fissure nearly parallel to the caldera-wall scarp. Lava flows from two of the vents plaster the wall from just below the rim to the floor and more than a fifth of a square mile of floor. Small, thin flows from the other vents between altitudes of 1,400 and 1,950 feet cover part of the wall but do not reach the floor. The lava flow on the caldera floor has no alluvial cover but is partly covered by basaltic andesite flows from cone *B*. The rock is aphyric and very similar to the basaltic andesite from cone *B*. Comparable flow and vent material abuts against the southwest wall of the caldera west of cone *A*. The modern glacier partly covers these lava flows, and their extent on the caldera floor is obscured by erupted material from cone *A*.

BASALTIC ANDESITE FLOWS FROM CONE B

Two flows of aphyric basaltic andesite and the associated cinder cone form approximately 1¼ square miles of the surface of the northeastern floor of the caldera. The older lava flow, thinly mantled with red-stained ash from the cinder cone, extends no more than three-quarters of a mile from the cone. The younger lava is devoid of ash cover and is made up of several parts: a few small flows lie on the ash-covered lava near the cone, but most of the younger lava extends southward beyond the southern margin of the ash-covered flow, apparently having moved laterally beneath the old lava and reached the surface at vents along its southern edge. The surface of both flows is rugged and broken; blocks of jagged lava are as large as a small house. Near the cone, blocks of tuff and agglutinate as much as 80 feet across have been rafted out on the surface of the flow. The volume of material at cone *B* is approximately 0.015 cubic mile.

The two lava flows appear similar, and their textures vary no more than between different specimens from the same flow. Both may be products of one eruption, which might be one of those reported from northeast Umnak in the early nineteenth century (Grewingk, 1850, p. 128–133).

BASALT FLOWS FROM CONE A

Cone *A* is a large compound cinder cone near the southwest wall of the caldera. Fumaroles were still emitting sulfur dioxide and other gases in 1948 from summit crater (Byers and Brannock, 1949, p. 722). At least five different lava flows extend from the cone and cover 2½ square miles of the caldera floor. The oldest, a sparsely porphyritic basalt, extends north to cone *E* (pl. 41). Its surface is mantled with ash in contrast to the younger flows. Two ash-free aa flows extend from different flanks of the compound cinder cone and merge to form the lava field covering 1½ square miles of the floor to the northeast. A lava flow of June to August 1945, issued from the west flank of the cone, then moved south, east, and northeast along the southeastern margin of the large barren lava field. In December 1945, a second flow issued from the north flank of the cone and spread in a ramified pattern toward the north, covering parts of the older lava field in most of its course. Both flows of 1945 and the pre-1945 flows of the lava field northeast of cone *A* are of vesicular porphyritic basalt. The surface of all four flows is jagged aa, of the same color and "fresh" appearance; if the two flows of 1945 had not been observed during emplacement, it would have been impossible to distinguish their surfaces from those of the older aa flows. All activity at cone *A* may have occured since the Russians first sighted the island in 1741. The volume of lava erupted in 1945 is estimated at 0.005 cubic mile; that of all cone *A* material, at 0.02 cubic mile.

PETROGRAPHY OF OKMOK VOLCANO

The rocks of Okmok Volcano are predominantly feldspathic basalts. Common phenocrysts are plagioclase, diopsidic augite and olivine, in varying proportions; hypersthene is extremely rare in contrast to the volcanic rocks of Mount Reschesnoi and Mount Vsevidof on southwestern Umnak. The lava flows of Okmok Volcano range in texture from aphyric to porphyritic with phenocrysts constituting over a third of the volume in many. In general, porphyritic rocks are more abundant among the older lavas, aphyric rocks among the younger lavas, though both textural types are found throughout. Porphyritic basalts containing magnesian olivine and diopsidic augite are most abundant among the older lavas, whereas lavas ranging in composition from andesite to rhyolite were erupted only during a late stage of construction of Okmok Volcano.

OLIVINE-RICH BASALT

Olivine-rich basalt is represented by 9 out of the 200 rock masses sampled and studied in detail, in the lower part of the Ashishik basalt near Cape Idak and the ridge west of New Jersey Creek. As much as 25 percent of the rock is magnesian olivine (Fo_{75-90}) in euhedral to subhedral crystals (maximum size, 5 mm) in an intergranular groundmass of tabular plagioclase (An_{75}), euhedral to subhedral monoclinic pyroxene and olivine, and opaque oxides. Chemical and petrographic analyses of olivine-rich basalt are given in columns 1 and 1A, tables 2 and 3.

PLAGIOCLASE-OLIVINE BASALT

Porphyritic basalts containing phenocrysts of both plagioclase and olivine are much more abundant (48 samples) than those with only olivine. They are particularly common among the older lava flows of the plateau northeast of Mount Idak and of Mount Idak itself, and make up the bulk of the satellitic vents on the outer slopes of Okmok Volcano. A few are found in the main structure of Okmok Volcano. Euhedral to subhedral plagioclase crystals have the average composition of bytownite (labradorite in the analyzed sample from Mount Tulik), but the cores of most are anorthite. Magnesian olivine is in euhedral to subhedral phenocrysts, but some are embayed and have reaction rims of clinopyroxene. Augite is present as microphenocrysts as well as in euhedral to subhedral grains in the intergranular groundmass of tabular labradorite, clinopyroxene, olivine and opaque oxides. A chemical and petrographic analysis of a specimen from Mount Tulik is given in column 2, tables 2 and 3, respectively. The percentages of the groundmass constituents are clinopyroxene, 24 percent; tabular labradorite, 26 percent; opaque oxides, 5 percent; and a mesostasis of alkali feldspar and brown glass, 3 percent. Small grains of olivine are rare in the groundmass.

PLAGIOCLASE-AUGITE-OLIVINE BASALT

Porphyritic mafic phenocryst basalt with conspicuous phenocrysts of both olivine and augite as well as plagioclase are most abundant (20 samples) among the mafic phenocryst basalt flows of the Ashishik basalt. The plagioclase basalt flows of cones *C* and *D* within the caldera are described here, though they are on the borderline between mafic phenocryst basalt and feldspathic basalt.

The upper 20 feet of a mafic phenocryst basalt flow on the southeast slope of Okmok Volcano is exposed 3 miles northwest of the hangar at Cape Air Force Base. Augite phenocrysts are much larger and more abundant in the lava 20 feet below the top of the flow than at the top. In the specimen collected near the top of the flow (columns 3 and 3a, table 12) diopsidic augite phenocrysts range

TABLE 12.—*Petrographic analyses of mafic phenocryst basalt, Okmok Volcano*

[All phenocrysts or crystals referred to are greater than 0.2 millimeters]

	1	1a	2	2a	3	3a	4	5	6	7
Chemical analysis number (table 2)	1	1	4	4	----	----	9	----	----	----
Mode in volume percent:										
Phenocrysts or crystals:							[1]			
Plagioclase	0.0	0.0	19.5	23.5	19.9	20.4	68.5	28.0	8.1	27.4
Augite	.0	.0	12.7	12.2	4.4	4.1	20.6	.0	4.9	.8
Olivine	24.2	20.2	7.9	4.6	7.3	6.8	1.8	4.0	2.0	1.4
Opaque oxides	.05	.05	.0	.0	.0	.0	4.5	.3	.1	.1
Groundmass or intersertal material	75.7	79.7	59.9	59.7	68.4	68.7	4.6	67.7	84.9	70.3
Range in composition, plagioclase crystals	----	----	An_{87-94}	----	----	----	An_{34-93}	An_{68-92}	----	----
Average composition, plagioclase crystals	----	----	An_{91}	----	----	----	An_{75}(?)	An_{80}(?)	----	----
Average composition, groundmass plagioclase	An_{75}	----	An_{70}	----	----	----	----	----	----	----
Average β index of augite crystals	----	----	1.695	----	----	----	1.697	----	----	----
2V of augite crystals	[2] (55°)	----	54½°	----	----	----	48°–54°	----	----	----
Range in composition of olivine crystals	Fo_{81-90}	----	Fo_{76-86}	----	----	----	Fo_{59-71}	----	----	----
Average composition of olivine crystals	Fo_{86}	----	Fo_{84}	----	----	----	Fo_{65}	Fo_{80}?	----	----

[1] The smallest crystal is about 0.1 mm.
[2] Data on groundmass augite.

1. Olivine basalt flow at Cape Idak (lat 53°31.4′ N., long 167°47.8′ E.).
1a. Olivine basalt flow; same specimen as above but section cut perpendicular to No. 1.
2. Anorthite-augite-olivine basalt flow (lat 53°25.7′ N., long 167°55.5′ E.), 3 miles N. 25° W. of Umnak Airfield. Specimen collected at nonvesicular base of 20-foot outcrop.
2a. Anorthite-augite-olivine basalt flow; same specimen but different thin section cut perpendicular to No. 2.
3. Anorthite-augite-olivine basalt flow, same locality as 2. Specimen collected 20 feet above No. 2 at vesicular top of flow. Note lower content of augite phenocrysts.
3a. Anorthite-augite-olivine basalt flow, same specimen, but different thin section cut perpendicular to No. 3.
4. Augite basalt flow at base of northeast wall of Okmok Caldera (lat 53°27.3′ N., long 168°05.5′ E.)
5. Olivine-bearing bytownite basalt flow near Mount Idak. Specimen collected 700 yards north of summit at an altitude of 1,000 feet (lat 53°28.4′ N., long 167°53.6′ E.).
6. Bytownite-augite basalt flow at top of Idak Plateau sea cliff facing Umnak Pass (lat 53°29.1′ N., long 167°48.6′ E.); altitude 1,280 feet.
7. Olivine-bearing bytownite basalt flow near base of Idak Plateau sea cliff facing Umnak Pass (lat 53°30.0′ N., long 167°47.5′ E.); altitude 240 feet.

in size from 1 to 3 mm and make up about 4 percent of the rock. A specimen collected 20 feet below the surface of the flow (columns 2 and 2a, table 12) contains 12 percent of diopsidic augite phenocrysts as much as 10 mm in maximum dimension. The greater concentration of large diopsidic augite crystals below the top of the flow suggests gravity settling of diopsidic augite in this particular flow. Anorthite phenocrysts (An_{91}) are in normally zoned, euhedral to subhedral crystals as much as 2 mm long; magnesian olivine phenocrysts (Fo_{84}) are in euhedral to subhedral crystals as much as 3 mm in diameter. The groundmass is intergranular (average grain size about 0.03), holocrystalline, and composed of tabular plagioclase, monoclinic pyroxene, and opaque oxides.

Augite basalt, exposed at the base of the east wall of the caldera, has some porphyritic facies grading into finely granular facies. The granular facies (column 4, table 12) contains strongly zoned, euhedral to subhedral plagioclase crystals which range in size from about 5 mm to 0.1 mm and in composition from An_{93} to An_{34}. The crystals of magnesian olivine are euhedral to anhedral and rimmed with pyroxene except on crystal faces protected by older crystals from reaction with the groundmass liquid. The augite crystals also range in size from about 3 mm to 0.1 mm. Some brown glass has a refractive index of about 1.50—about the same as that of the rhyolite obsidian.

A suite of samples from cone *D* and cone *C* shows textural gradation from the chilled vitrophyric margin of a lava pillow to the holocrystalline facies in the plug in the summit crater of cone *C*. The chilled vitrophyre contains almost 19 percent of plagiocase, 0.5 percent of augite, and 1.2 percent of olivine larger than 0.2 mm. Many smaller crystals of the same minerals range down to microlites in a groundmass of glass (refractive index, 1.592), sparsely dusted with opaque oxide. All crystals are euhedral to subhedral, including the olivine. In the holocrystalline facies, the mafic phenocrysts are slightly more abundant, and the olivine crystals are slightly embayed and surrounded by pyroxene grains. A chemical analysis of a specimen from cone *D* is given in column 7, table 2.

ANORTHITE BASALT

The anorthite basalt flows near Inanudak Bay and the 1945 anorthite basalt flows from cone *A* are extremely rich in anorthite phenocrysts. These are set in a dark groundmass that is slightly more mafic than most feldspathic basalts from Okmok Volcano. Inconspicuous mafic microphenocrysts comprise less than 2 percent in nearly all of the 10 specimens examined. Despite the slightly more mafic groundmasses and the sparse microphenocrysts, some of the anorthite basalt flows nonetheless approach anorthositic gabbros in composition.

The high anorthite content, abundance, and size of the plagioclase phenocrysts in the lava flows near Inanudak Bay is unusual, even in basalt. The specimen from Cinder Point (column 5, tables 2 and 3) contains 30 percent of anorthite phenocrysts in a microlitic groundmass of labradorite, clinopyroxene, and opaque oxides, averaging about 0.02 mm across. Most of the anorthite phenocrysts are approximately equidimensional euhedral crystals as much as 6 mm in greatest dimension, but some are subhedral and somewhat embayed by the groundmass. A few crystals having a pink tint were observed. All are coated with a thin shell of calcic labradorite (about An_{65}). The large core of each is not conspicuously zoned, commonly shows Carlsbad, albite, and pericline twinning (pl. 49) and has a composition averaging An_{93} (see fig. 51 and table 13). Determination of the alkalis suggests

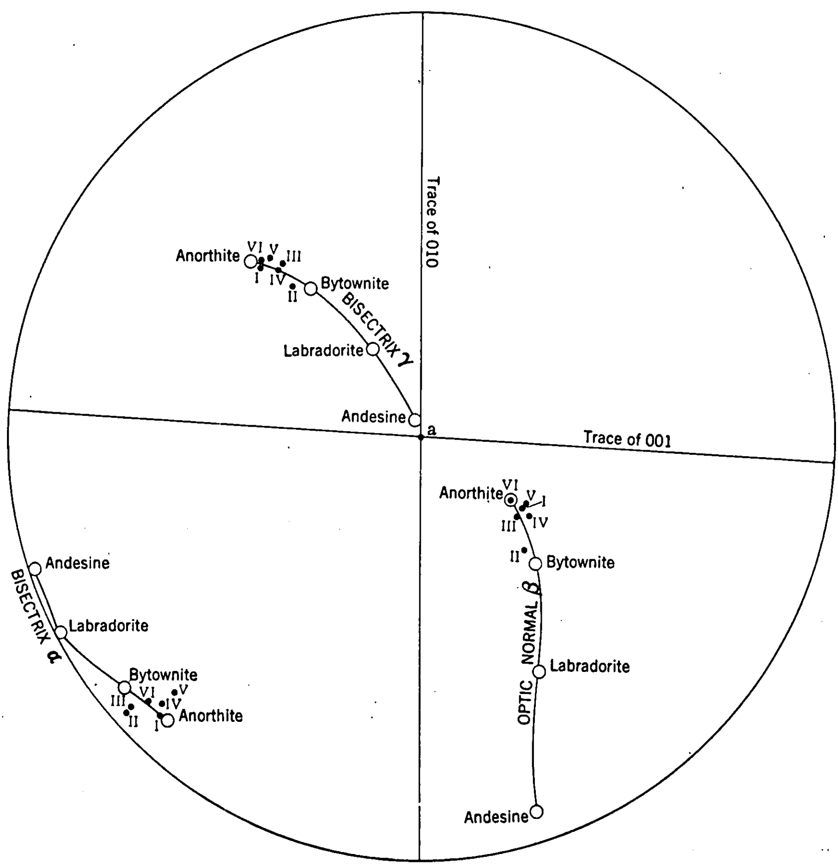


FIGURE 51.—Stereographic projection of bisectrices and optic normals of anorthite phenocrysts (nos. I to VI) in anorthite basalt projected on plane perpendicular to axis a. Open circles and curves after Duparc and Reinhard in Winchell (1933, p. 331).

TABLE 13.—*Optical data on anorthite phenocrysts in anorthite basalt near Inanudak Bay*

No. on fig. 51	2V [1]	Pericline twin plane and 001
I	(2)	−10°
II	79°	(2)
III	80°	(2)
IV	79°	−10°
V	(2)	(2)
VI	78°	(2)

[1] α is acute bisectrix.
[2] Unable to determine.

a composition of An_{91}. The same rock has some phenocrysts and microphenocrysts of olivine and a few of augite. The olivine crystals are all surrounded by a reaction rim of clinopyroxene, and those of augite by a reaction rim of opaque oxide and cryptocrystalline material.

A sample from the similar flow, 2 miles east of Cinder Point contains less than 5 percent of anorthite phenocrysts similar in composition to those at Cinder Point, a few microphenocrysts ranging up to a composition of An_{85}, and microlites of labradorite in a groundmass of glass with an index of refraction of 1.545. A few phenocrysts of olivine and augite have reaction rims comparable to those of the flow at Cinder Point.

The 1945 lava from cone *A* contains nearly 30 percent of phenocrysts of anorthite, 0.5 to 2 mm in length, and about 1 percent each of inconspicuous augite and olivine microphenocrysts (column 6, tables 2 and 3). The plagioclase crystals are slightly zoned from An_{93} to An_{89}. Olivine and augite are in euhedral to subhedral crystals; no reaction rim surrounds the olivine. The groundmass is microlitic, ranging from about 0.01 to 0.02 mm in average grain size, and contains plagioclase, clinopyroxene, and opaque oxides.

APHYRIC BASALT AND FELDSPATHIC BASALT

Four-fifths of the lava flows of Okmok Volcano consist of aphyric basalt and feldspathic basalt. The aphyric or nearly aphyric basalts consist almost entirely of a microlitic intergrowth of labradorite, clinopyroxene (pigeonitic?), and opaque oxides (see column 11, table 3), but all gradations may be seen between aphyric and feldspathic basalts by increase of plagioclase phenocrysts. Most of both varieties have rare microphenocrysts of augite. A few relict microphenocrysts of olivine can usually be found. The groundmass in similar, but more coarsely crystalline rocks, is intergranular, and the plagioclase crystals grade in size from the small phenocrysts to those in the groundmass. The olivine is commonly embayed and surrounded by a reaction rim of clinopyroxene. One typical microgranular feldspathic basalt contains about 17 percent of normally zoned phenocrysts of bytownite, a rare microphenocryst of augite, and a few embayed crystals of olivine surrounded by clinopyroxene reaction rims. The intergranular groundmass is composed of 38 percent laboradorite, 35 percent monoclinic pyroxene, 6 percent opaque oxides, and 4 percent interstitial light-brown glass (index of refraction, 1.498–1.503) and alkali feldspar.

ANDESITE AND LATITE

Rocks of andesitic to latitic composition form a few dikes, plugs, and stubby lava flows of the volcanic rocks of minor vents near the walls of the caldera, and occur as fragments in the pyroclastic rocks of Okmok volcanics. They are dark-gray to black, dense to glassy, nonvesicular rocks, commonly aphyric, and many contain small xenoliths of basaltic rocks. Most specimens have hyalopilitic groundmasses with varying amounts of glass. Microphenocrysts of plagioclase (An_{37} to An_{66}) are common to rare, and some rocks contain amhedral and embayed fragments of calcic bytownite (An_{80} to An_{88}). Anhedral fragments of augite, also embayed and commonly bent, are less abundant than those of calcic bytownite. Grains of olivine from several specimens have indices of refraction corresponding to the high fayalite olivines, hyalosiderite to ferrohortonolite (Fo_{50} to Fo_{23}) and contain no reaction rims of clinopyroxene. The index of refraction of the groundmass glass ranges from 1.545 in vitreous andesite to 1.511 in vitreous latite. Petrographic analyses of 4 specimens are given in table 14.

TABLE 14.—*Petrographic analyses of vitreous andesites and latite of Okmok volcano*

[Phenocrysts are all greater than 0.2 millimeters]

	1	2	3	4
Chemical analysis number (table 2)	15	----------	----------	17
Silica content (weight percent)	54.80	----------	[1] 60.2	63.5
Mode in volume percent:				
Phenocrysts:				
Plagioclase	0.2	0.8	1.1	4.7
Augite	.1	.1	.2	.3
Olivine	<.01	<.01	<.1	<.1
Opaque oxides	.1	.0	.2	.2
Groundmass	99.6	99.1	98.5	94.7
Range in composition of high-An plagioclase phenocrysts	An_{80-85}	----------	An_{84-88}	----------
Range in composition of low-An plagioclase phenocrysts	An_{50-66}	An_{37-57}	An_{46-55}	An_{43-58}
Range in composition of olivine phenocrysts	Fo_{50-70}	Fo_{23-34}	Fo_{23-35}	Fo_{30-35}
Refractive index of groundmass glass	(2)	1.545	1.530	1.511
Bulk specific gravity of rock	2.86	2.72	2.67	2.60

[1] SiO_2 determination by Leonard Shapiro, using rapid methods.
[2] Specimen contains a very fine microlitic groundmass charged with opaque oxides and hence the glass, if present, could not be determined.

1. Top of andesite pipe at intersection of Crater Creek gorge and Okmok Caldera (lat 53°28′ N., long 168°05.4′ E.)
2. Andesite flow exposed at 2,400 feet on south side, north arcuate ridge (lat 53°29.2′ N., long 168°06.6′ E.)
3. Top of small andesite plug or large block at 2,500 feet on north arcuate ridge (lat 53°29.3′ N., long 168°06′ E.)
4. Hand specimen of latite fragment in Okmok volcanics. Crater Creek canyon near Cape Tanak (lat 53°32.6′ N., long 167°59.2′ E.)

RHYOLITE

One apparently elongated dome of rhyolite was found on the outer northwest slope of Okmok Volcano. The rock ranges from light-gray felsitic vesicular rhyolite to nonvesicular black obsidian. Xenoliths of basaltic andesite are sparse to common in the obsidian but lacking in the felsite. The xenoliths apparently were being resorbed (pl. 47*B*) and fragments of laboradorite, augite and olivine in the rhyolite must be xenocrysts. Feldspar microlites in the glass have a composition of An_{25}, and the glass has an index of refraction of 1.497. Petrographic analyses are given in table 15.

TABLE 15.—*Petrographic analyses of rhyolite specimens and xenolithic inclusion, Okmok Volcano*

	1	2	3	4	5
Chemical analysis number (table 2)	19	----------	----------	----------	20
Mode in volume percent:					
Phenocrysts >0.2 mm:					
Plagioclase	0.5	0.2	9.4	4.0	0.0
Augite	.5	.4	.2	.6	.0
Olivine	.1	.1	1.8	.1	.0
Groundmass	98.9	99.3	88.6	95.3	100.0
Range in composition of plagioclase phenycrysts >0.2 mm	An_{65-70}	An_{67-70}	An_{67-70}	An_{67-85}	----------
Approximate composition, feldspar microlites in groundmass.	An_{25}	An_{25}	----------	----------	$Or_?Ab_?$
β of augite phenocrysts	1.712	----------	----------	----------	----------
Range in composition of olivine phenocrysts	Fo_{73-81}	[1] Fo_{78-84}	Fo_{74-82}	Fo_{68-77}	----------
Refractive index of groundmass glass	1,497	1.497	----------	1.497	----------
Bulk specific gravity of rock	2.40	2.41	----------	2.47	2.42

[1] Only one grain sampled.

1. Most vitreous obsidian band interlayered with less vitreous band and felsitic rhyolite near northwest end of northwestward extension of dome (lat 53°29.5′ N., long 168°10.3′ E.).
2. Most vitreous obsidian band interlayered with less vitreous band and felsitic rhyolite on northeast side of northwestward extension of dome (lat 53°29.2′ N., long 168°09.8′ E.).
3. Purplish basaltic andesite xenoliths in obsidian, same locality as 2.
4. Less vitreous obsidian band interlayered with more vitreous obsidian and felsitic rhyolite, same locality as 2.
5. Light-gray felsitic rhyolite, east end of dome on north side of north arcuate ridge (lat 53°29.4′ N., long 168°09′ E.).

PALAGONITIZED PYROCLASTIC ROCKS

Palagonitized pyroclastic rocks are most abundant and most completely altered in the agglomerate and tuff of the Ashishik basalt exposed in the walls on the outer slopes of the caldera. Partly palagonitized rocks are in the agglomerate of the Okmok volcanics more than 2 miles from the caldera, and in some of the pyrcolastic cones within it. The palagonitized rocks of the Ashishik basalt contain fragments of vari-colored scoria, gray to black xenolithic fragments, and broken crystals of plagioclase in a yellowish-gray, earthy matrix. Fragments of light-brown scoria contain cores of unaltered clear light-yellow glass rimmed by palagonitized glass. In different specimens, the index of refraction of the unaltered glass ranges from 1.560 to 1.575.

Fragments of yellow to orange-brown scoria consist of isotropic palagonite glass that ranges in refractive index from 1.54 to 1.57. The scoria fragments are slightly to moderately cellular with vesicles 0.05 to 0.1 mm in diameter. The xenoliths probably are broken wall-rock fragments of Okmok Volcano. Fragments of plagioclase, augite and olivine crystals may be in part xenocrystic as their abundance seems to vary directly with the abundance of xenolithic fragments. The matrix is a cryptocrystalline aggregate, apparently of palagonitized glass shards, as shard shapes are discernible in parts of the material. The cryptocrystalline palagonite is green, yellowish, to dark brown, as seen in plane-polarized light in thin section, and is made up of birefringent microlites in both felted and radial-fibrous texture.

Many vesicle fillings are compound and consist of a lining of concentric, moderately birefringent fibers, and a central filling of nonfibrous, low birefringent material with refractive indices 1.480 and 1.484 (chabazite ?). Some vesicles contain a yellowish to reddish-brown mineral in crudely spherulitic aggregates of curved concentric fibers with positive elongation, birefringence about 0.01, and index of refraction about 1.56 to 1.57. Another cavity-filling zeolite, in sheaflike aggregates of radiating fibers, has positive elongation, parallel extinction, and indices 1.467 and 1.470.

Chemical analyses of two specimens of palagonitized rock are given in columns 3 and 8 in table 2.

STRUCTURE OF OKMOK VOLCANO

The major structural features of Okmok Volcano—the caldera ring faults and the probability of two calderas—are mostly concealed by the Okmok volcanics and other pyroclastic debris. Therefore, their existence is in large part inferred from physiographic features and vent alinements, and by comparison with similar calderas elsewhere in the world. First, however, the known or observable structural features of Okmok Volcano are considered, followed by a discussion of the origin of the arcuate ridges.

Okmok Volcano is mainly composed of gently outward-dipping flows and interbedded pyroclastic rocks of the precaldera Ashishik basalt (see sections *AA′* and *BB′*, pl. 41). Dips greater than 5° are restricted to local vent masses of relatively small volume. The welded agglomerate beds of the east-central part of the north arcuate ridge actually dip gently southward toward Okmok Caldera. The low plateau between Mount Idak and Cape Idak is underlain by Ashishik basalt and minor pyroclastic interbeds that dip 2° to 3° northeastward, except in the eroded cone of Mount Idak. Inasmuch as the average outward dip of the layered volcanic rocks is less than the topographic slope, progressively younger flows are found as one ascends Okmok Volcano. Most of the dips observed in the Okmok volcanics are essentially parallel to the present topographic slope.

Okmok Caldera is in large part a feature of collapse and its infacing cliff walls are the slightly modified scarps of a ring fault. One fault, associated with the ring system, has been mapped. In the northeast wall of Okmok Caldera south of Crater Creek gorge (pl. 41), a fault that dips steeply southwest toward the caldera is exposed for about a mile. The southwestern block has subsided about 100 feet as shown by the displacement of a bed of welded agglomerate in the Okmok volcanics.

The bedded volcanic sediments in the caldera have been displaced in a few places by postcaldera movement, probably involving the caldera ring fault. Along the northwest wall, north of cone *H* (pl. 41), the bedded volcanic sediments dip as much as 30° toward the center of the caldera but decrease in dip at greater distance from the wall. Near the caldera wall south of the entrance to Crater Creek gorge, the lake beds dip away from the wall, with dips as much as 25° and open folds, too small to show on plate 41, have produced local ridges and closed depressions with a relief of 20 to 40 feet. These features were formed by postcaldera movements, but their location with respect to the caldera wall suggests that the fault involved is the caldera ring fault.

A few faults are radial to Okmok Caldera. Two north-striking faults are marked by scarps extending inland from the mouth of New York Creek on the north coast. The east block has dropped about 20 feet on each of these faults. A radial fault is suggested by the line of recent vents extending southeastward from the middle portion of the east arcuate ridge. Faultline control is suggested by the straightness of the cliffs bounding Mount Idak on the south and the northwest and by the parallel sea cliff along the southeast margin of the Mount Idak highland. Two hypothetical radial faults are also suggested by the north-trending cliff at the east end of the north arcuate ridge and by the northeast-trending cliff at the north end of the east arcuate ridge.

Three hypotheses are considered relating to the origin of the arcuate ridges.

As one hypothesis, the north and the east arcuate ridges (pl. 41) are possibly receding fault scarps controlled by a concealed underlying ring fault, between the caldera and the ridges. In the northwest wall of Okmok Caldera, north of cone *H*, a normal fault dips about 50° SE., toward the caldera. This fault separates Crater Creek basalt on the down-thrown side from the older Ashishik basalt (pl. 41) and may be a faulted depositional contact. About 100 feet of vertical displacement has occurred along this fault during or following the collapse of

Okmok Caldera, for the fault displaces the Okmok volcanics and can be followed as a recent scarp decreasiog toward the northeast (pl. 41). This fault, however, may have been localized along an earlier caldera fault, whose scarp is now the southerly slope of the north arcuate ridge. No trace of this hypothetical ring fault was found in the gap underlain by Crater Creek basalt between the north and the east arcuate ridges. Exposures of the Crater Creek basalt flows are continuous on each side of the gorge of Crater Creek in the area where the ring fault should be found; furthermore, the Crater Creek basalt is not disturbed or even flexed in this area. (See pl. 46*A*.) The exposure of older rocks of pre-Crater Creek age in the floor of the gorge is not continuous, so that this ring fault could be concealed. This fault or a similar fault intersects the east wall of Okmok Caldera northeast of cone *D* (pl. 41).

Two sets of ring faults are therefore suggested by the known faults, volcanic vents, and the topography: a younger ring fault bounding Okmok Caldera and truncating the Crater Creek basalt, and an earlier ring fault farther to the northeast, which bounds a possible older caldera whose rim includes the north and east arcuate ridges. The two Umnak calderas slightly separated in space and time are not unlike two similarly related caldera subsidences at the island of Mull, Scotland (Richey, 1935, p. 61–73; 1937, p. 13–25). The arcuate ridges are in part analogous to the elliptical arrangement of vent debris around Medicine Lake caldera in California (Anderson, 1941).

As a second hypothesis, the two ring faults referred to above may possibly have formed at nearly the same time during a single caldera-forming episode (Byers, Hopkins, Wier, and Fisher, 1947, p. 37). The present author no longer favors this hypothesis, because the slope of the arcuate ridges that faces the caldera has a subdued topography, blanketed by Okmok volcanics, in contrast to the youthful precipitous cliff of Okmok Caldera, and also because the thick sequence of many flows of the Crater Creek basalt at low altitude seemingly have been localized prior to Okmok Caldera in a gap between the arcuate ridges (see p. 313).

A third hypothesis is that the arcuate ridges are dominantly constructional. The vents that supplied the constructional debris were probably controlled by an underlying ring fissure (not shown on pl. 41), directly beneath the vents along the crest of the arcuate ridges. The chief evidence in support of this hypothesis is as follows: First, the many recent vents situated along the crest suggests that the arcuate ridges may have resulted from similar volcanic accumulations earlier in their history; secood, the gentle southerly dip of the Ashishik basalt on the south side of the north arcuate ridge is away from the crest of the ridge and toward Okmok Caldera; and third, the frequency of volcanic pipes and dikes is greater where cross sections of the arcuate ridges are exposed in the walls of Okmok Caldera and in the high cliff at the east end of the north arcuate ridge (the many dikes are not shown separately on pl. 41). Under the third hypothesis the growth of the arcuate ridges took place largely prior to the extrusion of the Crater Creek basalt, and no faults of large displacement would be required to account for the existence of the arcuate ridges. However, their origin is perhaps best explained by the first with subsequent modification under the third hypothesis.

ORIGIN OF OKMOK CALDERA

In the following discussion of the origin of Okmok Caldera an attempt is made to compare the missing summit mass of Okmok Volcano with the amount of xenolithic fragments in the known volume of Okmok volcanics, after the method used by Diller (1902) and Williams (1941 and 1942). Much and perhaps most of the original volume of the Okmok volcanics was deposited beyond the shores of Umnak, so the total volume of volcanic rocks cannot be calculated.

The total volume of rock missing from the summit of Okmok Volcano could easily be computed if the form and height of the missing portion on the site of the present caldera were known. Two possibilities are considered. As one possibility the missing central portion might have included an earlier caldera with relatively low summit area. The infacing cliff of the north arcuate ridge and the topographically low position of the Crater Creek basalt in the gap between the north and east arcuate ridges suggest that an earlier caldera may have existed. The gentle, radially outward dips of the precaldera volcanic rocks likewise suggest a low shieldlike volcano. As the second possibility the central portion might have consisted of a siliceous steep-sided pyroclastic cone surmounting the pile of Ashishik basalt. Although the vitreous andesitic lava fragments in the Okmok volcanics may represent chilled, juvenile lava, it is also possible that fragments of andesite, latite, and rhyodacite in the Okmok volcanics may have come from thick deposits of siliceous volcanic rocks closer to the central vent. An analogy to a possible form of Okmok Volcano prior to the caldera-forming eruption is afforded by the pyroclastic cone of Mount Vsevidof on southwestern Umnak. Were Mount Vsevidof to experience a caldera-forming eruption similar to that at Okmok, little evidence of the former presence of the cone would remain after caldera collapse except xenolithic andesitic scoria and dacitic pumice fragments of the cone in the pyroclastic ejecta beyond the limits of the caldera. Andesitic scoria fragments as lapilli and bombs in the Okmok volcanics are probably juvenile, though some of the broken fragments could conceivably have come from a precaldera cone. Hence, computations of the missing volume are made considering both possibilities as extremes.

Assuming an earlier caldera as one extreme, the average altitude of the summit area of Okmok Volcano prior to the caldera-forming eruption is estimated as 2,500 feet or about the same as the present average altitude of the caldera rim (fig. 52). The average altitude of the present caldera floor beneath the postcaldera deposits is estimated to be about 1,000 feet (fig. 52). The diameter of the summit area is taken as 5½ miles. The missing volume of rock calculated according to these assumptions would be about 7 cubic miles. As the other extreme, a pyroclastic cone is assumed with an average slope of 25° and a base, 5½ miles in diameter, at 2,500 feet (fig. 52), on top of and in addition to the minimum portion already computed. Under these assumptions the missing central portion of Okmok Volcano would be about 16 cubic miles. The actual missing volume is probably between 7 and 16 cubic miles.

The xenolithic fragments in the Okmok volcanics are probably derived from the mechanical disintegration of the former summit portion of Okmok Volcano. The volume of xenolithic fragments observed in thin sections of the welded agglomerates averages less than one percent (see table 11), but the sections were taken from samples selected so as not to include the larger xenolithic fragments. The welded agglomerate beds as observed in outcrop were estimated to contain at least 10 percent of xenolithic fragments (see pl. 47*A*). The two specimens of partly palagonitized agglomerates studied (see table 11) contain 15 to 20 percent of xenolithic fragments, and from a study of many outcrops 20 percent is believed to represent nearly the maximum content of xenolithic fragments. If we assume that an overall average of 15 percent of xenolithic fragments is in the 7 cubic miles of the Okmok volcanics deposited on Umnak (see p. 315) only about 1 cubic mile of the missing summit portion of Okmok Volcano is represented in the known portion of the Okmok volcanics. Even if the minimum figure of 7 cubic miles is assumed for the volume of the missing summit, at least 49 cubic miles of Okmok volcanics would have been deposited in order to contain the missing summit as xenolithic fragments, or 42 cubic miles of the pyroclastic rocks deposited beyond the present shoreline. Such a figure seems unreasonably large in view of the thinning of the Okmok volcanics from an average of about 300 feet at the caldera rim to an average of about 100 feet at the present coastline. Hence, most of the missing summit of Okmok Volcano is believed to have collapsed inward to form the present Okmok Caldera.

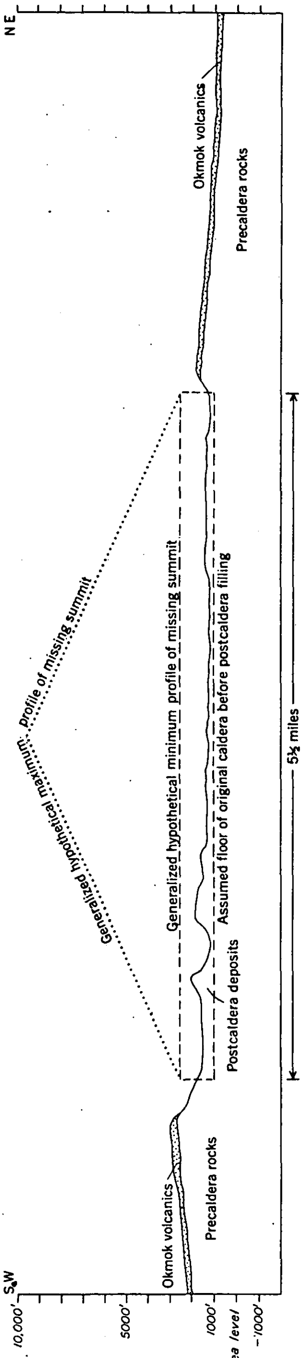


FIGURE 52.—Profile through the summit area of Okmok Volcano, showing idealized maximum (dotted) and minimum (dashed) profiles used in computing volumes of missing summit.

SURFICIAL DEPOSITS

The surficial deposits on Umnak Island range in age from late Pleistocene to Recent and comprise till, glacial outwash, beach deposits, dune sand, talus and alluvium.

TILL

Two tills have been differentiated on the geologic map. The older till is restricted to the southwestern part of the island, where it occurs on the slopes of Mounts Vsevidof and Recheschnoi (pl. 40). Near the base of these mountains the older till occurs as isolated patches of end moraines as high as 100 feet. Upslope from these end moraines the older till forms a discontinuous mantle of ground moraine on some of the gentler surfaces. Downslope from the moraines on the piedmont surface south of Mount Vsevidof are a few patches of older till, which were impractical to map because of the thick tundra cover. It is not known whether these patches represent a farther advance of the same ice that deposited the end moraines or whether they date from an earlier and more extensive glaciation. (Geomorphic evidence for this earlier glaciation is discussed under the heading "Nikolski Plain.") No soil profiles were measured on the older till but it has been exposed to weathering long enough so that it supports blueberry bushes.

The older till unconformably overlies the bedrock volcanic rocks, including the older lava flows of Mount Vsevidof. It is in turn overlain by the younger till, outwash, alluvium, and the oldest of the beach deposits. If, as is inferred below (see p. 345), the oldest beach ridges date from the post-Wisconsin thermal maximum of about 5,000 years ago, the till must antedate the thermal maximum and is therefore designated as Wisconsin(?) in this report. It may coincide with Sharp's (1951, p. 100) "later glaciation" in the Wolf Creek area of the St. Elias range, Yukon territory. Sharp dates this glaciation as latest Wisconsin and post(?)-Wisconsin.

The younger till occurs on the slopes of Mounts Vsevidof and Recheschnoi in the southwestern part of the island (pl. 40) and within Okmok Caldera (pl. 41) in the northeastern part. Its distribution is closely related to the pattern of existing glaciers, and it was evidently deposited in the very recent past when the glaciers were more extensive than they are today. In Okmok Caldera the younger till is represented by small patchy end moraines, many just below small rudimentary cirques in the caldera wall. One approximately half way between cones *G* and *H* represents the maximum advance of a postcaldera glacier here. Another is at the base of the east wall 1½ miles southeast of cone *D*. Some small moraines of the younger till probably have been buried by the recent lavas of cone *A*. The younger till consists entirely of unweathered bouldery debris. In contrast to the older till, which supports bushes, the exposed surfaces of the younger till are nearly bare. Some of the boulders in the end moraines of the younger till on Mount Recheschnoi are brightly stained by iron oxide that may have been developed by weathering prior to glacial transport. The younger till rests unconformably on the older till, the bedrock lavas, and the early postcaldera pyroclastic rocks in Okmok Caldera and is overlain only by some of the most recent alluvial deposits.

The unweathered character of the younger till and its areal association with existing glaciers indicates that it was deposited in late Recent time, possibly during Matthes' "Little Ice Age," (Matthes, 1941; Thorarinsson, 1939; Ahlmann, 1948; Lawrence, 1950; Sharp, 1951; and Mathews, 1951).

OUTWASH

Outwash consisting chiefly of boulder gravel fills most of the valleys that lead from existing glaciers on southwestern Umnak (pl. 40). The outwash ranges in age from that deposited penecontemporaneously with the younger till to that which is being laid down today. No outwash correlative with the older till was identified, although some remnants of older glaciofluvial deposits are probably preserved locally.

BEACH DEPOSITS

Beach ridges are found along both the northeast and southwest coasts of Umnak Island and are best developed behind those broad bights where the longshore currents and waves are generously supplied with glaciofluvial sediments. In several areas the supply of sediment has been sufficient to permit the seaward extension of the coastline more than one-half mile. Stages in this extension are marked by 12 or more concentric beach ridges subparallel to the present coastline. Along the Pacific side of Umnak, between Amos and Russian bays (pl. 40), 20 arcuate concentric beach ridges were deposited. No precise altitudes were measured, but the innermost or oldest ridge seemed to be roughly 10 feet higher than the outermost or youngest ridge.

The material of the beach ridges ranges in size from sand up through boulders. For convenience in mapping, those beach deposits that consist primarily of sand and pebble gravel have been called sand beaches and those which consist of coarser material have been called boulder beaches. In general, the boulder beaches are small and are insignificant, and are found chiefly in the smaller coves exposed to the open sea. Hypersthene andesite talus blocks from sea cliffs on some exposed headlands have been rounded by storm-wave action into nearly perfect spheres up to 6 feet in diameter.

Concentric beach ridges subparallel with the present shoreline have been observed by the author on Unimak, Akun, Akutan, and Unalaska islands in the eastern Aleutians and on Attu in the western Aleutians. Bradley (1948, p. 226) describes concentric beach ridges on Adak and also describes a wave-cut terrace along Kulak Bay on Adak Island, about 10 feet above present sea level. Bradley ascribed the higher beach ridges and the wave-cut bench to tectonic uplift of Adak Island. However, the presence of beach ridges and wave-cut benches at about the same altitude above sea level on so many of the Aleutian Islands, suggests a small eustatic fall of the sea rather than tectonic uplift.

Beach ridges, wave-cut benches, wave-cut cliffs and other shoreline features subparallel to the present coastline, record a recent stand of the sea roughly 10 feet (3 meters) above present sea level in many parts of the world. Many investigators have postulated that this higher stand of the sea coincided with the post-Wisconsin thermal maximum. (See Fairbridge, 1948, p. 62–63; Idem, 1950, p. 181–184; MacNeil, 1950, p. 1307–1308; Newell and others, 1951, p. 11; Ives, 1951, p. 220–221; Upson, 1951, p. 425–427.) The writer suggests that the oldest beach ridges on Umnak Island were formed during the same high stand of the sea that was responsible for the 3-meter shoreline elsewhere in the world and, therefore, presumably date from the post-Wisconsin thermal maximum.

According to Flint and Deevey (1951, p. 275–278), the thermal maximum occurred 4,000 to 6,000 years ago, and a reasonable check on the correlation of the oldest beach ridges of Umnak with this period is provided by a carbon-14 age determination of charcoal from the Nikolski archeological site. The Nikolski site is on top of one of the older gravel beach ridges (not shown on pl. 40) along the southern shore of Mueller Cove in Nikolski Bay. The material at the site consists of windblown silt, volcanic ash, and human occupational debris (William S. Laughlin, written communication, 1951). A carbon-14 age determination of charcoal collected from a level about 150 centimeters above the top of the beach gravel gives an age of 3,018 $\pm$ 230 years, (Arnold and Libby, 1951, p. 118). By extrapolating from the dated layer, Laughlin (written communication, 1951) estimates that the oldest deposits in this site are about 5,000 years old. Therefore, the beach ridge on which the site rests is probably older than 5,000 years, and may well have been formed during the thermal maximum.

SAND DUNES

Sand dunes derived principally from the beach deposits are encroaching on and burying their parent materials along several parts of the coastline, particularly on western and northern exposures, where on-shore winds frequently exceed 100 miles per hour during the winter months. The average height of the dunes in most areas is about 30 feet but some of the larger dunes at Geyser Bight, Russian Bay, and back of the bight south of Mount Vsevidof, are as high as 75 feet. Most of the dunes were active in 1947; a few were stabilized and partly covered with grass.

TALUS AND OTHER COLLUVIUM

Talus and other colluvium in the form of cones and aprons are at the base of all, or nearly all the steep slopes on the island, but only locally are the deposits large enough to warrant separate mapping. In most places they have been included with the pyroclastic debris, and on the slopes of Mount Recheschnoi they have in places been included with the older till.

ALLUVIUM

Recent alluvium consisting chiefly of reworked pyroclastic material has been deposited as alluvial fans by intermittent streams, and as flood plain deposits by the larger streams that are not fed directly by glaciers. The larger areas of alluvium have accumulated at low altitudes just inland from the oldest of the beach ridges. The largest area in the southwestern part of the island underlies the flood plain of the stream draining into Geyser Bight (pl. 40). In the northeast part of the island are several large areas of alluvium. One area covers about 5 square miles just northwest of Mount Idak (pl. 41), and another area of nearly 7 square miles has accumulated behind the beach ridges north of Cape Kigunak. Still another area is found at Izhiga Cove, where no beach ridges are present and the alluvium has been subject to marine erosion. The alluvium rests on all bedrock and surficial deposits except some of the most recent glacial outwash and some of the most recent flows within Okmok Caldera. These outwash deposits and flows locally overlap alluvial deposits. Although alluvium is currently being deposited by many streams, at several localities, especially near the coast, erosion is actively gullying older alluvial deposits. The gullied deposits may well be graded to the higher beach deposits and therefore may be as old as 5,000 years.

GLACIER ICE

For convenience, glacier ice has been included under the category of surficial deposits. Except for an arcuate patch of ice, probably stagnant, along the south rim of Okmok Caldera (pl. 41), the existing glaciers on Umnak are confined to the southwestern part of the island on the slopes of Mount Recheschnoi and Mount Vsevidof (pl. 40). Altogether, there are 9 major valley glaciers on these 2 mountains, and in addition several small glaciers and perennial snowfields. Seven of the 9 glaciers head from the central summit ridge of Mount Recheschnoi; 4 drain to the north and are in general longer and narrower than the 3 which drain to the south. The north-flowing glaciers extend down to altitudes of 200 to 300 feet, whereas the south-flowing glaciers, although bigger in volume, terminate at altitudes ranging from 500 to over 1,000 feet. Possibly the south slope of the mountain is both warmer and moister than the north slope; therefore, although the supply of ice may be greater, the wastage is also more rapid and the fronts terminate at higher altitudes than those on the north side.

Both glaciers on Mount Vsevidof head in the extinct summit crater. One drains to the north and divides into two branches about 1 mile from the crater. The other glacier flows east, then south, joining the westernmost glacier of Mount Recheschnoi. These two glaciers from Mount Recheschnoi and Mount Vsevidof are separated by a medial moraine.

All 9 valley glaciers have excavated their valleys to depths of about 500 feet. The termini of 8 of the glaciers lie close to the end moraines of the younger till, the exception being the most westerly of the glaciers of the north slope of Mount Recheschnoi. The terminus of this glacier is more than 1 mile back of its recent end moraine, indicating that for some reason this glacier has retreated more rapidly than the others of Umnak Island.

EROSIONAL FEATURES

Three major physiographic features, not directly associated with either the volcanic deposits, or the surficial deposits, are described and interpreted in this section. These features are Crater Creek Valley, pedimentlike slopes on Okmok Volcano, and the Nikolski plain.

CRATER CREEK VALLEY

Crater Creek heads in Okmok Caldera, from which it flows northeast about 8 miles, entering the Bering Sea about 1½ miles southeast of Cape Tanak (pl. 50). For a distance of about 2 miles from the rim of the volcano, Crater Creek flows in a deep gorge cut into the volcanic rocks of Okmok Volcano. The gorge is the result of downcutting of the outlet of the lake that once occupied Okmok Caldera. The gorge thus postdates the formation of the caldera and the 1,560-foot level of the caldera lake. Many small cascades 5 to 10 feet high, and one large waterfall 80 feet high indicate that rapid downcutting of the gorge is still in progress. Downstream from the gorge, Crater Creek crosses a broad gently sloping plain south of Cape Tanak. Many strath terraces and abandoned channels subparallel to the present valley of Crater Creek indicate that the stream has wandered widely during its dissection of this plain. Two principal sets of terraces were noted; one about 200 feet above the present valley floor and the other about 50 feet above the present stream bed (see pl. 50).

PEDIMENTLIKE SLOPES ON OKMOK VOLCANO

Most of the lower slopes of Okmok Volcano (pl. 50) are gentle, concave-upward erosional surfaces that in less humid climates would be called pediments. The surfaces start at altitudes ranging from 700 to 900 feet with gradients of 200 feet per mile that gradually flatten seaward to about 100 feet per mile. The slope of the volcano just above the heads of the pediments is 250 to 500 feet per mile. Recent gullies of the perennial streams have been incised about 100 to 200 feet into the pedimentlike slopes (pl. 50). The bedding in the Okmok volcanics parallels the lower pedimentlike slopes, which are in many places constructional surfaces. Whether the pedimentlike surface on the Okmok volcanics reflects a buried erosion surface or is merely the result of smoothing a buried irregular topography could not be determined.

THE NIKOLSKI PLAIN—EVIDENCE OF AN OLDER GLACIATION

The southwestern part of Umnak Island (pl. 40) consists of a gently rolling piedmont plain with a relief of less than 300 feet, herein called the Nikolski plain. Except for a few scattered patches of questionable till and some flanking beach deposits, the Nikolski plain is free of surficial deposits, but its surface is dotted with many undrained depressions, some of which serve as basins for small lakes. A few of the lakes near the coast have been drained by the cutting down of their outlets, and all of these former outlets are now youthful V-shaped gorges. The majority of the lakes have not been altered since they were formed.

A study of the air photographs of the islands south of Umnak suggests that they also have been glaciated. Kigul and Ananiuliak Islands (see pl. 39) consist of rolling surfaces with undrained depressions similar to the Nikolski plain, suggesting that the glacier extended a considerable distance south of the present shores of Umnak.

Comparison of the relatively flat level surface of the Nikolski plain with the flat submerged continental shelf area of the Aleutian Ridge (see pl. 39) suggests that the Nikolski plain is an uplifted portion of the shelf somewhat modified by extensive piedmont glaciation. Studies in the Near Islands of the western Aleutians (H. A. Powers, J. P. Shaefer, and others, oral communications, 1950) indicate similar widespread glaciation of both the islands and the continental shelf areas.

The overall lack of drainage integration of the Nikolski plain suggests that the glaciation of the area was late Pleistocene, possibly Wisconsin in age. Capps (1937, p. 161–168) has described and illustrated similar features on Kodiak Island, and ascribes them to the latest Pleistocene or Wisconsin stage. Further work is necessary to substantiate this hypothesis. If the piedmont glacier that extended over the Nikolski plain and the island south of Umnak represented one of the late Wisconsin substages, it is possible that the older till of the end moraines (Qmo pl. 40) may represent some post-Wisconsin advance of the ice.

GEOLOGIC HISTORY

The earliest known geologic event was the deposition of a thick sequence of waterlaid bedded tuffs and volcanic muds, whose metamorphosed equivalents are now bedded tuff and argillite of the albitized sedimentary and igneous complex, exposed on southwestern Umnak Island. This event possibly took place as early as late Paleozoic time but more likely occurred sometime between the early and middle parts of the Tertiary period. Following deposition, the bedded tuff and argillite was folded along northwest axes, which are at a high angle to the present trend of the Aleutian arc. It is not known whether extrusion and intrusion of igneous rocks, now keratophyres and albitized dioritic rocks, occurred prior to or following the folding.

Volcanism probably continued intermittently until sometime in the middle to late part of the Tertiary period, when the plutonic rocks were emplaced. The plutonic mass was largely quartz diorite varying to diorite and quartz monzonite. In the latest stages of consolidation of the plutonic mass, granophyre dikes were injected and portions of the dioritic mass adjacent to the granophyre were altered to a rock richer in quartz, orthoclase, and hydrous ferromagnesian minerals. A related and possibly contemporaneous alteration locally affected masses of the Tertiary lavas to produce quartz, chlorite, serpentine, zeolites, adularia(?), epidote, green amphibole, tourmaline, and rare iron sulfides.

Following emplacement of the quartz diorite pluton, erosion exceeded volcanism during uplift in late Tertiary and early Quaternary time. Extensive erosion surfaces, at least in part marine, were cut on the plutonic and older rocks, although minor volcanism continued near the narrow part of Umnak. Volcanic activity possibly may have begun at the sites of Mount Recheschnoi and Okmok Volcano during the latter part of this erosional episode.

The building of the composite hypersthene andesite cone of

Mount Recheschnoi probably had begun by early Quaternary time. The mafic phenocryst basalt of Kshaliuk Point was probably extruded during the same interval, though it might possibly have been extruded in latest Tertiary time. During the Pleistocene epoch, the central vent of Mount Recheschnoi moved westward. During Pleistocene glacial maxima, Mount Recheschnoi was deeply dissected by mountain glaciers, but cone-building activity predominated over glacial erosion. In latest Pleistocene or early Recent time a pyroclastic flow of hot wet mud and lava poured down a glacial valley 2 miles southwest of Russian Bay, and basaltic andesite was extruded at the site of Mount Vsevidof.

Meanwhile on northeastern Umnak the upbuilding of Okmok Volcano had begun probably sometime during latest Tertiary or early Quaternary time. The earliest eruptions consisted largely of mafic phenocryst basalt flows of the Ashishik basalt. A few feldspathic basalt flows also were extruded in the early stages of the upbuilding of the volcano. As Okmok Volcano grew, explosive eruptions extruded gas-charged pyroclastic material that became palagonitized upon emplacement. As the extrusion of the basaltic rocks comprising the Ashishik basalt neared completion, feldspathic basalt flows formed the dominant extrusive product. During the latest stages of Ashishik activity and immediately following, domes and short viscous flows of vitreous andesite and subordinate rhyolite were extruded close to potential fissures along which subsidence later took place. Satellitic vents extruded viscous lavas charged with olivine and plagioclase crystals. These lavas accumulated into steep-sided piles, such as Mount Tulik.

An early caldera block may have subsided just inward from the present site of the arcuate ridges shortly after the extrusion of the andesite-rhyolite association. A wedge-shaped volcanic sector graben may likewise have subsided at the gap between the north and east arcuate ridges. Whatever the origin of the gap between the arcuate ridges, a topographically low, seaward-sloping surface probably existed prior to the outpouring of the Crater Creek basalt.

During the latter part of Pleistocene and early Recent time, flows of the Crater Creek basalt were extruded from vents situated somewhere within what is now Okmok Caldera. At least 15 flows poured northeastward through the gap between the arcuate ridges. Toward the end of the period of extrusion of the Crater Creek basalt, a few small cones and flows of basalt were extruded on the outer flanks of Okmok Volcano. The stage was now set for the catastrophic caldera-forming eruption.

A catastrophic eruption at the summit of Okmok Volcano deposited the Okmok volcanics during early Recent time. The earlier phase of the eruption appears to have been peleean and consisted of gas-charged glowing avalanches (nuées ardentes). As the eruption increased in violence, red-hot glowing avalanches of molten bombs were welded together when they stopped moving to form continuous beds of welded agglomerate close to the source vents. The glowing avalanches were gas-charged and had great mobility as they moved swiftly down the slopes of Okmok Volcano. By the time they came to rest on the lower slopes, the avalanches had cooled and incorporated water from snow and ice so that they became partly palagonitized. The later phase of the eruption appears to have been violently vulcanian and consisted of showers of dark andesitic ash, bombs, lapilli, and large xenolithic blocks of earlier basalt and palagonitized rock to form a widespread blanket as much as 300 feet thick near the source vents.

Very soon after the catastrophic eruption, the central part of the caldera collapsed to form Okmok Caldera inside a new ring fissure eccentric and 1 mile south with respect to the hypothetical earlier ring fissure suggested by the arcuate ridges. Immediately after collapse, the newly formed Okmok Caldera began to fill with water. Early postcaldera eruptions built bedded debris cones under water. Basalt flows of cones *C* and *D* were extruded when the water level of the lake had reached an altitude of about 1,350 feet. The highest recorded level of 1,560 feet was reached when the lake spilled over the lowest point on the hard upper surface of Crater Creek basalt near the present Crater Creek gorge. Further eruptions furnished material that was sorted into beds of silt and sandy ash by the lake. Foreset beds whose upper constructional surface was graded to the 1,560-foot lake level were formed. As the lake outlet was cut into the Crater Creek basalt, Crater Creek gorge was formed, and wave scars on the lava flows of cone *D* were recorded at 1,140, 1,120, and 1,100 feet.

On southwestern Umnak, late or post-Wisconsin glaciers deposited the belt of older end moraines on the piedmont surface south of Mount Vsevidof and Mount Recheschnoi. The glaciers then receded to positions high in the mountains—some may have disappeared completely. At the same time the sea level rose in response to the world-wide deglaciation to a level 3 meters above present sea level, and Umnak enjoyed a slightly warmer climate during the post-Wisconsin thermal maximum than at present. Near the seacoast the older end moraines were partly buried by beach sand; older, now dead sea cliffs were cut by storm seas higher than present seas.

A succession of beach ridges was deposited in favorable bights as the sea withdrew from its 3-meter stand.

As the sea level continued to drop from the 3-meter level to its present stand, the glaciers on southwestern Umnak and those in Okmok Caldera advanced to the positions marked by the unweathered terminal moraines within less than 1 mile of the present glacier fronts or cirque heads. Northwesterly winds built parabolic sand dunes behind beaches with westerly and northerly exposures. The date of the most recent glacial maximum recorded on Umnak probably coincided with that of the worldwide glacial maximum, 100 to 300 years ago. Following their maximum extent, the glaciers have receded. The greatest recession occurred in those glaciers that had previously been most successful in extending their fronts to a low altitude.

While the glaciomarine events were taking place during the early part of the Recent epoch, the quartz-olivine andesite flow, the rhyolite domes, and the youngest hypersthene andesite flows of Mount Recheschnoi were extruded. Basaltic andesite flows continued to accumulate at the site of Mount Vsevidof. Toward the end of this period the cone of Mount Vsevidof attained its present height by a succession of frothy pumice and scoria eruptions. Lava flows, ranging in composition from basaltic andesite to latite poured out over the pumice and scoria on the north, south, and west sides of the volcano, probably beginning shortly after the culminating summit eruption and continuing into historic time. A chain of cinder cones was built along a rift extending down the west slope. Several lava flows were extruded from this west rift and formed Cape Kigushimkada. The latest flow was latite from the west rift and probably was extruded during the recorded historic eruption of 1878. The most recent activity, probably on the west flank, was reported in 1957.

On northeastern Umnak the most recent volcanic activity occurred within Okmok Caldera, although outside the caldera a few piles such as the two cinder cones northeast of Mount Idak and anorthite basalt flows near Inanudak Bay may have been extruded during the past few thousand years. In Okmok Caldera, cones *E* and *F* and their flows were extruded after the caldera lake had receded from the sites of their vents. The pit crater of cone *E* was formed soon after the extrusion of flows from cone *E*. Wall-fissure flows and those from cone *B* were extruded on what is essentially the present alluvial surface. Finally, the lava flows of cone *A* were extruded—probably since the first Russians sighted the island about 200 years ago. The most recent flows from cone *A* were extruded in 1945.

GEOLOGY OF BOGOSLOF

GEOLOGY OF BOGOSLOF IN 1947

The rocks exposed on Bogoslof Island in 1947 (fig. 53) are all of historic age. Igneous rock units include: vent agglomerate of 1796 in fault contact with the andesine-hornblende andesite of Castle Rock

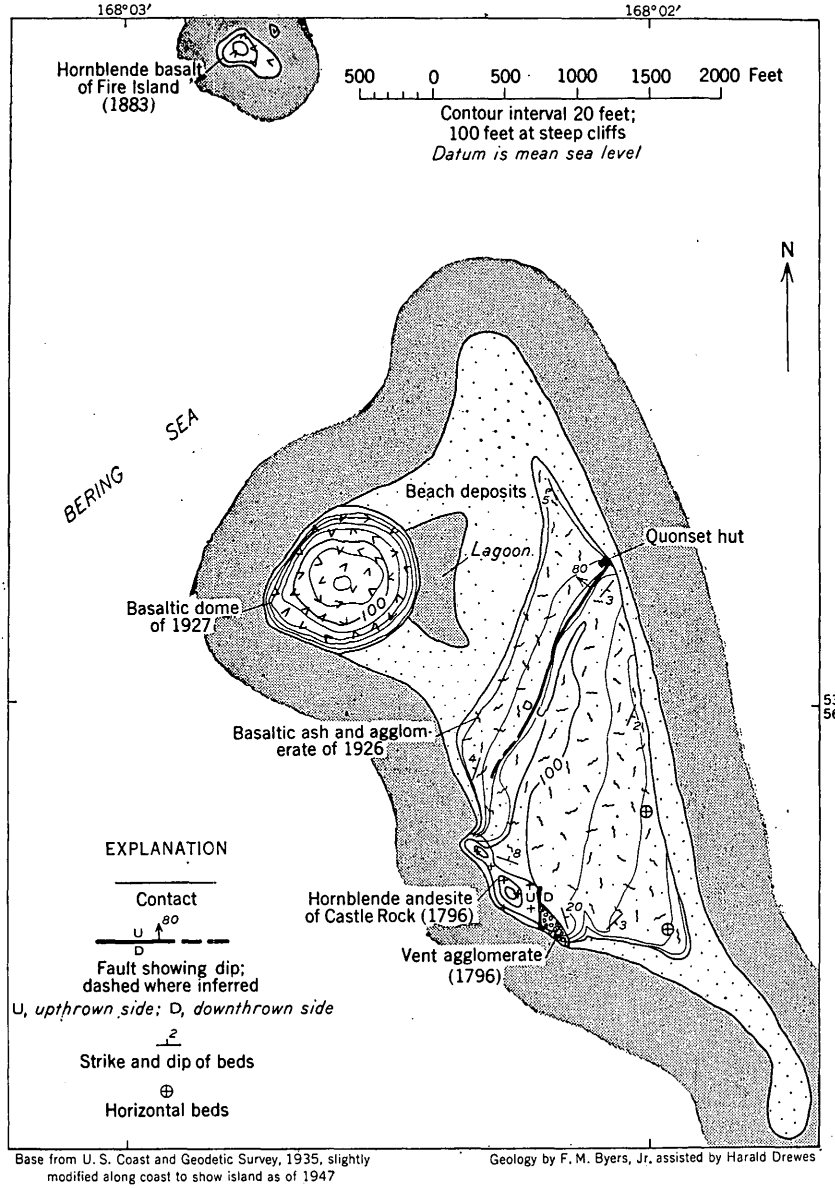


FIGURE 53.—Geologic map of Bogoslof in 1947.

extruded in 1796; hornblende basalt of 1883 on Fire Island; basaltic agglomeratic ash of 1926 and earlier explosive eruptions on Castle Rock and Fire Island; and bytownite-salite-hornblende basalt extruded in 1927 on Bogoslof Island. Sand and boulder beaches form most of the shoreline of Bogoslof.

Two minor high angle faults are mapped; the attitudes of beds mapped in the agglomeratic ash are probably gentle initial dips.

VENT AGGLOMERATE OF 1796

The vent agglomerate is exposed in the southeast end of the sea cliff that rises to Castle Rock (fig. 53). It occurs in fault contact with the andesine-hornblende andesite of Castle Rock, and is overlain by the basaltic agglomeratic ash of 1926 and earlier explosions.

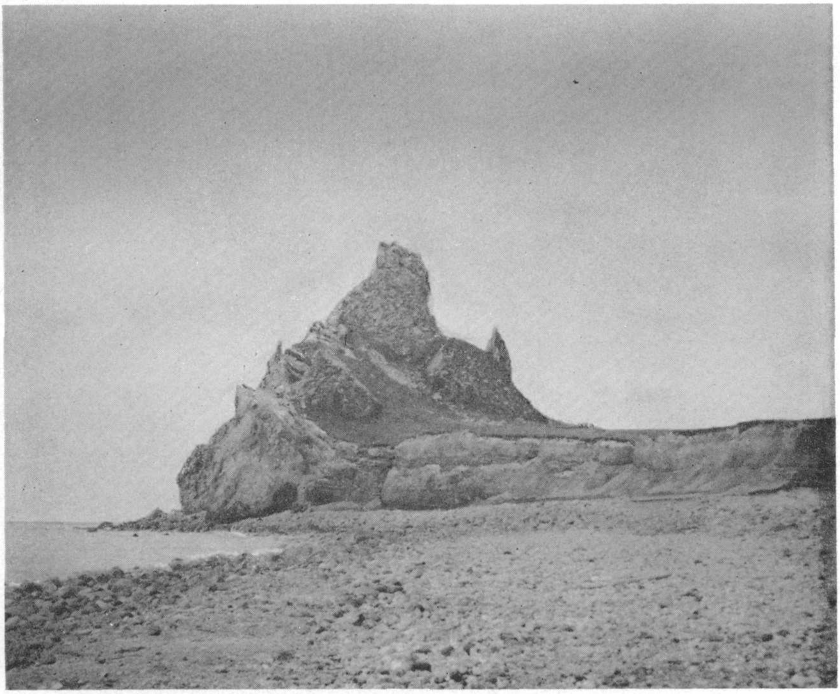
The vent agglomerate contains abundant angular fragments of limonite-stained lava in a grayish matrix of ash. The lava fragments are of olive-gray, dense andesite porphyry containing conspicuous phenocrysts of black hornblende, commonly 2 or 3 millimeters, but as much as a centimeter in length. As seen in thin section the rock contains phenocrysts of monoclinic pyroxene, hornblende, and sparse labradorite in a microlitic groundmass of andesine, clinopyroxene, opaque oxides, orthoclase, and a little antigorite(?). Remnants of the original hornblende are pleochroic (pale yellow to brownish green) and have a maximum extinction angle of 12°. The rims, cores, and in places entire crystals of the hornblende phenocrysts have been altered to an aggregate of magnetite, clinopyroxene, oligoclase(?), and antigorite(?). Calcite and chabazite occur in rare vesicles.

The vent agglomerate is exposed well within the area originally occupied by the large dome of Old Bogoslof extruded in 1796 but has a composition slightly different from the material of Castle Rock, the remnant of Old Bogoslof. Although there is no written record of its emplacement, the agglomerate must be an explosive phase of the 1796 eruption, for no volcanic mass occupied its site prior to 1796 (see fig. 54).

HORNBLENDE ANDESITE OF CASTLE ROCK

The hornblende andesite of Castle Rock is an eroded remnant of the dome extruded in 1796. The twin-spired pinnacle of Castle Rock appears to have had approximately its present shape and size since about 1906 (Jaggar, 1931, p. 2–3). Chart 6433 of the U. S. Coast and Geodetic Survey, 1935, shows an altitude of 269 feet on the northwest pinnacle, and 333 feet on the southeast pinnacle. No change was observed in the shape and altitudes of the pinnacles in 1947 (pl. 51).

Castle Rock is composed of a very light gray, fine-grained, holocrystalline andesine-hornblende andesite with abundant black horn-



Castle Rock, Bogoslof Island, from the southeast in 1947. Agglomerate ash beds of 1926 and older eruptions overlie Castle Rock on inland slope.

blende laths ranging from a fraction of a millimeter to 3 millimeters in length. The abundant plagioclase phenocrysts about a millimeter in diameter are not conspicuous against the light-colored groundmass. Phenocrysts seen in thin section are plagioclase, oxyhornblende, ferrosalite and accessory minerals. Plagioclase phenocrysts are zoned andesine to calcic oligoclase (An_{25}), but many contain a sharply defined core of anorthite-bytownite. The core boundary is generally sharp enough to be conspicuous in plane-polarized light, but is gradational in some crystals. A few of the andesine phenocrysts are veined with albite. Accessory microphenocrysts include magnetite (strongly magnetic grains), stubby prisms of apatite less than 0.3 millimeters in length, and sphene in both wedge-shaped and stubby prismatic forms. The groundmass is a fine-grained, xenomorphic aggregate of untwinned oligoclase-albite, orthoclase, analcite, and glass, with sparse subhedral microlites of clinopyroxene, apatite, and opaque oxides. The analcite is intergrown with other minerals in the groundmass, but also occurs as cavity fillings. It is isotropic to weakly birefringent (0.001–0.002) with mottled extinction and in a few grains resembles the polysynthetic twinning of albite. The identification as analcite was confirmed by X-ray photography by Richard C. Erd, of the Geological Survey. Chemical and quantitative analyses of the rock are given in column 35, tables 2 and 3, respectively. The chemical analysis is similar to an earlier one of a specimen from Castle Rock (Emerson, 1904; C. N. Fenner 1926, p. 706–707).

HORNBLENDE BASALT OF FIRE ISLAND

As seen from a short distance in 1947, Fire Island was a flat-topped stack resembling a lighthouse, less than one-half the size mapped and photographed in 1935 (Lukens, 1936, fig. 1). Two specimens of lava collected in 1884 by Lt. G. M. Stoney of the U.S. Revenue Cutter *Corwin* are described by G. P. Merrill (1885, p. 31–33). The petrographic description of one of them fits the lava of Castle Rock, but the other one is a dark-gray hornblende basalt, probably from Fire Island. Hornblende makes up about 10 percent of the rock, and plagioclase microlites are abundant in an indeterminant groundmass. This specimen was analyzed chemically by T. M. Chatard. Two specimens acquired by Diller (1885, p. 67) were from the lava of Fire Island and from the ash that fell at Unalaska village. Two determinations of silica by Chatard on the lava specimen were 51.54 and 51.65 percent; the silica content of the ash was 52.48 percent, significantly higher than the two silica determinations on the lava specimen.

Chemical analysis and norm of hornblende basalt from Fire Island dome (New Bogoslof)

[T. M. Chatard, analyst; in Merrill, 1885, p. 33]

Analysis (weight-percent)		Norm (weight-percent)	
SiO_2	51.54	or	14.46
Al_2O_3	20.31	ab	29.60
Fe_2O_3	4.64	an	28.91
FeO	3.56	ne	3.55
MgO	3.16	di	12.01
CaO	9.55	ol	3.54
Na_2O	4.29	mt	6.73
K_2O	2.47	il	0.61
Ignition	0.34	ap	1.34
TiO_2	0.32		
P_2O_5	0.57	Total	100.75
MnO	0.32		
Total	101.07		

BASALTIC EXTRUSIVE ROCKS OF 1926–27

Basaltic ash and agglomerate of the explosions of 1926 are plastered against the steep north and east cliffs of Castle Rock (pl. 51) and form the extensive terrace that slopes away from Castle Rock to the northeast. None is on the dome-shaped western mass formed by the viscous extrusion of bytownite-salite-hornblende basalt in 1927. In an exposure at the north end of the east sea cliff the section of pyroclastic material contains two thin ash beds separated by about 8 feet of dark-colored agglomeratic ash. The lower bed of fine ash is 3 inches thick and contains a grayish-yellow incrustation; the upper bed is 1 inch thick and contains a pale-yellowish-green incrustation, abundantly present as microbotryoidal coatings on the ash fragments. Gypsum, $CaO \cdot SO_3 \cdot 2H_2O$; paratacamite, $CuCl_2 \cdot 3Cu(OH)_2$; botryogen, $2MgO \cdot Fe_2O_3 \cdot 4SO_3 \cdot 15H_2O$; and caledonite, $2(Pb,Cu)O \cdot SO_3 \cdot H_2O$ were identified in the incrustation from the upper ash bed by Richard C. Erd of the Geological Survey.

The lavas of both the dome and the larger fragments in the agglomeratic ash are medium-dark-gray, fine-grained basalts with conspicuous phenocrysts of hornblende, and inconspicuous phenocrysts of plagioclase and clinopyroxene. Differences in mineralogy of the lava thrown out explosively in 1926 with the lava extruded as a large dome in 1927 can probably be correlated with the different cooling history of the two rock types. In the pyroclastic rock, phenocrysts of hornblende are unaltered, with extinction angles as much as 18°, whereas in the rock of the dome the hornblende has been partly to completely decomposed. The least altered hornblende has extinction angles as much as 14°, and is pleochroic in grayish yellow and brown. Clinopyroxene in clear, unaltered, subhedral to euhedral phenocrysts occurs in both rocks. In the rapidly chilled ejecta of the agglomerate, some of the larger crystals have grown around a core of unaltered hornblende. Both rocks contain inclusions composed of crystals of plagioclase, clinopyroxene, and unaltered hornblende like that in the phenocrysts. The groundmass of the chilled ejecta of the agglomerate is a fine-grained, dark aggregate of microlitic plagioclase, clinopyroxene, and opaque oxides in a matrix of dark glass. In addition to these constituents a feldspar of low index, probably anorthoclase, is in the groundmass of the dome. Nepheline was not identified, though it appears as a theoretical mineral in the norm (column 34, table 2).

BEACH DEPOSITS

Beaches composed of rounded cobbles and boulders as much as 6 feet in diameter are found along three parts of the coast extending southeasterly from the rocky cliffs of Castle Rock, and both northeasterly and southeasterly from the rocky cliffs cut in the dome of 1927 lava. A sand beach forms the east coast of the ash and agglomerate terrace. Sand and gravel with scattered cobbles and boulders form a large deposit around the saltwater lagoon.

STRUCTURE

Two faults were mapped on Bogoslof Island (fig. 53). The longer is poorly exposed in the agglomeratic ash in the northeast sea cliff, but displaced beds exposed on opposite sides of the fault show that the northwest side has been dropped 5 feet relative to the southeast side. A prominent topographic scarp between altitudes of 60 and 80 feet marks the probable trace of the fault to the southwest across the raised terrace almost to Castle Rock. This scarp is a prominent feature on air photographs taken in 1934. However, Jaggar states (1930, p. 3) that explosion debris enclosing the lagoon in July 1927, reached only about 10 feet above high tide. If his description applies to the terrain of the faulted terrace, the uplift of the terrace and the formation of the fault scarp must have taken place between 1927 and 1934. The shorter southern fault separates the lava of Castle Rock from the vent agglomerate. The trace of the fault in the south sea cliff is nearly vertical. The direction of movement indicated on the map is inferred from the written record that the lava of Castle Rock is an extruded dome and presumably rose with respect to the vent agglomerate.

GEOLOGIC HISTORY

The first written record of the existence of Bogoslof is on the track chart of Krenitzin and Levashef, 1768–69 (Coxe, 1787, plate facing p. 205), on which a small unnamed island, later known as Ship Rock (Baker, 1906, p. 570), is shown on the approximate site of Bogoslof Island (see fig. 54*A*). Captain Cook placed Ship Rock 17 miles north of the north shore of Umnak on the chart of his voyage in 1778–79 (Davidson, 1884, p. 282). A small island in the same position is also

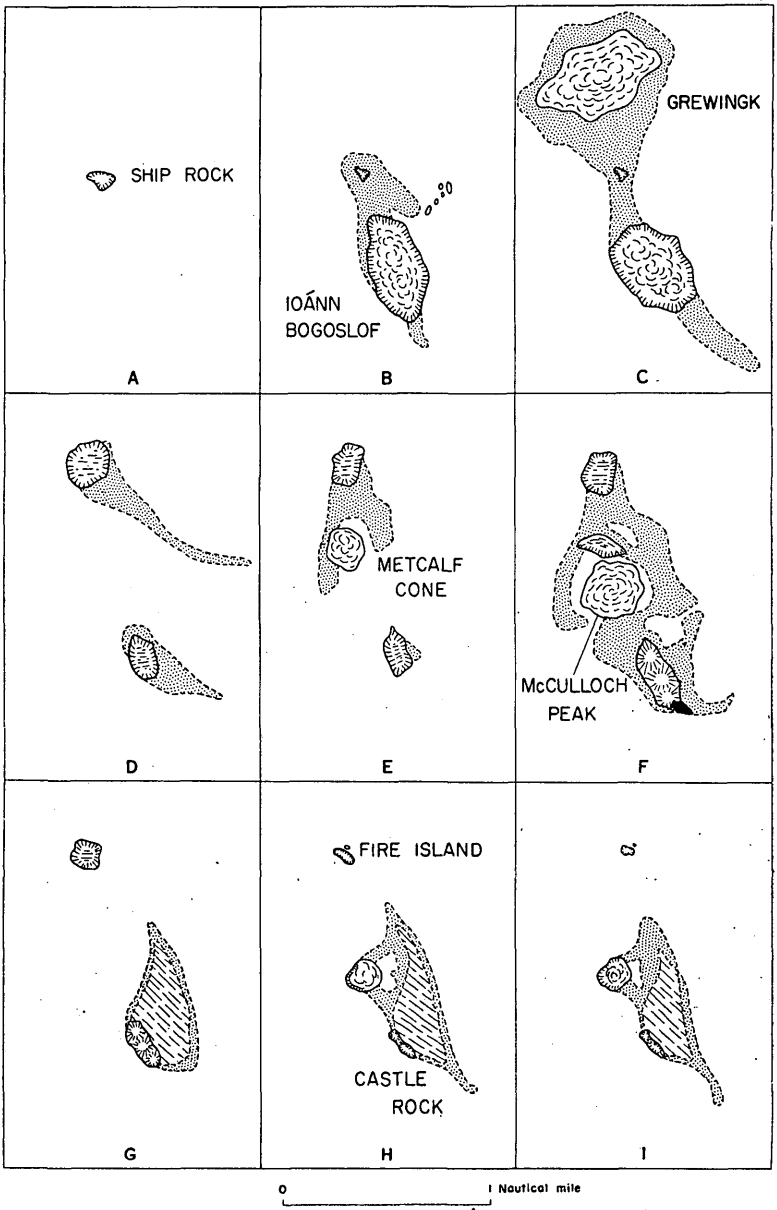


FIGURE 54.—Significant changes in Bogoslof Island between 1768 and 1947 (diagrams *A–G* after Jaggar, 1907 and 1931; diagram *H* after map in files of U.S. Coast and Geodetic Survey and after Lukens, 1936).

shown on Billings' track chart of 1802 (Baker, 1906, p. 570) and was named Ship Island. Some of the earliest works to which references are made were not accessible to the author, but those included within parentheses were consulted.

In May of 1796, eruption of explosive debris and the extrusion of a viscous lava dome built an island about a quarter of a mile south of Ship Rock (Grewingk, 1850, p. 136; Dall, 1870, p. 467). The new island was named Bogoslof by the Russians at Unalaska. The mass steamed and fumed as it continued to rise in altitude. The steaming had ceased by 1804, but in many places the surface was still uncomfortably hot. In 1806 lava flowed from the summit into the sea on the north side, and apparently the rising of the whole mass was renewed. This increase in size and altitude is said by Veniaminof (Grewingk, 1850, p. 140) to have ceased in 1823, when the dome was of pyramidal form (see fig. 54*B*). Estimates of the height of the new island ranged from 350 to 2,500 feet (Grewingk, 1850, p. 140), but later, more careful measurements by Dall (1884, p. 32) indicate that the lower estimate was probably closer to the true height. The lava dome later became known as Old Bogoslof (Merriam, 1902, p. 297), and the U. S. Coast and Geodetic Survey early in the present century first showed the official name, Castle Rock (Powers, 1916, p. 218), on the hydrographic charts.

No further volcanic activity occurred until 1882, when it was reported that residents of Unalaska noticed steam rising from the ocean somewhat north of Ship Rock (Merriam, 1902, p. 305). On September 27, 1883, Capt. Anderson of the schooner *Mathew Turner* first observed a new volcanic dome rising just to the north of Ship Rock (Davidson, 1884, p. 283; Merriam, 1902, p. 303). On October 20, 1883, a violent eruption showered ash on the village of Unalaska, 60 miles to the east. A week after the eruption the cone was seen to be still steaming by Capt. Hague of the schooner *Dora*. Capt. Hague suggested the name, New Bogoslof, for the new island; slightly later, Dall (1884, p. 92) proposed the name, Grewingk Island. The new island was visited several times during the following year by the U. S. Revenue Cutter *Corwin*, and the three Bogoslof islands were charted by Lieut. Cantwell of the *Corwin* in 1884 (Healy, 1889, p. 39–41). (See fig. 54*C*.) The 3 Bogoslof islands were visited again by William C. Greenfield in 1887, at which time the 3 islands were connected as 1 by bars of volcanic debris and boulder and sand beaches. The new island to the north had a craggy profile, with pinnacles reaching to an estimated altitude of 500 feet. Old Bogoslof apparently had been greatly reduced in area and altitude, its three main crags appearing somewhat lower than the summit of New Bogoslof. Ship Rock was still in existence in 1887, but had begun to disintegrate. In 1890, Capt. Z. L. Tanner of the U. S. Fish Commission steamer *Albatross* reported that Ship Rock had fallen but that its original position was still marked by debris (Merriam, 1902, p. 312). In 1891, Merriam (1902, p. 313) visited the Bogoslof Islands and found steam and sulfur fumes escaping with a roaring noise from the principal fissure of New Bogoslof. An open channel separated Old and New Bogoslof. In 1895 (see fig. 54*D*) when Becker and Dall (Becker, 1898, p. 26; Merriam, 1902, p. 317) visited the Bogoslof Islands, New Bogoslof was still steaming "vigorously, though not violently" and had also been changed to a flat-topped island about 300 feet in altitude. Later reports in 1897 and 1899 by passing mariners indicate that New Bogoslof or Grewingk Island had finally cooled (Merriam, 1902, p. 319–320).

In 1906 another extrusion of viscous lava appeared in the water about midway between old and new Bogoslof (see fig. 54*E*). The new island, called Metcalf Cone, was conical, showing at the summit a broken spine similar to the famous Pelee spine on Martinique (Jaggar, 1908, p. 388). An explosion early in 1907 destroyed the south half of Metcalf Cone, and another dome of lava grew into an island connecting Metcalf Cone with Old Bogoslof. This 1907 dome was named McCulloch Peak (see fig. 54*F*). A violent explosion on September 1, 1907, only 23 days after the Massachusetts Institute of Technology expedition had left Bogoslof, showered the village of Unalaska with a quarter inch of volcanic ash. McCulloch Peak disappeared in the explosion, and the debris mantled the surfaces of the remaining island. In 1909–10, a new conical island, Tahoma Peak, was pushed up in the bay that was formed by the destruction of McCulloch Peak (Powers, 1916, p. 218–221). A deep crater in the summit of Tahoma Peak was formed by explosions on September 18 and 19, 1910.

Metcalf Cone and Tahoma Peak had a very short existence. By 1922, explosion, collapse, and marine erosion had removed all traces of them (see fig. 54*G*). Fire Island, a new name for New Bogoslof Island, was adopted by the Coast and Geodetic Survey on its published hydrographic charts. The island had been reduced further by erosion to a small islet. Castle Rock (Old Bogoslof) had been reduced to two rocky horns, and a big accumulation of sand and gravel had been heaped against them, particularly on the northern and eastern sides. A wide channel of open water separated Fire Island and Castle Rock (Jaggar, 1930, p. 3).

Submarine explosions between the two island remnants during the summer and fall of 1926 preceded the rise of another conical dome of lava during the winter of 1926–27. A ring of explosion debris, rising about 10 feet above high tide, surrounded the new dome and again completely connected Fire Island and Castle Rock into one elongate island. In July 1927, the new dome, about 200 feet high, was almost circular, a thousand feet in diameter, and surrounded by a shallow lagoon of warm water (Jaggar, 1930, p. 3). "Fire" was still observed at the 1927 dome as late as October 31, 1931, and quantities of pumice floated in the water south of the island (Jaggar, 1932, p. 2).

In 1935, an open water channel again separated Fire Island from a larger southerly island that contained the 1927 dome and Castle Rock (see fig. 54*H*). Both islands were mapped by the Coast and Geodetic Survey at this time (Lukens, 1936, p. 205–206), and the name Bogoslof was officially applied to the larger island that included Castle Rock, pyroclastic rocks of the 1926 eruption, and the 1927 dome.

The geology of Bogoslof Island was mapped in the summer of 1947 by the present author. Between 1935 and 1947 the size of both Fire island and Bogoslof Island was appreciably reduced by erosion (see fig. 54*I*). A Navy quonset hut erected sometime during World War II was partly undermined by retreat of the east-facing sea cliff. On September 21, 1951, a coastwise vessel ran through "muddy water" for about 2 miles near Bogoslof; this may have been the result of a submarine eruption or landslide. Early in November, 1951, Bogoslof was again seen by G. R. MacCarthy of the Geological Survey, but no activity was observed (Volcano Letter 516, p. 8). Bogoslof was visited still later on August 13, 1953, by Adrian F. Richards (written communication, 1955), who reports further retreat southward and westward of the east sea cliff so that Bogoslof Island was reduced in area by about 25 percent. The Navy quonset hut was gone and must have fallen over the east sea cliff as it was cut back by high waves sometime between 1947 and 1953.

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