Geology of Great Sitkin Island Alaska

By FRANK S. SIMONS *and* DONALD E. MATHEWSON

INVESTIGATIONS OF ALASKAN VOLCANOES

GEOLOGICAL SURVEY BULLETIN 1028-B

Prepared in cooperation with the Office, Chief of Engineers, U. S. Army

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1955

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - $1 (paper cover)

PREFACE

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

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

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

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By Frank S. Simons and Donald E. Mathewson

ABSTRACT

Great Sitkin Island lies near the middle of the Aleutians, about 25 miles northeast of the Army-Navy base on Adak Island. It is about 11 miles in maximum diameter, and its highest altitude is 5,740 feet, the summit of Great Sitkin Volcano. The island is very rugged—an active volcano makes up most of the northern half, and the deeply dissected remnant of an older volcano makes up most of the southern half.

The oldest rocks exposed are the Finger Bay volcanics, which form the rugged headlands of the south and southeast coasts. These rocks, believed to be of late Paleozoic age, are highly altered and deformed lavas, volcanic breccia, and tuff of andesitic and basaltic composition, cut by numerous dikes. The source of the rocks is unknown.

The Sand Bay volcanics, which form most of the southern half of the island, comprise a lower pyroclastic sequence, consisting mainly of agglomerate, and an upper sequence of andesite and basalt flows. The age of these rocks is believed to be late Tertiary. They are essentially undeformed, and their radial dips suggest a source near the present cone.

The rocks of the main cone that form the northern half of the island, are designated Great Sitkin volcanics and are of late Tertiary and Quaternary age. The uppermost rocks of the cone are lava flows, similar in appearance to the lava flows of the Sand Bay volcanics, but the steep slopes of the cone suggest that its core is made up of pyroclastic material. The crater of Great Sitkin Volcano lies on the west slope of the cone at an altitude of about 4,000 feet; it is about three-quarters of a mile long and half a mile wide. The eruption that produced the crater blanketed the island with a layer of pumice and rock fragments ranging in thickness from a few inches to more than 20 feet. A recently formed volcanic dome occupies the center of the crater. Five plugs have been intruded into the northwest flank of the cone. A recent deposit of ash, apparently erupted from a vent a short distance northwest of the crater, blankets the northwest slope of the cone. The floor of one creek valley is covered by a fairly recent mudflow.

The cone supports 5 small glaciers, the 2 largest of which have built large moraines. More extensive glaciation occurred in the past, but the only glacial deposits found at lower altitudes, other than those of the present glacier fronts, consist of erratic boulders on the floor of the valley of Big Fox Creek.

Entrenched streams and low marine terraces suggest that the island has been uplifted recently.

The geologic history of Great Sitkin Island comprises at least four stages of volcanism designated as Finger Bay, Sand Bay, peak volcano, and crater volcano stages. An angular unconformity separates deformed Finger Bay volcanics from deposits of the Sand Bay volcano. After prolonged erosion the center of volcanic activity shifted north and formed the peak volcano, and then shifted west to form the crater volcano. Each stage ended with the partial destruction of its volcano. The crater volcano was modified by erosion and decapitated by an eruption during which the pumice blanket was deposited. Great Sitkin Volcano, the present double cone, is a composite of the ancestral peak and crater volcanoes.

Minor volcanic activity was reported in 1792, 1829, 1904, and 1933; a crater dome, which was formed probably in March 1945, was emitting much steam and some acid gas in September 1946.

A survey of geologic literature on volcanic domes similar to that of Great Sitkin Volcano indicates that the course of their evolution cannot be predicted with certainty; some have been destroyed or partly destroyed by violent explosions, others have not. The 1945 dome of Great Sitkin Volcano may remain quiescent indefinitely, or it may become violently active.

INTRODUCTION

Great Sitkin Island, one of the Andreanof Islands, is near the middle of the Aleutians about 25 miles northeast of the large Army-Navy base on Adak Island. An active volcano occupies most of the northern half of the island. The possible source of danger of the volcano to the installations on Adak and to the naval station led to a geologic investigation of the island during the summer of 1946. Field work was carried out from August 16 to October 2 by a party including Frank S. Simons, geologist-in-charge, Donald E. Mathewson, geologist, and Joseph C. Roberts and Thomas E. Turner, recorders.

Acknowledgment is made of the cooperation of Commander S. O. Cole, chief staff officer of the Adak Sector, and Lt. J. R. Geis, officer-in-charge of the naval fueling station at Sand Bay, in providing transportation, quarters, and mess facilities.

HISTORY

Great Sitkin Island was probably first sighted on September 8 or 9, 1741, by Chirikof, of the Bering Expedition, who visited Adak Island on September 9 on his return voyage from southeastern Alaska to Kamchatka. Bering, in another ship, sighted the island on September 25 (Collins, Clark, and Walker, 1945).

The Andreanof Islands were explored in 1760–1764, and were named for Andrean Tolstykh, one of the explorers. A report by a member of the party, Peter Vasyutinsky, mentions Great Sitkin Island in a more detailed description of Adak: "The third island, Chetkin, lying to the east, across the strait, at a distance of about 40 versts [26.4 miles] has a circumference of about 80 versts [52.8 miles]. There are many mountain ridges, one mountain of which is called

Belaya [white]. In the valleys are hot springs. No rivers are found on the island. It is inhabited by about 400 families." (Jochelson, 1933.) Although Vasyutinsky calls the island Chetkin, its location and size and the hot springs he ascribes to it coincide with those of Great Sitkin Island.

Little is known of the subsequent history of the island until 1943, when the naval fueling station was established at Sand Bay. No evidence of permanent inhabitation by Aleuts was found by the geologic party; apparently they left the island many years ago. However, the island was used as a fox farm before World War II.

GEOGRAPHY

LOCATION

Great Sitkin Island, together with Adak Island and the chain of intervening smaller islands, forms the middle part of the Andreanof Islands, which lie near the middle of the Aleutian arc (fig. 2). The island is about 600 miles west-southwest of the tip of the Alaska Peninsula and 480 miles east of Attu Island, which is at the west end of the chain. Its geodetic position is 52° N., 176°06′ W. (Sand Bay).

TOPOGRAPHY

Great Sitkin is a deeply dissected, extremely rugged island about 11 miles in maximum diameter (fig. 3). Most of the northern half is occupied by Great Sitkin Volcano, whose altitude is 5,740 feet at a distance of only 2½ miles from the north coast. A crater that measures about half a mile by three-quarters of a mile, and whose walls rise to a maximum height of 600 feet, lies on the west flank of the cone at an altitude of about 4,000 feet. Many steep-walled valleys radiate from the summit. The original constructional surface of the cone has been almost completely destroyed. This asymmetrical cone offers a striking contrast to the perfect cone of Kanaga Volcano, 40 miles west-southwest.

The southern half of the island is separated from the cone by the deep valleys of Sitkin Creek on the east and Akuyan Creek on the west. It consists of the dissected remnant of a former shield volcano upon which the present cone has been built.

U-shaped valleys radiating from the center of the island have been cut 1,000–1,500 feet below the intervening ridges and are headed by cirquelike amphitheaters. The ridges are generally very narrow, and many are knife edged, although in a few places the original surface is preserved in broad rolling uplands. Several large streams and many small creeks drain the island; in the main valleys the streams occupy meandering courses incised 5–15 feet below the valley levels.

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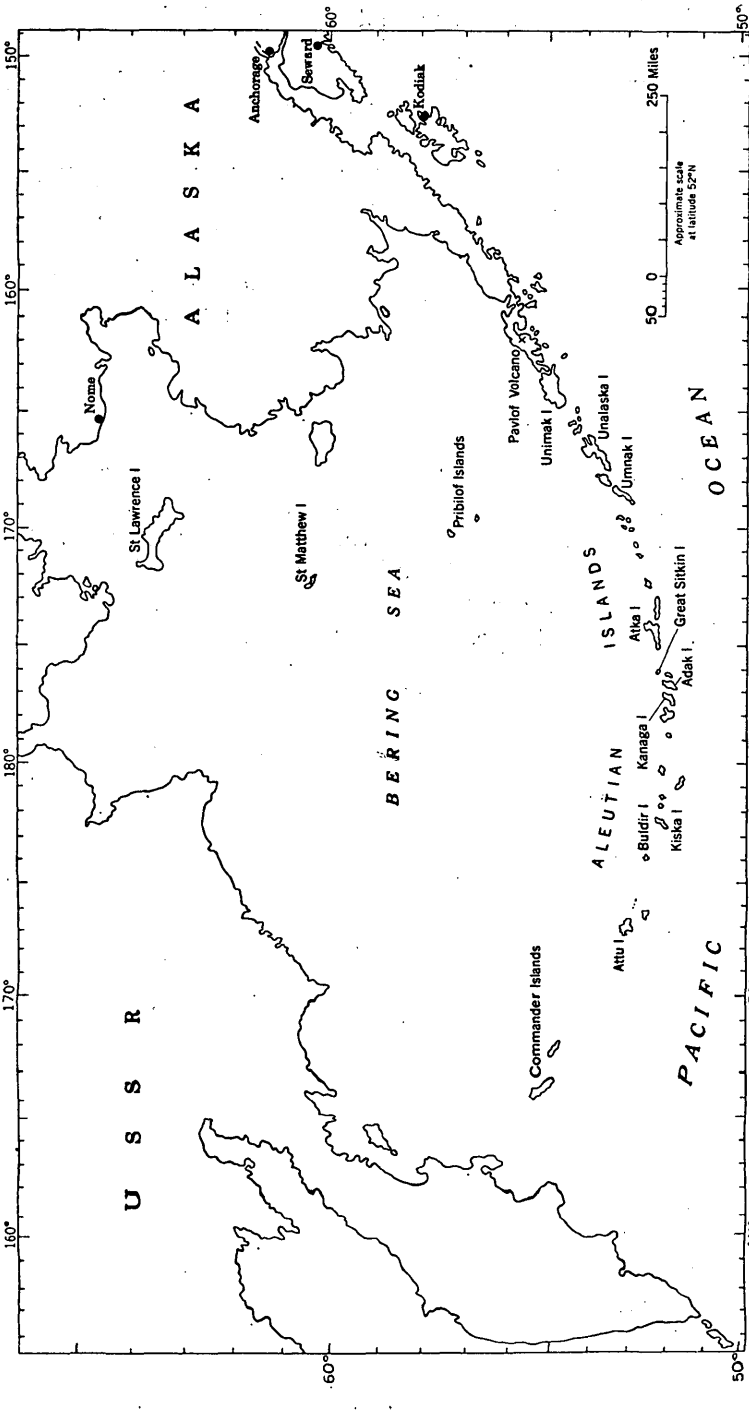


FIGURE 2.—Map of the Alaska Peninsula and Aleutian Islands.

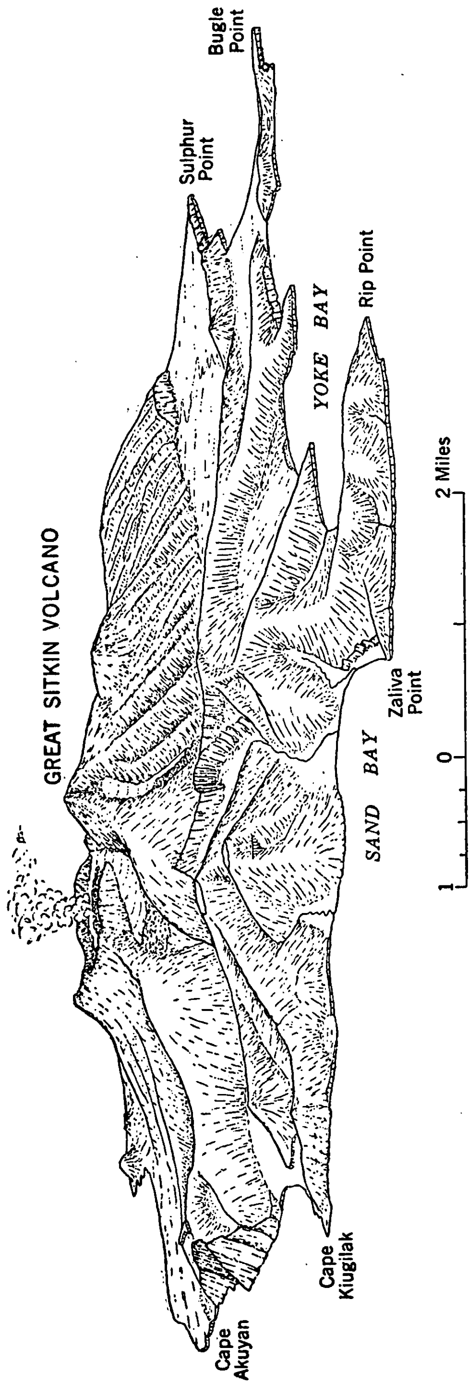


FIGURE 3.—Isometric drawing of Great Sitkin Island, looking north.

The coastline is rocky and irregular. Sea cliffs as much as 1,000 feet high alternate with narrow sandy beaches at the mouths of valleys. Along the south coast are a few terraces. Natural harbors are nonexistent and sheltered anchorages are few; Sand Bay and Yoke Bay are fairly well sheltered.

Several small lakes fill depressions on or near beaches. Two rock-basin lakes are known, one on Bugle Point and the other on Sulphur Point.

Five small glaciers occupy valleys on the upper slopes of the cone. The crater itself is partly filled with ice, which moves out through saddles in the north and south walls to form two glaciers; the largest of these glaciers, 1 mile long and nearly 1 mile wide, is very active and has built up a large moraine in the valley of Glacier Creek.

CLIMATE

The climate of Great Sitkin, like that of the other Aleutian Islands, is cool and wet. Prevailing winds are from the north in winter and from the southwest in summer. High ridges and peaks near Sand Bay cause the wind to blow in strong gusts and to make rapid variations in direction in that area. During much of the summer, fog blankets the island from sea level to altitudes of 3,000 or 4,000 feet. The upper slopes of the volcano are usually cloud covered, but the top of the cone is visible enough of the time to be useful as a landmark for navigation.

VEGETATION

The lower parts of the island support a heavy growth of grass, which reaches a height of from 4 to 5 feet in late summer. Interspersed with the grass are patches of moss and lichen, which give the landscape a blotched appearance from the air. Most of the small gullies are choked with ferns, and at places some are completely bridged by heavy mats of grass, moss, and lichen. Many plants are in flower during the summer, the most conspicuous of which are monkshood and lupine. Vegetation is heaviest at sea level; above an altitude of about 1,500 feet there is practically no plant life. Trees do not grow on the island.

ANIMAL LIFE

The only land animals seen were blue foxes, which presumably were introduced. Marine life, however, is abundant; the tide pools and rocky basins along the coast abound in sea urchins, red and orange sea anemones, chitons, and mussels. The sea urchins, which form a green mantle on many submerged rocks, are particularly abundant. Numerous salmon were seen in Turmath, Big Fox, and South Yoke Creeks, and many Dolly Varden trout in Big Fox Creek.

GEOLOGY

The geology of Great Sitkin Island is shown on plate 5. The island can be divided both topographically and geologically into two principal units: the nearly flat-lying remnants of an old shield volcano, which form most of the southern part of the island, and a young, steep-sided cone and its related plugs and parasitic cone, which form most of the northern part of the island. The shield volcano is fringed on the south and east by small areas of much older volcanic rocks.

A recent explosive eruption blanketed the island with a mixture of pumice and rock fragments to depths ranging from a few inches to more than 20 feet. The crater produced by the explosion lies west of the summit of Great Sitkin Volcano and about 1,700 feet below it; the crater is filled with ice. Into it a basalt dome was recently intruded, apparently in March 1945. By September 1946, considerable ice had melted from the crest of the dome, which occupied about half of the crater, and steam was rising to an altitude of about 3,000 feet above the center of the dome (pl. 6).

IGNEOUS ROCKS

FINGER BAY VOLCANICS

The oldest rocks exposed are those forming the rugged headlands of the south and southeast coasts. These rocks have been correlated by Coats (1955a) with rocks exposed at Finger Bay on Adak Island, which have been named by him the Finger Bay volcanics. The chain of islands between Great Sitkin and Adak seems to be composed largely, if not entirely, of Finger Bay volcanics. These islands were seen only from a boat, however, and may consist in part of younger rocks.

The Finger Bay volcanics are predominantly andesitic and basaltic greenstone, but include coarse- to fine-grained porphyritic flows, amygdaloidal flows, coarse flow-breccia, pillow lava, dense fine-grained rocks that are probably flows, and coarse- to fine-grained tuff. The rocks are cut by numerous dikes, as much as 3 feet wide, and by a few thin quartz veins. All the rocks are altered, the dikes commonly less so than the flows and tuffs. Plagioclase phenocrysts are milky and ferromagnesian minerals are generally altered to a fine-grained green aggregate. Calcite, epidote, pyrite, and prehnite are the principal secondary minerals: calcite occurs in veins and irregular patches; epidote in veins, irregular masses, and vesicles; and pyrite in veins and tiny scattered grains.

The source of the Finger Bay volcanics is not known and probably cannot be determined from the sparse exposures on Great Sitkin Island.

The rocks are intensely deformed and commonly have dips ranging from 60° to vertical. No well-defined structures were found, but detailed structural analysis was not attempted. In general, the rocks are very resistant to erosion; the topography that has developed on them is characteristically hummocky, and sea cliffs that have formed in the rocks are as much as 800 feet high.

The age of the Finger Bay volcanics is not definitely known, but is believed to be late Paleozoic, which is the age tentatively assigned to similar rocks on Adak Island (Coats, 1955a).

SAND BAY VOLCANICS

The gently dipping volcanic rocks that form the southern half of the island are well exposed in the vicinity of Sand Bay and are designated Sand Bay volcanics (pl. 7A). They overlie the Finger Bay volcanics unconformably. The Sand Bay volcanics comprise a lower pyroclastic sequence consisting of agglomerate and a few thin flows, and an upper sequence composed of andesitic and basaltic lavas.

The source of the Sand Bay volcanics is not exposed, but dips of the lava flows are roughly radial and suggest a central vent near the present cone. The age of these rocks is not accurately known. They are older than the Great Sitkin volcanics, which have been glaciated, and of which at least part are probably of Pleistocene age. In the absence of diagnostic fossils, the age of the rocks can only be surmised by analogy with rocks of better known areas. The present cycle of volcanism is believed to have begun on the Alaska Peninsula in the early Tertiary (Capps, 1934; Knappen, 1929), and Tertiary fossils have been found in tuffs on Akutan, Unalaska, Umnak, and Atka Islands (Capps, 1934). The Sand Bay volcanics are therefore tentatively assigned a Tertiary age. Many volcanic rocks of the western Aleutians were beveled by a marine abrasion plane, presumably in the middle Tertiary (Coats, 1955b). Because the Sand Bay volcanics do not show evidence of this beveling, they are believed to be of late Tertiary age.

Agglomerate.—The lowest part of the exposed section of the Sand Bay volcanics is at the base of the south end of the Akuyan cliffs on the west side of the island. At the base of the cliffs, coarse well-bedded tuff that dips north at small angles is overlain by 1,000 to 1,500 feet of coarse agglomerate. Numerous dikes are exposed in the cliffs. Similar agglomerate forms the lower slopes of the southern half of the island. It is well indurated and in many places forms cliffs several hundred feet high. At Sand Bay the agglomerate is fairly well bedded but poorly sorted; it is composed of subangular to rounded boulders, as much as 3 feet across, in a tuff matrix. The boulders are mainly of two rock types: a black, glassy, highly vesicular lava, and a reddish vesicular porphyry containing phenocrysts of plagioclase feldspar, pyroxene, and olivine. Farther inland, toward the cone, the agglomerate contains interbedded thin lava flows and is cut by dikes. The ridge west of the valley of Big Fox Creek and the one overlooking Cape Kiugilak are capped by lava flows interbedded with agglomerate.

Lava flows.—The main ridges in the southern part of the island are capped by andesite and basalt flows, which reach an aggregate thickness of 400 feet on Triple Divide Peak at the head of the valley of Middle Yoke Creek.

The lava flows are porphyritic and include andesite, olivine andesite, andesite flow-breccia, and basalt. Their colors are black, purplish gray, reddish gray, and light gray. Most of the flows are medium grained but a few are very fine grained. Platy lavas are rare, and most of the rocks show little or no flow structure. Columnar jointing is common. The most conspicuous lava flow on the island caps the ridge west of Sand Bay, forming the top of a 300-foot cliff. It consist of olivine andesite, is about 40 feet thick, and exhibits excellent columnar jointing (pl. 7A).

The lava flows are notably fresher in appearance than those of the Finger Bay volcanics. Plagioclase, pyroxene, olivine, and magnetite can be distinguished in hand specimens. Most of the flows appear to contain little or no glass, and highly glassy lava seems to be absent. Vesicular flows are rare. The lava flows dip south or southeast at small angles, and they thicken toward the center of the island. Nowhere do they appear to be folded or faulted.

GREAT SITKIN VOLCANICS

The rocks of the north half of the island include the rocks of the main cone of Great Sitkin Volcano, a newly formed crater dome and five older plugs, a basalt flow near the head of Sitkin Creek, and a parasitic tuff cone on the northwest flank of the main cone.

The main cone is composite, built up of lava flows and tuff beds; the flows predominate, at least in the upper part of the cone. The flow rocks, which consist mostly of porphyritic andesite and basalt, are similar to those of the Sand Bay volcanics. On the lower slopes of the cone the rocks are fresh, but the rocks forming the summit peak are altered, discolored, and riddled with tiny, irregular cavities lined with tridymite crystals. The lava flows are clearly exposed in the walls of the crater, but are difficult of access because the walls are steep and high. Most of the rocks of the main cone are covered by a thin blanket of pumice and rock fragments.

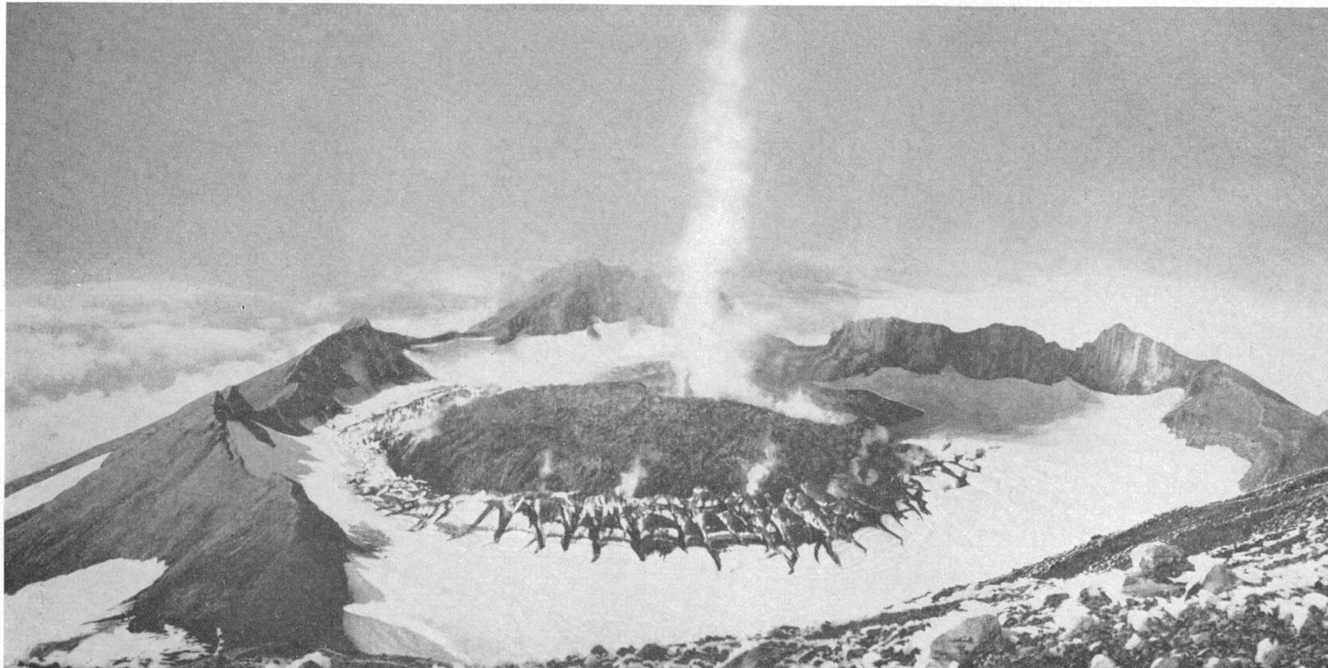
The only mineralized rocks seen on the cone are near the foot of the large glacier on the southeast slope. Here a greenish breccia containing angular to rounded fragments as much as 8 inches across has been thoroughly impregnated with pyrite, which locally forms as much as 10 percent of the rock. The breccia is highly altered and contains much calcite and chlorite. The feldspar phenocrysts of the breccia fragments are dull and milky. The altered rocks crop out in an area 75 by 200 feet, probably the site of former solfataric activity.

The crater is occupied by a dome of black glassy porphyritic basalt. A sample of the basalt, collected by R. R. Coats, was analyzed by W. W. Hommel, Ledoux, and Company. The analysis is given below; the normative values and the Niggli values were calculated by R. R. Coats.

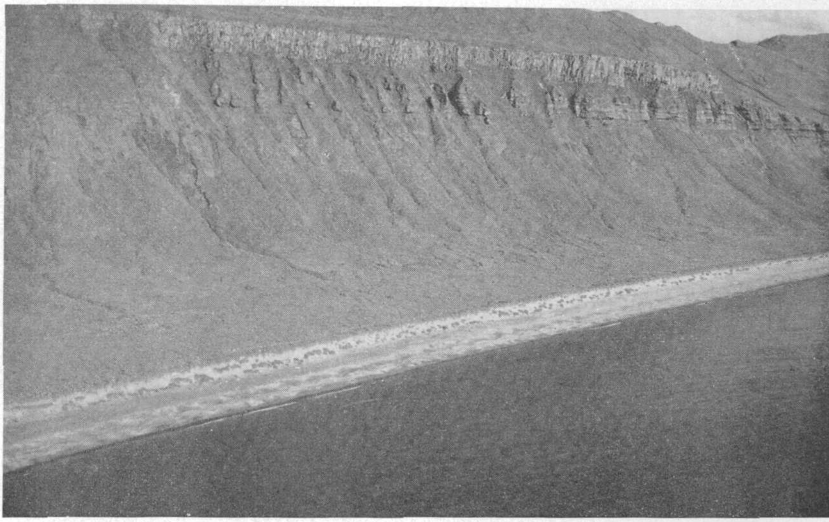
Chemical analysis		*Norm*		*Niggli values*	
SiO_2	57.42	q	9.13	si	166
Al_2O_3	17.12	or	8.57	al	29.2
Fe_2O_3	4.36	ab	35.28	fm	35.9
FeO	4.47	an	23.70	c	22.5
MgO	3.03	wo	4.41	alk	14.4
CaO	7.23	en	7.55	k	.186
Na_2O_3	4.17	fs	3.19	mg	.386
K_2O	1.45	mt	6.32	qz	8.2
H_2O^+	.13	il	2.00		
H_2O^-	.03	ap	.57		
TiO_2	.84	Symbol II, (4)5,3,4''			
P_2O_5	.24	Andose			

The dome is roughly oval, about one-quarter of a mile wide by three-eighths of a mile long. Its top surface is blocky and rather flat, and its sides are steep. It resembles the 1909 dome of Tarumai Volcano on Hokkaido Island, Japan (Powers, 1916), and the 1912 dome of Novarupta in the Katmai region, Alaska (Fenner, 1923). It differs from the latter in that the lava contains abundant phenocrysts instead of being largely glassy. Presumably in March 1945, the dome intruded a thick icefield, which filled the crater, doming the ice and melting much of it. On September 12, 1946, the dome resembled a gigantic aster, the petals outlined by crevasses in the rim of the breached ice (pl. 6). Steam was escaping from a number of vents around the edge of the dome, but the main steam column rose from near the center to a height of about 3,000 feet above the crater. The steam was under little or no pressure, and probably was being produced largely by vaporization of melt water from the surrounding ice. Occasionally, acrid gas was detected; and the rime ice on the peak east of the crater had a sour taste, indicating the emission of acid gas.

Three plugs on the slope of the cone, probably intruded along a fissure, are aligned in a northwest direction from the crater. The plug nearest the crater rim is believed to have been the source of the

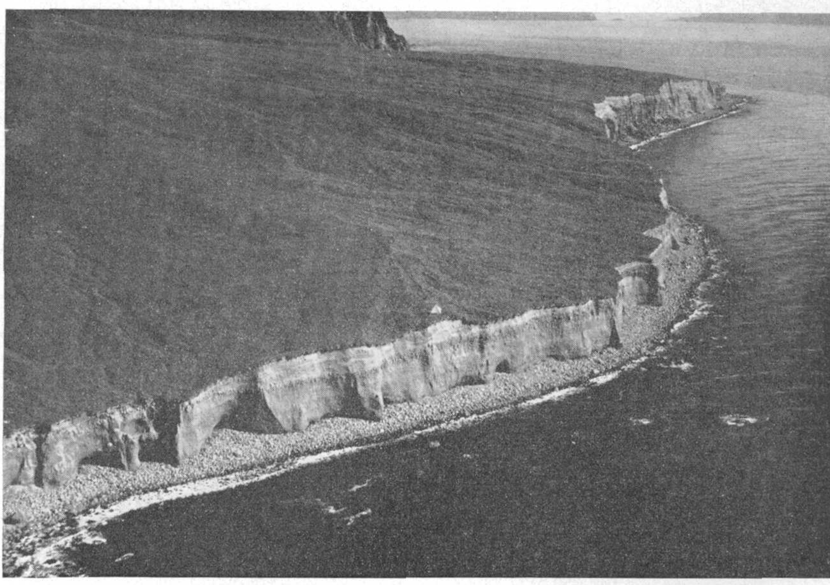


CRATER AND 1945 CRATER DOME OF GREAT SITKIN VOLCANO



A, SAND BAY VOLCANICS NORTH OF ZALIVA POINT.

The cliff, 300–350 feet high, is composed of well-bedded agglomerate, capped by an olivine andesite flow 40 feet thick. The flow shows excellent columnar jointing. Photograph by U. S. Navy.



B, ALLUVIAL FAN NORTH OF CAPE AKUYAN.

Sea cliff in foreground is about 30 feet high. The narrow boulder beach is typical of the west and north coasts of the island. Photograph by U. S. Navy.

MARINE TERRACE AND POND BETWEEN CAPE KIUGILAK AND TURMATH CREEK

The terrace was cut on landslide material. Sand Bay volcanics and valley of Turmath Creek are in background. Photograph by U. S. Navy.

recent ash that blankets the northwest slopes of the cone. Two other plugs, one of which forms Swallow Head, the northernmost point of the island, are aligned in a north-northwest direction. The plugs range from 1,000–3,000 feet in diameter and exhibit well-developed columnar jointing. They were not examined and their composition is not known.

A thick basalt flow near the head of Sitkin Creek, the only fairly young flow that was found, was extruded from the flank of the cone. It is 100–125 feet thick, and its columnar jointing is conspicuous. The flow is at least half a mile long; its lower end has been destroyed by glacial erosion, so its original length is unknown. The source is buried by pumice.

The Great Sitkin volcanics unconformably overlie the Sand Bay volcanics. The upper parts of the cone of Great Sitkin Volcano have been dissected by glaciers that have largely disappeared. Therefore, the building of the present cone probably began in late Tertiary or early Quaternary time and was largely completed before the end of Pleistocene glaciation.

Pumice.—Pumice, mixed with scoria and rock fragments, blankets the island to depths ranging from a few inches to more than 20 feet. The pumice blanket is not shown on the geologic map because it would obscure the bedrock geology.

The pumice is buff to light brownish gray in color, and is composed of fragments as much as 4 inches across. Several miles south of the crater the pumice is extremely light and frothy and will float on water, but it is progressively less vesicular in the direction of the crater, and on the slopes of the cone itself much of the rock is more properly termed scoria. Crystals of transparent plagioclase, pyroxene, and amphibole, set in a matrix of pale glass, can be easily recognized with a hand lens; some of the pyroxene crystals are as much as one-quarter of an inch across.

Mixed with the pumice are angular fragments of dark-gray porphyritic basalt as much as 3 inches across. From 10–15 percent of the pumice deposit near the crater is composed of these fragments; at increased distances from the crater the number of fragments decreases, and at Sand Bay practically none are present. These fragments are thought to have been torn from the throat of the volcano and from the summit of its cone at the time of the pumice eruption.

A minor but striking constituent of the pumice blanket is a very coarse-grained gabbrolike rock consisting of transparent plagioclase and amphibole, and small amounts of olivine, pyroxene, and magnetite. Only a few pieces of the rock were seen, the largest being 4 inches across. Amphibole crystals 1 inch long and plagioclase tablets half an inch across are common. The rock having alternate coarse- and fine-grained layers is prominently banded; the coarse-grained layers are themselves separated into feldspar-rich and amphibole-rich bands. The pumice of some areas, particularly on the ridge south of Sitkin Creek, contains many single crystals that evidently were derived from the gabbrolike rock by fragmentation.

The thickest pumice deposit was seen near the divide between Sitkin Creek and the west fork of Big Fox Creek. Here, gullies 20 feet deep have been cut in the pumice without exposing the base of the deposit. Thick deposits also occur in the upper valley of Sitkin Creek and as a major constituent of the moraine at the head of Glacier Creek. At other places reworked pumice forms alluvial-fan deposits 8–10 feet thick; these fans are especially well developed west of Big Fox Creek, where the original pumice deposit, overlain by 6–8 feet of alluvial pumice, is exposed in gullies. A thin, discontinuous pumice bed resting on sand dunes is exposed in several road cuts at the mouth of the valley of Little Fox Creek, and between Zaliva Point and Rip Point, in the area most remote from the crater.

Presumably, the great eruption that produced the pumice occurred long before the discovery of the Aleutian Islands by white men. The freshness of the pumice, the very small amount of soil developed on it, and its presence in considerable quantity on divides such as those between Sitkin Creek, Big Fox Creek, and Glacier Creek, indicate that it is not more than few thousand years old.

Ash deposit of northwest side of Great Sitkin Volcano.—The northwest slopes of the main cone are covered with a very recent deposit of ash, apparently ejected from the flank vent immediately northwest of the crater. This deposit was seen only from the sea, but its distribution is readily determined from aerial photographs. The ash is light colored and appears to be several feet thick in places. It overlies the pumice deposit and is at most only a few hundred years old.

SEDIMENTARY ROCKS

Alluvium and beach deposits.—Most of the valleys in the southern half of the island are floored with alluvium. In the lower course of Sitkin Creek well-bedded fanglomerate about 100 feet thick is exposed in the walls of gullies cut by recently rejuvenated streams. Elsewhere the exposed thickness of alluvium is less; a minimum of 30 feet of aluvium is exposed in the cliff at the lower edge of the large alluvial fan north of Cape Akuyan (pl. 7B). In the valleys of Big Fox and Little Fox Creeks the most recent alluvium is largely reworked pumice.

Narrow sandy beaches lie along the island's coasts, except on the rugged north and northwest sides where there are only a few small boulder beaches. Sand dunes are present on all beaches along the south and east coasts from the narrow beach at the mouth of Turmath Creek to the beach, 1½ miles long, between Sulphur and Bugle Points. At Bugle Point the dunes are roughly elliptical in plan, their long axes trending north. Most of the dunes are grass covered and appear to be relatively stable; those at the mouth of Little Fox Creek are mantled with pumice and soil. At present, dunes do not appear to be forming.

Mudflow.—The floor of the lower part of the valley of Glacier Creek is made up of what is believed to be a fairly recent mudflow. It was seen only from the sea at a distance of several hundred yards. The valley averages 2,000 feet in width for a distance of about 1½ miles from its mouth, and its floor is slightly convex upward in transverse cross section. Along each side of the valley is a steep-walled canyon incised well below the present valley surface; Glacier Creek occupies the larger of the two canyons, the one along the southeast side. The mudflow is thought to have had its source in the extensive moraine at the head of Glacier Creek, and was perhaps activated by heating and consequent melting of snow and ice around the moraine during some phase of the volcano's activity.

Exposures along the low cliff at the end of the mudflow suggest that two mudflows rather than one may lie in the valley—an older mudflow, made up largely of pumice, along the southeast side of the valley; and a younger and more extensive flow, made up of coarser debris, along the northwest side.

Glacial deposits.—Two of the island's five small glaciers have produced fairly large moraines.

The larger of the two glaciers, which is south of the crater at the head of Glacier Creek, is about 1 mile wide and half a mile long. Its moraine extends for at least half a mile down the valley; the upper part is made up largely of pumice, which has been built up into a hummocky terrain.

The smaller of the two glaciers occupies a valley on the southeast slope of the cone. It has built a blocky moraine that extends to the bottom of the valley of Sitkin Creek, a distance of about half a mile. The higher part of the moraine is actually a rock glacier. A medial moraine, between the main moraine and a small tongue of ice to the east, forms a ridge 10–15 feet high. Deep striations on outcrops hundreds of feet below the present terminus of the glacier indicate that formerly the glacier was of greater extent.

About three-quarters of a mile north of the mouth of Big Fox Creek many angular boulders are strewn across the valley floor. The largest is about 8 feet across. They are composed of well-indurated agglomerate. The blocks may have slumped from the canyon walls, but in view of the fact that some of them lie several hundred yards from the nearest local source, it seems more likely that they are glacial erratics. The valley of Big Fox Creek is believed to have been glaciated.

Landslides.—One landslide and two other features believed to be landslides are shown on the geologic map. The lower course of Middle Yoke Creek has been blocked by a large landslide from the steep valley wall to the northeast, and landslide material extends across the beach to the sea. Nearly 1 square mile is covered by this landslide debris, forming a typical hummocky surface. A small pond probably occupied the valley above the slide for a short time.

The rounded low headland between Cape Kiugilak and the valley of Turmath Creek is probably an ancient landslide; the cirquelike indentation above, the irregular topography of the lower slopes, and the large blocks of rock near the beach, all suggest a landslide origin. Another landslide may have occurred near the north bight of Yoke Bay, where a block 4,000 feet long and 400 feet high appears to have slid 50–100 feet down the steep slope forming the central part of the northwest shoreline.

HOT SPRINGS AND FUMAROLES

A large group of hot springs, mud pots, and fumaroles occurs at an altitude of about 2,000 feet near the head of the west fork of Big Fox Creek. On clear days a conspicuous cloud of condensed steam hangs over the largest of the springs. An area about 1,000 feet long and 400 feet wide is underlain by almost completely decomposed rocks that are bright red, pink, and yellow in color. Most of the rock whose texture has been preserved is a breccia of porphyritic volcanic rocks; it probably fills an old vent. The ground in the area is warm: grass and moss grow profusely, whereas the surrounding terrain is barren, and dark-green gelatinous algae clog the overflow channels of the springs.

Several of the low mounds in the fumarole area are hollow shells, from beneath which can be heard the sound of boiling water. The largest mound is about 25 feet long, 20 feet wide, and 6–8 feet high. The shell of the largest mound is about 2 feet thick, and the water level seems to be several feet below the roof. The roofs of some of the mounds are not strong, and may break under a man's weight. Steam vents are especially abundant on all the mounds.

The largest vent contains a pool of hot muddy water 6–8 feet across through which steam was bubbling with considerable violence. Little water was being discharged at the outlet, indicating that the boiling was due largely to passage of steam and not to the influx of boiling water. Most of the springs in the area discharge very little water; they appear to be fumarole craterlets in which surface water has collected. Many of the springs are muddy, and several are mud pots containing viscous gray mud. Pyrite was being deposited in one of the mud pots. Sublimates are rare; the bright color of the rocks is due mainly to rock alteration.

A gas sample was collected from each of the four largest fumaroles in a heat-resistant glass pipette (volume, 25 cubic centimeters) by inserting the pipette in the fumarole and allowing it to be filled by the gas pressure of the fumarole; because much steam was being emitted from each fumarole, it was easy to ascertain when gas was passing through the pipette. The pipette was sealed off with an oxybutane torch. Results of the gas analyses are given in the following table:

Analyses, in volume percent, exclusive of water, of samples of fumarole gases from Great Sitkin Island

[By mass spectrometer, National Bureau of Standards. After Byers and Brannock, 1949, p. 732]

Sample no.	H	N	O	A	CO_2	SO_2	Total
1	--------	[1] 69.2	17.8	0.8	12.1	0.1	100.0
2	--------	[1] 78.2	20.9	.9	.02	--------	100.02
3	0.2	72.5	17.9	.9	8.5	--------	100.0
4	--------	16.7	.8	.2	[1] 81.5	0.8	100.0

[1] Fraction is uncertain.

Sample 1: Fumarole 1, on low rounded knoll beneath which is hollow shell and bubbling water.
Sample 2: Fumarole 2, six to eight feet above bottom of gully.
Sample 3: Fumarole 3, at bottom of gully.
Sample 4: Fumarole 4, at bottom of gully, within 50 feet of fumarole 3.

The water from 12 hot springs was tested for temperature, pH, and Cl^- (with $AgNO_3$), and SO_4^{--} (with $BaCl_2$) ions. The range in temperature was from 88°–98°C, and in pH, from 2–7; only one spring had a pH as low as 2. The water of 7 springs had a strong reaction to the test for SO_4^{--}, the water of 4 had a weak reaction, and the water of 1 was too murky to test. All but one sample had a positive reaction to the test for Cl^-.

STRUCTURE

The structure of Great Sitkin Island is diagramed in the geologic sections of plate 5.

The oldest rocks, the Finger Bay volcanics, are intensely deformed and are overlain with marked structural and erosional unconformity by the nearly flat lying Sand Bay volcanics. These, in turn, are overlain unconformably in the northern part of the island by the present cone of Great Sitkin Volcano.

The slope of the cone is considerably steeper on the north, northwest, and west sides than elsewhere; moreover, the crater is located somewhat west of the center of the cone. A two-stage development of the cone is suggested to account for these anomalous features. The first may be called the peak volcano stage, and the second, the crater volcano stage (see p. 39–40). The center volcano is thought to have been built after the destruction of part of the peak volcano, and is the site of the present crater.

The present crater is believed to have been formed by both explosion and subsidence. The minimum volume of the cavity, before the cavity was partly filled with snow and ice and before the emplacement of the crater dome, is estimated to have been 2.5×10^8 cubic yards. A comparable volume of rock was probably present in the part of the cone that formerly extended above the level of the crater rim. However, the amount of cone rock that occurs as fragments in the pumice deposit seems to be less than the amount of rock removed from the cone.

A rough calculation has been made that is believed to give the maximum amount of fragmental rock ejected. Inasmuch as few rock fragments occur in the pumice at Sand Bay, the distance of Sand Bay from the crater (10,000 yards) was taken as the radius of a circular area over which rock fragments probably were deposited. The greatest observed depth of pumice was 20 feet, although this depth may be exceeded locally. Rock fragments from the cone are estimated not to exceed 10 percent of the total volume. Assuming an average initial depth of 5 yards of pumice, having an average rock-fragment content of 10 percent, the total volume of ejecta (pumice and rock fragments combined) would be 1.57×10^9 cubic yards; the volume of the rock fragments alone would be 1.57×10^8 cubic yards. Only about 32 percent of the rock removed is accounted for on the basis of these generous assumptions of average thickness of pumice (in which allowance is not made for the high porosity of pumice) and proportion of rock fragments.

It is concluded, admittedly on inadequate information, that not more than 25 percent of the rock removed can be accounted for by explosion. Probably the remainder of the cavity was formed by subsidence of part of the cone during or after eruption of the pumice, when abrupt evacuation of the gas-filled lava in the form of pumice, perhaps accompanied by intrusion of dikes or sills at depth, removed support from the upper part of the cone. The sequence of events which seems to have produced Great Sitkin crater approximately parallels that which Williams (1942) proposes for the formation of the crater of Crater Lake, Oregon.

GEOMORPHOLOGY

Aside from Great Sitkin Volcano and its crater, the most striking features of the island are the deep, steep-walled valleys radiating from near the center of the island, and the sea cliffs, which reach their greatest development in the towering Akuyan cliffs on the west side of the island south of Cape Akuyan.

The valleys of Akuyan, Glacier, Turmath, Big Fox, Little Fox, South Yoke, Middle Yoke, and Sitkin Creeks have a number of features in common. They have wide, more or less flat bottoms, and steep, in places precipitous, walls that merge smoothly into the floors to give the valleys roughly U-shaped cross sections. The steepness of many slopes is reduced by accumulation of alluvium in broad fans. Alluvial fans are best developed along the north side of Sitkin Creek, where they form a piedmont fan nearly 3 miles long.

That glaciation was once more widespread than at present is inferred largely from topographic evidence, such as U-shaped valleys and the knife-edge ridges at the heads of Glacier, Big Fox, and Middle Yoke Creeks. Rock-basin lakes of unquestionable glacial origin do not occur on the island. The glacial striae seen were above an altitude of 1,500 feet and cannot with certainty be attributed to other than recent glaciation. Moraines that might have been left by more extensive glaciers are now covered by alluvium and pumice. The large erratics in the valley of Big Fox Creek make up the only glacial deposits seen at low altitude. Although glaciation was clearly more extensive in the past, there were probably many separate centers of ice accumulation rather than one large ice cap. For example, there is no evidence that glaciers heading on Great Sitkin Volcano ever occupied the valleys to the south, for all these valleys have cirquelike heads rather than notches leading to the valley of Sitkin Creek. That the valley of Sitkin Creek had been at least partly eroded before the last extensive glaciation is shown by the glacially eroded nose of the basalt flow on the floor of the valley.

A rather curious geomorphic feature is the névé (granular ice) ridges in the pumice field in the upper part of the valley of Sitkin Creek at an altitude of about 2,500 feet. It had been noticed on August 16 that some of the pumice at altitudes of 3,500–4,000 feet on the lower slopes of the cone was underlain by coarsely crystalline névé, exposed in the bottoms of several gullies cut through 8–10 feet of pumice. At that time no névé ridges were present, but on August 26 several had formed. In cross section they resembled miniature fault-block mountains; the steep fronts exposed stratified névé and the gently inclined back slopes were capped by pumice. Invariably the ridges formed on slopes and were elongated parallel to the direction of maximum local slope. Most of them formed along the sides of snow- and ice-filled gullies. The longest ridge was several hundred feet long and exposed 4–5 feet of névé in its steep front. No ridges formed in flat terrain.

A tent was pitched at the lower end of one of the ridges, near the foot of the steep névé front. During the 5 days that the tent was so situated, its foundation rose several inches and titlted 3°–4° away from the newly forming ridge; a dull crunching sound was heard at irregular intervals.

The ridges are clearly the result of faulting of a névé layer underlying the pumice, probably induced by differential downhill sliding of some part of the névé-pumice mantle. Inasmuch as the ridges were not seen by R. R. Coats, who crossed the same area in June (personal communication), nor by the writers earlier in August, it appears that a long period of relatively warm weather is a prerequisite for their formation. Perhaps water from melting snow percolates to the base of the névé and acts as a lubricant, which makes sliding possible.

The island has been uplifted recently, or the level of the sea has fallen, as indicated by terraces and entrenched streams. The landslide just east of Cape Kiugilak has a wave-cut terrace at its tip, 6–8 feet above sea level (pl. 8). There are numerous small terraces elsewhere at about the same altitude. Rejuvenated streams also suggest recent uplift; all the main creeks are incised in their valley fill, and Big Fox and Sitkin Creeks have incised meanders.

The great cliff south of Cape Akuyan is the most prominent coastal feature of the island. It is nearly vertical at its base and very steep to a height of more than 1,000 feet; its maximum height is 2,400 feet. Although the rocks forming the lower 1,000 feet of the cliff are part of the Sand Bay volcanics, those of the upper part are thought to be the remnant of a cone whose summit was a short distance west of the cliffs. This cone, now almost destroyed, probably reached an altitude of about 3,000 feet. The method of destruction of the cone is unknown; it may have been by explosion, downfaulting, marine erosion, or by some combination of these factors.

GEOLOGIC HISTORY

The formation of Great Sitkin Island appears to have occurred during at least four stages of volcanic activity, which, from oldest to youngest, are in this report designated the Finger Bay, Sand Bay, peak volcano, and crater volcano stages.

The geologic record of the island probably begins in late Paleozoic time with the deposition of the Finger Bay volcanics. Events of the Finger Bay stage are practically unknown, as outcrops of the rocks of this stage are limited to a few headlands. It is apparent, however, that these rocks were intensely deformed and altered, and were considerably dissected by erosion before deposition of the Sand Bay volcanics, which are essentially undeformed and unaltered. These conditions indicate that a long time interval occurred between the two stages. Apparently the main land mass of Finger Bay and early

Sand Bay time lay to the south, as Finger Bay volcanics were not found on the north coast of the island.

Beginning in late Tertiary time, Sand Bay volcanics were extruded from a vent or group of vents, probably near the present cone. Early Sand Bay activity was explosive; coarse tuff was deposited first, then agglomerate. Explosive activity was followed by the quiet effusion of andesite and basalt lava. The Sand Bay volcano at the height of its development had much gentler slopes than Great Sitkin Volcano, was probably considerably larger in area, and late in its history may have resembled a shield volcano.

A long period of erosion ensued, during which the volcano was dissected and its summit lowered. The writers believe that the valley of Sitkin Creek was formed and eroded to considerable depth shortly after Sand Bay time, and that the course of Sitkin Creek, which is broadly convex to the south, has been shifted southward by accumulation of volcanic material forming the cone.

Toward the end of Tertiary time or in early Quaternary time a vent became active on the dissected north slope of the Sand Bay volcano, and formation of the present cone began. This vent probably was intermittently active from late Tertiary to Recent time. Most of the cone probably was constructed during the Pleistocene, as the cone appears to have been subjected to prolonged erosion since the last significant eruption of ash and lava. Most of the rocks exposed on the cone are lavas, but the steep slopes indicate that the core of the volcano is probably made up of pyroclastic material. While the cone was being built, the plugs of the northwest slope were intruded.

The building of the cone may have taken place in two stages, a somewhat hypothetical peak volcano stage, and a crater volcano stage. During the peak volcano stage a cone reaching an altitude of perhaps 6,500 feet was built and partly destroyed. The cone of the crater volcano stage was then built a short distance west of the former cone and may have reached nearly the same altitude. The peak volcano stage may have terminated when a crater east of the present crater was formed, but little evidence has been obtained to indicate that this crater existed. However, the highest point on the island is so much higher than any other point on the crater rim and so far from the present crater that it appears unlikely that the peak is actually a part of the rim; the peak may be part of an older crater rim, produced when the peak volcano was partly destroyed. Possibly, the peak volcano vent was sealed after formation of a crater, and the vent relocated farther west, in its present position.

If the cone of the peak volcano was decapitated by explosive eruption before the construction of the crater volcano cone, the products of the eruption have been eroded away or covered by the products of later eruptions, as no deposits containing fragmental material of appropriate composition appear to be exposed.

A basalt flow was extruded in the upper part of the valley of Sitkin Creek after the crater volcano cone had been built but before the last extensive glaciation.

During the Pleistocene several small glaciers probably covered parts of the southern half of the island, and almost certainly a small ice cap lay on the cone. The glaciers modified the valleys cut in the Sand Bay volcano and may have reached the sea, although the island does not have a fiord coastline such as that of Adak Island.

A glacier descended the southeast slope of the cone at least as far as the floor of the valley of Sitkin Creek where it removed the lower part of the young basalt flow. The glacier still exists but has retreated more than a mile from Sitkin Creek.

Perhaps a few hundred years ago, after the withdrawal of the ice to about its present position, the summit of the crater volcano cone was destroyed by a great eruption that covered the island with pumice and rock fragments, and the present crater was formed. The hot springs and fumaroles are known to have been active for nearly 200 years and may have been formed at the time of the pumice eruption. After the pumice eruption, a vent was opened on the northwest slope of the cone, and a small amount of ash was erupted from it.

After its formation the crater was filled with snow and ice, and from time to time minor eruptions occurred. Smoke was seen in 1829 and 1904, and minor explosive eruptions were reported in 1792 and 1933 (Coats, 1950). The ash of the northwest slope may have been deposited during one of these eruptions. Other eruptions may not have been detected because Great Sitkin Island is remote from the principal shipping lanes.

Extrusion of the crater dome marks the latest phase of activity. The dome is thought to have formed in March 1945, at which time a glow was visible at night from Adak Island, and Army aviators noticed clouds of steam rising from the crater. During that month a strong earthquake was felt at Sand Bay. Activity since formation of the dome has been limited to emission of steam and occasionally smoke; a small smoke cloud was visible from Adak Island on August 14, 1946.

FUTURE VOLCANIC ACTIVITY

The likelihood of dangerous eruptions in the future by Great Sitkin Volcano can be estimated only by comparison with volcanoes of other areas of similar geologic setting for which more detailed histories are available. Several of these volcanoes, which are discussed in a general summary of volcanic domes by Williams (1932a), are referred to on page 41. The histories of volcanic domes of andesite, basalt, and similar rocks, are different; some domes have been destroyed or partly destroyed by violent and destructive explosions, and others have not. Among those that have not been destroyed are the 1866 domes, Georgios Kaméni, Aphroessa, and Reka, on Santorin in the Grecian Archipelago; the 1909 Tarumai dome on Hokkaido Island, Japan (Powers, 1916, p. 261–263); and the Ousu dome of Volcano Usu, also on Hokkaido Island (Powers, 1916, p. 263–267). Those domes whose emplacement was followed by violent eruption include two domes in the crater of Merapi Volcano in Java, which were destroyed in the late 19th century; the 1914 dome of Ruang Volcano in the Sangi Islands, East Indies; the 1906 and 1907 domes of Bogoslof Island in the Aleutians; the 1922 dome of Santa María Volcano in Guatemala, which erupted nuées ardentes 7 years after its first appearance; and the two domes of the Chaos Crags in Lassen Volcanic National Park, California (Williams, 1932b).

It is evident that the evolution of volcanic domes follows no single course, and that the future of a dome cannot be predicted with certainty on the basis of present knowledge. Powers (1916, p. 272) has remarked that the formation of a dome often terminates the volcanic activity at a vent, and Williams' summary contains a number of such examples. That the termination may not be permanent was demonstrated at Mount Pelée on Martinique Island in the West Indies, where the dome that was formed after the catastrophic eruption of 1902 was partly destroyed and replaced by a new dome following the eruptions of 1929 and 1930 (Perret, 1937). The surface of the dome of Great Sitkin Volcano is blocky and broken by many fissures, a condition which Williams believes has a tendency to minimize the danger of explosive decapitation by offering easy escape to the volatiles thought to be the motivating agents in dome formation and destruction.

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