Geology of Little Sitkin Island Alaska

By G. L. SNYDER

INVESTIGATIONS OF ALASKAN VOLCANOES

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PREFACE

In October 1945 the War Department (now Department of the Army) requested the Geological Survey to undertake a program of volcano investigations in the Aleutian Islands-Alaska Peninsula area. The field studies were made during the years 1946–1954. The results of the first year's field, laboratory, and library work were hastily assembled as two administrative reports, and most of these data have been revised for publication in Geological Survey Bulletin 1028. Part of the early work was published in 1950 in Bulletin 974–B, Volcanic activity in the Aleutian arc, and in 1951 in Bulletin 989–A, Geology of Buldir Island, Aleutian Islands, Alaska, both by Robert R. Coats. Unpublished results of the early work and all the later studies are being incorporated as parts of Bulletin 1028. The geological investigations covered by this report were reconnaissance.

The investigations of 1946 were supported almost entirely by the Military Intelligence Division, Office of the Chief of Engineers, U. S. Army. From 1947 until 1955 the Departments of the Army, Navy, and Air Force joined to furnish financial and logistic assistance.

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GEOLOGY OF LITTLE SITKIN ISLAND, ALASKA

By G. L. Snyder

ABSTRACT

Little Sitkin Island, in the Rat Islands group of the Aleutian Islands, is composed of extrusive igneous rocks ranging in age from late Tertiary (?) to Recent. The youngest rocks are about half a century old. The island is in a calcic petrographic province and has an alkali-lime index of 63.5. Composition of lavas and pyroclastic debris ranges from basalt to rhyodacite, but most rocks are andesite, bandaite, or dacite. Three main periods of volcanism were separated by periods of caldera formation. Lavas and pyroclastic debris of the first volcanic period were dominantly andesite and originally constituted 78 percent by weight of all extrusive rocks on Little Sitkin. Lavas of the second period were high-silica dacite containing many andesite inclusions and originally constituted 17 percent by weight of all extrusive rocks on Little Sitkin. Lavas of the last, and presently active, period are low-silica dacite that now constitutes 4 percent by weight of all extrusive rocks on Little Sitkin. Minor amounts of dacitic and andesitic pyroclastic debris were ejected during or following each caldera-forming episode.

Considerable heterogeneity of magma type characterizes each extrusive epoch. Lavas from the same or adjacent vents differ markedly in composition. In one case rhyodacite and low-silica dacite were extruded simultaneously as a lava flow from the same vent. Similar phenomena are recorded in layered inhomogeneous volcanic bombs. The lack of local compositional pattern contrasts markedly with the overall chemical interrelationships of the suite of rocks on Little Sitkin Island. All oxide constituents of 12 of 13 chemical analyses have a remarkably rectilinear relationship with each other when plotted against SiO_2 on a variation diagram. The best explanation of the volumetric, temporal, and compositional relationships of lavas on Little Sitkin is believed to be as follows: tectonic kneading in the Aleutian welt has mechanically mixed portions of continental and oceanic rock; subsequently magmatic melts, which are local in both space and time, have developed in this mixed zone and penetrated to the surface.

INTRODUCTION

Little Sitkin Island is in the Rat Islands group of the Aleutian Islands (fig. 39) approximately 48 statute miles northwest of Constantine Harbor on Amchitka Island and approximately 36 statute miles east of Kiska Harbor. The Rat Islands have no permanent inhabitants; the nearest human habitations are 200 miles away on Shemya Island in the Near Islands group and on Adak Island in the Andreanof Islands.

The rocks of Little Sitkin Island are all subaerial lavas and pyroclastic deposits or shallow-water sedimentary deposits derived from nearby volcanic rocks. Eight bedrock units have been distinguished (pl. 23). The chemical, temporal, and volumetric interrelationships of these eight units pose complex problems in petrogenesis.

CLIMATE

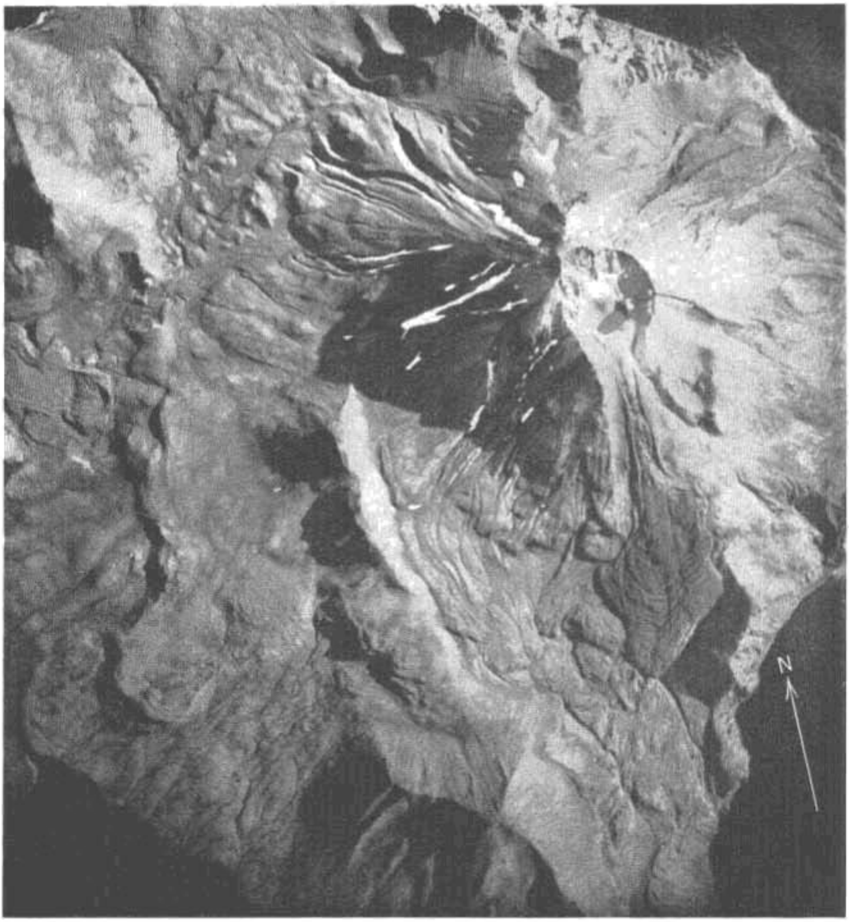
Little Sitkin Island has a maritime climate characterized by relatively high humidity and small range in annual temperature. Like other Aleutian Islands, Little Sitkin lies along the North Pacific belt of storms and thereby receives abundant wind, rain, and fog. Owing to its strong relief (3,897 feet) and rugged topography the orographic effect is an important factor in local weather conditions.

Short-term weather records from nearby Kiska and Amchitka Islands indicate a maximum annual temperature range of only 50° F. The mean July temperature falls in the range 44°–49° F. for the recorded years, and the mean January temperature falls in the range 28°–33° F. for the recorded years. The lowest winter temperature to be expected is 15° F. The annual precipitation ranges from 30 to 35 inches and the mean annual snowfall is about 70 inches. Cloud ceilings average less than 1,000 feet, and visibility is less than 3 miles during 60 percent of the year and during 83 percent of the summer. Winds average 20 to 25 miles per hour, but gales of 70 to 80 miles per hour are common; gusts as much as 150 miles per hour occur (Arctic Weather Central, 1950, p. 1–52; U. S. Coast and Geodetic Survey, 1947, p. 1–147; Weather Central Alaska, 1945, p. 1–59).

A dangerous Aleutian wind phenomenon common on Little Sitkin is the "williwaw", a type of downslope wind that results from the damming of air on windward slopes followed by a very gusty overflow of air down the leeward slopes. The unfavorable weather impedes fieldwork considerably and is a major logistic and economic factor influencing activity on the island.

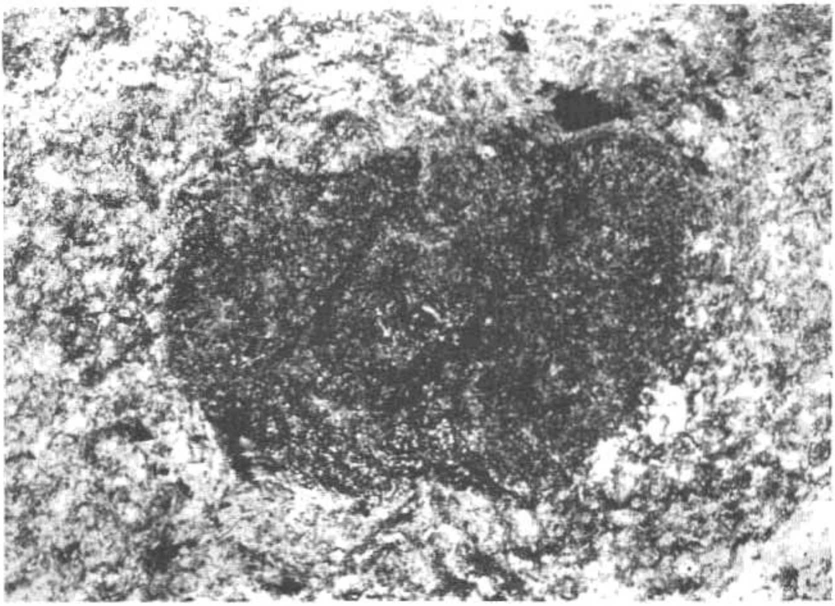
VEGETATION, WILD LIFE, AND HUMAN HABITATION

Low leafy plants, moss, grass, and sedge grow profusely on Little Sitkin below 1,500 feet altitude, annually adding organic debris to the blanket of peat on which they grow. The few woody plants are



VERTICAL AERIAL PHOTOGRAPH OF THE CENTRAL PART OF LITTLE SITKIN ISLAND

Taken from an altitude of 18,000 feet.



INCLUSION OF MIAROLITIC ANDESITE IN HIGH-SILICA DACITE LAVA OF DOUBLE POINT DACITE

Arrows show location of "pressure-shadow" cavities. About twice natural size.

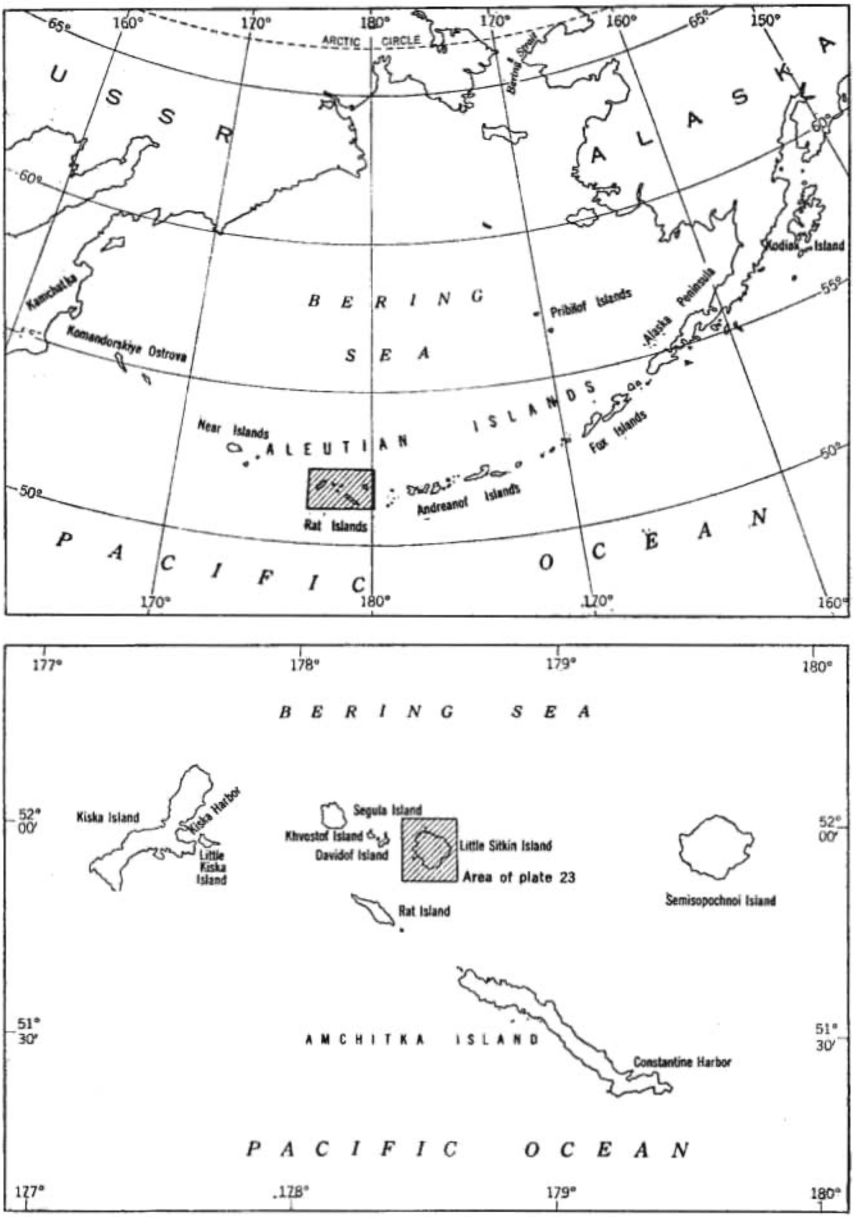


FIGURE 39.—Index map of the Aleutian Islands and land bordering the Bering Sea, showing location of the Rat Islands, and index map of the Rat Islands, showing location of Little Sitkin Island.

low, creeping types. The vegetal mantle thins at highest elevations, and exposed ridges are completely barren.

The animal life consists of the blue fox, a very few sea birds, a few insects, and the marine invertebrate assemblage of the littoral zone. In 1930 an estimated 250 blue foxes, kept to this level by native trappers, lived on the island. In 1951 there were considerably fewer foxes. The foxes live along the coast and subsist mostly on echinoderms, snails, and sand "fleas". Neither trout nor salmon are known to run in the streams. Sea otters, seals, and sea lions are sometimes seen offshore but no rookeries are known on the island.

Apparently the native Aleuts who formerly inhabited the Rat Islands found Little Sitkin inhospitable, for there are no village sites and kitchen middens such as are quite common on the other Rat Islands. The Aleuts may have avoided Little Sitkin because of its rugged topography, or, more probably, because of its volcanic activity. The Aleut word "sitkin" connotes "excretion", indicating that volcanic vents of the island were probably active when the island was named.

PHYSIOGRAPHY

The general shape of Little Sitkin is a quadrilateral with rounded corners extending toward each of the main compass points. The northwest side is fretted by small bays and sharp headlands, but elsewhere the coast is remarkably smooth. The coastline is about 27 miles long and encloses an area of about 24 square miles. The longest dimension, almost 7 miles, trends northwest.

The land surface is rugged. Six mountains rise more than 1,300 feet from sea level and the highest reaches 3,897 feet. Along a northward-trending caldera scarp in the center of the island, the slopes are very steep or vertical; slopes are also steep at higher elevations on a cone of Recent age, and along the sea cliffs that completely surround the island. The sea cliffs along the northeastern coast rise precipitously for 2,000 feet or so. Somewhat more than 60 percent of the island has a surface slope exceeding 30 percent, but level land is found near the mouths of alluviated valleys, atop some grass-covered lava flows, and along benches above sea cliffs.

The topography of Little Sitkin is dominated by constructional land forms, such as volcanic cones, lava flows, and blankets of ash. Erosive forces are also important in the development of the landscape. Running water, wind, waves, frost, and mass wasting have all been operative on Little Sitkin. The amount of erosion of a constructional form can locally be useful for estimating relative age. In many places on Little Sitkin comparison of the dissection of two or more volcanic landforms affords an estimate of their relative ages.

FIELDWORK AND ACKNOWLEDGMENTS

A topographic map at a scale of 1:25,000 was published by the U. S. Army Corps of Engineers in 1943. The U. S. Coast and Geodetic Survey began work on a 1:20,000 scale topographic map in 1950. An advance copy of this map was used as the base for the present geologic map (pl. 23).

Geologic fieldwork was completed during the summer of 1951 by Richard A. Robie and the author. The equivalent of 21 working days was spent mapping the island. Carl Vevelstad, and Charles Best provided the logistic support necessary for many small boat landings. Walter H. Newhouse, Hans Ramberg and Tom F. W. Barth contributed many ideas to an early form of the manuscript which was submitted in partial fulfillment of the requirements for the degree of Master of Science at the University of Chicago.

DESCRIPTION OF ROCK UNITS

WILLIWAW COVE FORMATION

The formation, here named the Williwaw Cove formation from exposures in sea cliffs on the west side of Williwaw Cove, includes the oldest rocks of Little Sitkin Island: a thick sequence of dacite, andesite, and basalt flows and associated pyroclastic rocks, widely exposed along the north side of the island (see pl. 23). The Williwaw Cove formation extends beneath the island, cropping out elsewhere around the coast, and forms the base upon which all later volcanic deposits accumulated.

Between Finger Point and Williwaw Cove the rocks are light-gray to purplish-gray porphyry with phenocrysts of feldspar and pyroxene. Vertical sea-cliff exposures, as much as 550 feet high, appear to represent a single flow. A wide bench extending southeastward from the sea cliff suggests that this flow continues inland beneath the 1,303-foot mountain. On the upper part of the mountain thinner flows of similar feldspar porphyry are exposed.

Near Patterson Point the lavas vary from light-gray pyroxene porphyry to dark-bluish-gray andesite containing sporadic large phenocrysts of plagioclase. From Patterson Point along the coast to East Point, light- to dark-gray andesite flows contain phenocrysts of augite, plagioclase, and sparse hornblende. Half a mile west of East Point an outcrop of chloritized andesite tuff-conglomerate is possibly the oldest rock exposed on Little Sitkin Island.

Massive purplish-gray to light-bluish-gray andesite of the Williwaw Cove formation is exposed in a steep 850-foot cliff southeast of East Point. It is strikingly like the flow from Williwaw Cove to

William Cove; possibly the two flows were extruded during a single voluminous eruption.

Southwest of Pratt Point, rocks of the Williwaw Cove formation vary from light-gray feldspar porphyry to dark-gray pyroxene porphyry. Olivine phenocrysts are rare. Local flows, dikes, and pyroclastic deposits of basalt contain 30 to 50 percent augite. They are the most basic rocks on the island and have the largest content of basic megaphenocrysts. The flows capping the 1,405-foot mountain and the southern end of the 540-foot hill southwest of it are, however, silicic.

The Williwaw Cove formation in the southern part of the island contains many varieties of andesitic and basaltic flows and pyroclastic deposits. The flows near the summit of the 1,960-foot mountain are black glassy feldspar andesite, greenish-gray cryptocrystalline andesite, or gray to purplish-gray olivine basalt; near the coast they are nonporous, dark-gray plagioclase porphyry, augite basalt, or andesite. On Sitkin Point, flows in the Williwaw Cove formation have been highly altered by fumarolic activity, locally to a multicolored soft clay. The andesite of the Williwaw Cove formation adjacent to the West Cove member of the Little Sitkin dacite is similarly altered. Pods of chloritized material are preserved locally within the fumarolically altered areas.

In summary, the flows of the Williwaw Cove formation are andesite with minor amounts of basalt and dacite. With these flows, except in the northwestern part of the island, are moderate to abundant amounts of interbedded pyroclastic debris. The pyroclastic deposits average 10 to 50 percent coarse lapilli, bombs, and lithic debris in a finer ash matrix and occur in beds, 1 to 40 feet thick, interbedded with the flows. The relative proportion of pyroclastic debris to flows is much greater in the Williwaw Cove formation than in all the succeeding formations. The contact of the Williwaw Cove formation with younger rocks is very irregular; locally it has a relief of several thousand feet. The Williwaw Cove rocks are probably late Tertiary or early Quaternary judging from their advanced dissection. No fossils were found on Little Sitkin Island.

The dikes in the Williwaw Cove formation are here considered a part of the formation. Most of them are nearly vertical. Dike swarms occur on the north side of the 1,960-foot mountain and along the sea cliffs of the southeast coast. The dikes north of the mountain radiate crudely from the center of the island. The other dikes are not systematically oriented. Isolated dikes crop out east of Prokhoda Point and at two localities on the north coast.

Dikes on the southeast coast are composed of augite basalt, and apparently were feeders for augite basalt flows in this area. The other dikes are andesite, mostly vesicular, many with the vesicles elongated in layers parallel to the walls. Dikes of vesicular porphyritic andesite and massive nonporphyritic andesite crop out side by side on the northeast spur of the 1,960-foot mountain and a dike of vesicular andesite cuts the volcanic sequence in the west spur. Massive, slightly chloritized andesite dikes with zeolite amygdules occur on the north coast. Several dikes have crude columnar joints normal to the walls and sheeting parallel to the walls.

SITKIN POINT FORMATION

The Sitkin Point formation is here named for a sequence of water-laid pyroclastic deposits more than 450 feet thick exposed at Sitkin Point. The formation is also exposed along the low saddle on the caldera rim north of the 1,960-foot mountain.

On the tip of Sitkin Point the formation consists of semiconsolidated volcanic wacke or graywacke (Williams, Turner, and Gilbert, 1954, p. 303) containing sparse boulders of gray dacite and sparse smaller fragments of white glassy pumice in beds 2 to 20 feet thick and averaging about 4 feet thick. Individual beds are massive and have well-developed vertical parting or jointing.

The boulders and rock fragments in the graywacke become more abundant toward the east. In the upper part of the cliff at the right-angle bend of the coast north of Double Point, 10 to 15 percent of the deposit is boulders, and round fragments of black pumice make up another 10 to 15 percent. These boulders have no preferred orientation.

In the Sitkin Point formation north of the 1,960-foot mountain many massive beds of dacite boulder tuff-breccia are exposed in the caldera scarp. The rock contains as much as 50 percent angular blocks of massive to pumiceous dacite. The sorting is very poor, but the boulders lie parallel to the bedding in some of the upper layers (see fig. 40). This preferred orientation is probably due to current action in a shallow body of water.

As shown in figure 41, the beds on Sitkin Point lie on inclined subaerial lavas of the Williwaw Cove formation. The beds of tuffaceous partly consolidated sedimentary rock rise slightly and thin toward the inclined contact. The basal contact is also exposed on the south side of West Cove where the contact and beds rise eastward. Similarly the beds in the central area are believed to overlie the Williwaw Cove formation unconformably. The deposit is interpreted as subaqueous debris close to the volcanic source. The Sitkin Point for-

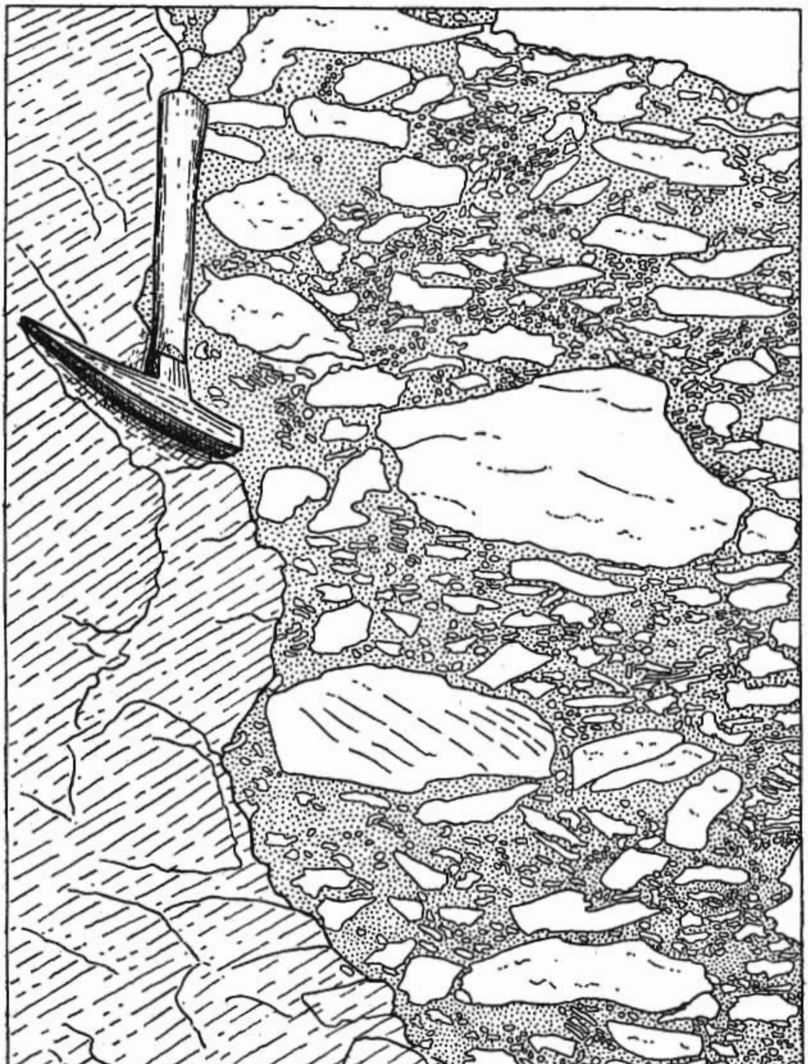


FIGURE 40.—Cliff exposure of tuff-breccia in the Sitkin Point formation as exposed in vertical face of "Caldera Two" scarp north of the 1,900-foot mountain. The boulders are alined parallel to bedding. Drawn from a photograph.

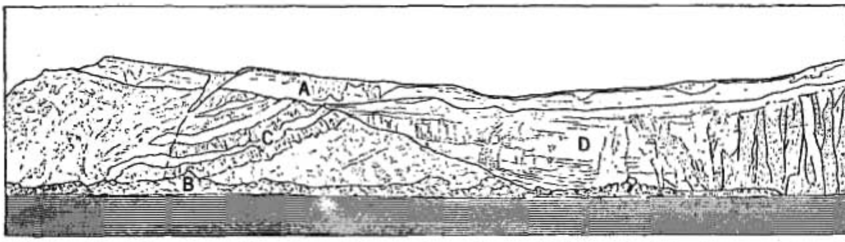


FIGURE 41.—Diagrammatic view of unconformity on Sitkin Point looking northwest. Drawn from a photograph. *A*, ash and turf mantle; *B*, boulder beach; *C*, massive and iron stained breccia layers of subaerial flows of Williwaw Cove formation; *D*, horizontally bedded, vertically jointed tuffaceous graywacke of Sitkin Point formation.

mation is probably early Quaternary because it overlies the rocks of the Williwaw Cove formation.

EAST POINT FORMATION

The East Point formation is here named for an uninterrupted sequence of andesitic lava flows, over 500 feet thick, exposed at sea level on either side of East Point. Two dozen separate flow units can be distinguished in the 700-foot sea cliff on the southeast side of East Point. The extent of this formation is shown by Collins, Clark and Walker (1945, pl. 7) in an excellent aerial oblique photograph.

Lavas of the East Point formation are light- to dark-gray andesite and basalt locally containing plagioclase, pyroxene, and olivine phenocrysts. Massive phases predominate, but clinkery flow tops are vesicular. At one place near the base the flows are interbedded with rhyolite(?) pumice that is probably slopewash deposited between flow gushes rather than dissimilar eruptive material contemporaneous with the flows.

The East Point formation rests on a very rugged terrain, apparently in a large valley. The basal contact of this formation rises 750 feet in a half mile on both sides of East Point.

The mutual stratigraphic relations of the East Point formation and the Sitkin Point formation are in doubt, but the topography of their upper and lower contacts perhaps suggests clues as to their relative age. The topography beneath the East Point formation is more deeply dissected than that beneath the Sitkin Point formation. The overlying Double Point dacite is unconformable on the Sitkin Point formation, but apparently conformable on the East Point formation. These relations perhaps suggest that the East Point formation is the younger.

DOUBLE POINT DACITE

The Double Point dacite is the name here given to the dacite flows exposed north of Double Point on the southwest coast of Little

Sitkin Island. These flows form a volcanic pile 3,000 feet high. Although as shown by their chemical composition (p. 194) the rocks are classified as high-silica dacite (Rittmann, 1952, p. 93–102), the composition ranges into rhyodacite. The Double Point dacite is composed of light- to dark-gray, glassy to lithoidal rocks containing many small plagioclase phenocrysts ordinarily visible in hand specimen. The rocks commonly are irregularly vesicular, the vesicles commonly being lined with sugary-textured altered glass, tridymite, or both.

The largest outcrop area extends from Double Point northeastward to the drainage of the Williwaw Cove stream and includes the present caldera scarp. Most of the rock is a light-gray high-silica dacite but ranges, very locally, from low-silica dacite, 1 mile southeast of the 1,303-foot mountain, to rhyodacite north of Double Point. Topographic remnants of the outlines of individual lava flows are apparent throughout this area, obvious in the southwest half, but less so along the caldera scarp and in the north (see pl. 24). Outlines of flows indicated on plate 23 show where the general dip of the formation parallels the general slope. At the mouth of the stream entering the angle of the coast north of Double Point, lava flows of the Double Point dacite are bordered by a deposit of glassy, spherulitic, flow-layered and irregularly vesicular (some semipumiceous) dacite boulders in a finer, unconsolidated ash matrix. Possibly this debris resulted from marginal explosions induced by surface water at the edge of a flow (as described by Wentworth and MacDonald, 1953, p. 28). If so, this deposit would indicate that sea level during Double Point time was within 200 feet of present sea level.

The second largest area of Double Point dacite, southwest and west of East Point, occupies the whole northern flank of the Little Sitkin cone. As elsewhere, light- to dark-gray high-silica dacite is predominant. At least a dozen thin flow units are exposed in cross section on the partly dissected steep slope northwest of Little Sitkin volcano, but the sharp spurs radiating to the north, northeast, and west, appear to be part of a single thick flow. Smooth flow layers are prominent on the northeast spur. From a distance the steep northern sea cliff appears to be made of thick flows. Landslides at the base contain gigantic blocks of massive dacite. At an 1,825-foot elevation due north of the summit a thin layer of tuff-breccia is interbedded with the flows.

Two inliers of Double Point dacite are surrounded by ash of the Patterson Point formation on the northwest flank of the Little Sitkin cone. These rocks are presumed to be high points on a caldera rim, which formed in post-Double Point time.

An outlier of the Double Point dacite on the east flank of the 1,960-foot mountain is bounded on the east by younger lava flows of the Little Sitkin dacite and on the west by a normal fault. In places, a whitish-gray frothy phase is intimately associated with the massive lava flows. A few lapilli-ash beds crop out in the southern quarter. Another outlier, a single flow thick, at the base of the south spur of the 1,303-foot mountain is a normal feldspar dacite. Several small dikelets of dacite richer in feldspar, tridymite, and vesicles than the more usual rock, cut the outlier. Near this outlier several float blocks of bluish-black glass rich in spherulites, resembling blocks in the debris at Double Point, are believed to be part of the Double Point dacite.

Almost every outcrop of Double Point dacite contains many round inclusions of miarolitic andesite; tiny crystals of feldspar, pyroxene, and hornblende can be seen with a hand lens projecting into spherical or irregularly shaped vesicles. The crystals are characteristically long and needlelike. All the inclusions have a distinct intersertal rock texture markedly different from the texture of any of the subaerial lava flows. The inclusions probably comprise only 5 percent of the Double Point dacite but locally, as on the 850-foot knoll due east of the head of West Cove, they make up 30 percent of the volume. They range in size from microscopic to 4 feet in diameter and average 1 to 3 inches. Stream or flow lines ordinarily surround the inclusions and pressure-shadow cavities occur at both ends (see pl. 25). The presence of these unusual pressure-shadow cavities attests to the relative solidity of the glassy inclusions when the lava flows of the Double Point dacite were erupted and to the viscosity of the dacite flows. The inclusions are surprisingly well-rounded, possibly owing to a combination of mechanical attrition and chemical solution. Xenoliths like this occur in other formations but not as abundantly. Andesitic rocks of the East Point or Williwaw Cove formation, or their intrusive equivalents are probable sources of the inclusions.

The basal contact of the Double Point dacite is well exposed in only two places: on the sea cliff south of West Cove and on the sea cliff on the west side of Double Point. Neither contact was visited, but, from a small boat directly offshore, the relations appeared clear. On the south side of West Cove tuffs beneath the Double Point dacite are chaotically jumbled. On the north side of the island the Double Point dacite terminates at the base of a prominent south-facing scarp in the Williwaw Cove formation which is interpreted as an eroded remnant of an older caldera fault scarp. West of East Point two streams, emerging from the steep northern sea cliff at an altitude of 600 feet, probably mark the contact. North of the 1,960-foot mountain the basal contact is indicated by changes in lithologic character of the rocks and topography. The edge of the formation west of the mountain has not been visited but is drawn at the prominent break in slope. Fumarolic alteration has made it difficult to determine the boundary of the formation in the northwestern part of the island.

The age of the Double Point dacite is judged to be middle Quaternary because of its partly dissected lava-flow topography, and because of its overlap relationship with the Williwaw Cove formation, the Sitkin Point formation, and the East Point formation.

PATTERSON POINT FORMATION

A deposit of ash several hundred feet thick, extending 2 miles northwestward from Little Sitkin volcano toward Patterson Point, is here named the Patterson Point formation after the feature of that name. The type section is designated as the exposure in the stream cut north of the 1,980-foot mountain at latitude 51°57′40″ N., longitude 178°30′50″ E. Because the ash is only semiconsolidated it forms few outcrops, but V-cut stream valleys dissect it and mark its extent (see pl. 24). The best exposures are in two streams in the west central part of the formation where from 20 to 40 feet of the end of the deposit is well exposed and two lithologic varieties can be distinguished. An upper unit 10 to 15 feet thick consists of light-grayish-white to bluish-gray, firmly consolidated ash and pumiceous lapilli and contains about 1 to 2 percent angular to subangular lava blocks as much as 2 feet in diameter. The blocks range from hornblende andesite and feldspar basalt to dacite and their long dimensions lie parallel to the slope. A lower unit as much as 25 feet thick consists of salmon-pink to grayish-white (depending on the relative abundance of ferric oxide), very firmly consolidated or welded dacitic glass and pumice containing from 5 to 10 percent rounded to subrounded bombs. The bombs differ from their dacitic matrix and consist of conspicuously contrasted layers of black and white glass. The black glass is dominant, averaging 70 percent of the bombs; the white glass commonly is isolated as layers, blebs and stringers. The composition of the two types of glass was not determined, but the general lithologic character of the black phase suggests a composition different from the dacitic matrix.

The salmon-pink oxidation color of the matrix of the lower unit probably indicates that the ash contained enough heat to oxidize its iron when deposited. Most of the ash is massive or irregularly vesicular, but some contains very "hairy" or "stringy" pumice resembling boiled sugar and water at the "string" stage. The "hairs" are elongate parallel to the underlying slope showing that the ash was plastic and evolving gas when deposited, and was stretched by further creep downslope.

The Patterson Point formation is massive except for oriented glass strings and foreign blocks. The upper and lower units intergrade through a zone about 6 inches thick. The basal contact of the lower unit is poorly exposed in a gulch at one place but lithologic details are obscured.

Other less complete exposures of the Patterson Point formation are higher on the volcano. At 3,500 feet elevation southwest of the summit 15 to 30 feet of ash is exposed. The lower 5 to 10 feet consists of dark-grayish-black pumice in a lighter ash matrix; the upper 10 to 20 feet consists of white to pinkish pumice and less-vesicular material in a reddish "sand" matrix.

Northeast of the Little Sitkin summit partly indurated ash, pumice, and lithic debris, several hundred feet thick, are exposed. The pumice consists of black glass, black and white layered glass, and reddish glass.

Ash and pumice of the Patterson Point formation on the northwest side of the 1,980-foot mountain are poorly exposed, but slope wash of black pumice, black and white layered pumice, reddish pumice and hornblende andesite rock debris, which resembles that in the main body of the formation, are distributed over a wide area.

Areal distribution of the Patterson Point formation and its internal structure and lithology suggests its mode of origin. Eruption of pyroclastic material and layered bombs was succeeded by a gas-generating "glowing cloud", probably like the "St. Vincent vertical" type of *nuée ardente* (MacGregor, 1952, table 2), which rushed down the northwest slope of Little Sitkin volcano. A rain of ash, pumice, and rock debris ended the eruption. The Patterson Point formation blankets a caldera fault scarp cutting the Double Point dacite (Caldera Two, see p. 185). The eruption producing the deposit may have been trigged by the collapse of the caldera.

LITTLE SITKIN DACITE

The name Little Sitkin dacite is here introduced for widespread lava on the east and south sides of Little Sitkin volcano. The type section is designated as the exposure in the crater rim of Little Sitkin volcano at latitude 51°57′2″ N., longitude 178°32′57″ E. Although these lavas are shown by analysis to range in composition from andesite to rhyodacite, 90 percent by volume are estimated to be low-silica dacite (see table 4). At least 300 feet of Little Sitkin dacite is exposed in cliffs on Pratt Point and near the crater, but the formation is doubtless even thicker because it fills two valleys and part of a caldera depression. The estimated maximum thickness shown on sections *A-A′* and *B-B′*, plate 23, is about 1,000 feet. Constructional flow forms are generally recognizable everywhere on the surface of the Little Sitkin dacite (see pl. 24). The outlines of individual flow units, as indicated by the topography, are shown on plate 23.

Two members have been mapped separately from the bulk of the Little Sitkin dacite. They are here named the Pratt Point member and West Cove member. The type locality of the Pratt Point member is the exposure on the north side of Pratt Point along the coast. The type locality for the West Cove member is the exposure along the coast on the north side of West Cove. The Pratt Point member of the Little Sitkin dacite is a long narrow body of obsidian (chemically a rhyodacite) from 200 to 700 feet wide and about 2 miles long that extends from the crater rim to the coast north of Pratt Point. The rhyodacite ranges from light-gray to white glass, has many plagioclase and a few pyroxene and hornblende phenocrysts, ranges from slightly to very vesicular and, locally, contains small pink devitrification spherulites.

The contact of rhyodacite of the Pratt Point member with surrounding low-silica dacite of the Little Sitkin dacite is extremely complex. Rhyodacite and dacite interfinger in complex swirls and loops. The zone of interfingering is from several yards to several tens of yards wide. Fresh and oxidized phases of each kind of rock are randomly interlayered. In several areas the dacite contains sharp angular fragments of rhyodacite, but on a smaller scale dacite is also included in the rhyodacite. Apparently the rhyodacite and dacite were extruded contemporaneously from the same vent (a vent that later supplied the homogeneous "crater flow").

The West Cove member consists of two aa flows, one at West Cove (cove flow) the other due south of the present crater (crater flow). "Push moraines" of blocky surface debris and "lateral moraines" or "levees" are distinct surface features on both flows. The crater flow breached the south side of the crater and flowed down to an altitude of 500 feet. The cove flow rose from a fissure (probably on an old caldera fault zone) and flowed westward to a point 150 feet below sea level in West Cove (see pl. 23, section *A-A′* and Gates and Gibson, 1956, fig. 9). The rocks of both flows are black glassy dacite containing abundant small plagioclase phenocrysts and shown by analyses to be low in silica for dacite. Judging from amounts of vegetation on each flow at the 700-foot altitude, the crater flow is the younger. A similar comparison with vegetation on the northeast Recent flow of Kanaga Volcano on Kanaga Island which erupted in 1906 (Coats, 1952, p. 492; 1956, p. 79) suggests that the "crater flow" on Little

Sitkin is not older than the eruption on Kanaga. The fragmentary historical records give no reliable date for the eruption on Little Sitkin (Coats, 1950, p. 37, 39; table 2). Probably the crater flow and cove flow are nearly contemporaneous and were extruded about 50 years ago.

Most rocks of the Little Sitkin dacite are black, glassy to cryptocrystalline dacite shown chemically to be low in silica. A few massive light-gray nonporphyritic andesites occur interbedded with the other lava, for example on the east side of Sealy Point and west of the center of the crater flow. A few areas of small miarolitic, basic inclusions have been noted but nowhere in the abundance and persistence of the inclusions in the Double Point dacite. Where the lava is well exposed, irregularly conchoidal joints are prominent. Locally these joints group themselves in vertical sets that roughly resemble columnar joints. The upper portions of flows, beneath the surface aa blocks, locally have contorted flow layers especially on the east flank of the volcano.

The northwest edge of the Little Sitkin dacite is easily mapped. A marked lithologic contrast with the Double Point dacite and a prominent erosional scarp mark the boundary. The topographic contrast is reversed along the west margin where flows of the Little Sitkin dacite lap up against the caldera scarp of the Double Point dacite. Where the Little Sitkin dacite is in contact with the rocks of the Williwaw Cove formation along the east and south boundaries of the mass, lithologic distinctions are more difficult. Except for the surficial deposits the Little Sitkin dacite overlies all other rocks.

SURFICIAL DEPOSITS

The unconsolidated surficial deposits on Little Sitkin have been grouped into four categories: alluvium, beach deposits, colluvium, and eolian deposits. Although glacial deposits are not definitely recognized, debris left by former glaciers may lie somewhere beyond the shore. In addition to the deposits mapped, a mantle of surficial ash, peat, and turf is widespread and boulder and block beaches are everywhere along the coast except at very exposed headlands.

Eight mappable deposits of alluvium are scattered around the island. Three are at valley mouths and two on flats below masses of fumarolic clay. The alluvium in the valley between Sealy and Prokhoda Points, and that at Williwaw Cove are composed of gravel and sand. The alluvium at William Cove and north of the source of the cove flow is composed of sand, silt, clay, and organic muck. Four deposits are on the gentler slopes near the base of the cone and consist mostly of thin deposits of very coarse bouldery debris moved downslope during the Spring runoff. Many other local alluvial deposits are too small to map.

Beach deposits on Little Sitkin Island are of two ages: those now forming, and those that record a higher stand of the sea. Older beach deposits are preserved at two places on the east coast. One, half a mile north of Pratt Point, consists of well-rounded boulders, gravel and sand atop a 50-foot high bedrock terrace backed by a cliff. Thick peat covers the deposit. The other, 2 miles southwest of Pratt Point, is a semiconical mound of partially indurated conglomerate at the mouth of the stream draining the volcano crater. The top of the mound is about 50 feet above sea level. The present stream has cut a channel through the deposits. This mound may have been deposited at a relatively higher stand of the sea.

The beach between Prokhoda and Sealy Points is composed of boulders and gravel. The deposit in William Cove is a shingle beach of small flattened pebbles. The beach in Williwaw Cove is sand.

Colluvial deposits on Little Sitkin Island are varied. Materials mapped as colluvium include: talus inside the crater and along the west side of the crater flow; a long probably active mudflow above the head of West Cove; and several landslides. A land slide at the head of West Cove consisting of slumped rotated lava blocks may still be moving slowly. Two landslides west of East Point, which may have occurred at about the same time, contain disoriented blocks of lava tens of feet in diameter. A deposit of unsorted material east of the 1,980-foot mountain is regarded as colluvium; one of unconsolidated surficial debris exposed in the sea cliffs southeast of Finger Point is possibly glacial till.

A large area of partially grass-covered sand dunes lies back of the Williwaw Cove beach. A blowout on Prokhoda Point exposes an area of windblown sand too small to map.

STRUCTURAL GEOLOGY

Relict topography gives important clues to the structural relations on Little Sitkin Island. Four peaks, 1,303, 1,405, 1,960, and 2,095 feet high, within the Williwaw Cove formation around the margin of Little Sitkin Island have steep inner slopes and lie along the circumference of a circle 3.8 miles in diameter. Between the 1,303-foot mountain and the 2,095-foot mountain is a low curvilinear scarp that faces south. These mountains are apparently greatly dissected remnants of a caldera rim. The inference of a caldera from the topography is supported by the attitude of the bedding, which dips generally outward from the center of the island. The beds were probably all laid down on a single large volcanic cone rather than in separate smaller volcanic piles. The postulated caldera, here called Caldera One, has been almost completely filled by younger deposits since its formation.

Topographic relations in the Double Point dacite indicate a second caldera, here called Caldera Two. A steep, northward-trending scarp, that traverses the central part of the island culminating in the 1,980-foot mountain, is interpreted as a fault scarp. On the north in line with the scarp is a wide horizontal bench in an otherwise steep slope. The inner boundary of this bench is regarded as the fault trace and its marked change in surface expression is probably due to a change in attitude of the fault plane. The fault is probably nearly vertical along the western scarp; in the northern area the fault plane is probably nearly horizontal. Direct evidence of the caldera scarp is buried by younger formations on the east, south, and northwest. Little Sitkin volcano, a mountain 3,900 feet high, is a large block of the Double Point dacite that did not collapse far into Caldera Two. Probably the block tilted toward the center of the caldera, as indicated by nearly horizontal lava flows on the northern side of the summit. By analogy with normal lava flow attitudes near the summit of a volcano, these beds have been tilted at least 30°.

Caldera One, as postulated, is roughly circular and about 3 miles in diameter. Caldera Two is an elliptical structure measuring 1.7 by 2.5 miles. Coats (1950, p. 43) lists and Gibson and Nichols (1953, p. 1184) repeat a diameter for a Little Sitkin caldera of 4.5 km (=2.8 miles). This probably represents the long dimension of Caldera Two. The two calderas may have utilized the same zone of weakness on their eastern and southern margins. Several faults branch off from the southern part of the Caldera Two fault and are evident topographically at the northeast base of the 1,960-foot mountain. They extend southeastward beneath the Little Sitkin dacite to the sea, whence their submarine extension is expressed by a topographic scarp, the Prokhoda Scarp, that can be traced for 35 miles between Little Sitkin Island and Semisopochnoi Island (Snyder, 1957, pl. 22). Movements along this larger structural feature may have triggered the collapse of one or both of the Little Sitkin calderas.

The magma of the cove flow of the West Cove member has probably risen along the old Caldera One zone of weakness (see section *A-A′*, pl. 23). The cove flow issues from beneath the Double Point dacite near where the dacite covers the old fault trace.

In the northwest part of the island a relatively undissected scarp as much as 50 feet high outlines three sides of a downthrown block (see pls. 23 and 24). The volume of material displaced by the dropped block (more than 1 billion cubic feet) is roughly equivalent to the volume of the cove flow (less than 1⅓ billion cubic feet). This plus the roughly equivalent age of each suggests a causal relationship between the two.

A structurally weak zone is suggested by the west northwest alinement of three major areas of fumarolic activity across Little Sitkin Island passing through the present crater. The alinement roughly parallels the trend of the volcanic centers of Davidof, Segula, and Little Sitkin Islands and is expressed on the ocean floor by parallel linear ridges and troughs west northwest of Finger Point (Snyder, 1957, pl. 22).

Most joints on Little Sitkin Island are confined to individual flow units; though few are columnar, they probably formed during cooling. A well-developed set of shear joints on Finger Point probably formed at the margin of a flow of the Williwaw Cove formation, but may be related to tectonic movements. Prominent linear depressions in the crater flow of the West Cove member (see pl. 24) are believed to be shear zones formed when this flow was nearly solidified; the confinement of these depressions to this flow suggests a volcanic rather than a tectonic origin.

PETROGRAPHY

Petrographic characteristics of the volcanic rocks on Little Sitkin Island are summarized in table 1. Compositions of plagioclase feldspar were determined principally from extinction angle curves of high-temperature plagioclases as given by Tröger (1952, fig. 234). Although the feldspar megaphenocrysts range in composition from calcic oligoclase (An_{24}) to sodic bytownite (An_{76}), the great majority range between andesine (An_{40}) and labradorite (An_{60}). This range occurs within single oscillatory zoned crystals as well as between different crystals. The microphenocrysts are generally somewhat more sodic than the megaphenocrysts, as are the normative feldspars. Apparently the phenocryst and groundmass are in disequilibrium as is normally true of glassy lava. Because most of the rocks on Little Sitkin contain more cryptocrystalline or glassy groundmass than phenocrysts, nomenclature based on the mode as indicated by the phenocrysts might give an inaccurate root name. Accordingly the chemical classification of Rittmann (1952, p. 93–102) which has been proposed for use in the International Catalogue of Volcanoes, is used in this report. The Rittmann names sometimes contain mineralogical modifiers that are confusing if these minerals are not present in the actual rock. Only Rittmann's root names have been retained in this report.

Individual formations mapped on Little Sitkin Island are statistically uniform petrographically. The rocks of the Williwaw Cove

TABLE 1.—*Summary of petrographic characteristics of volcanic rocks on Little Sitkin Island*

	Plagioclase feldspar				Occurrence of			Relative abundance of clinopyroxene and orthopyroxene
	Megaphenocrysts		Microphenocrysts	Average normative [1]	Free silica	Olivine	Oxyhornblende	
	Average composition	Range	Average composition					
Williwaw Cove formation	An_{56}	An_{40-78}	An_{65}	An_{46}	None	Rare to common	Rare to abundant.[2]	CL>OR; rarely CL<OR
Sitkin Point formation	An_{45}	----------	An_{43}	----------	None	Rare	Rare	CL≷OR
East Point formation	An_{58}	An_{33-76}	----------	----------	None	Present	None	CL>OR
Double Point dacite	An_{43}	An_{33-83}	An_{40}	An_{33}	Tridymite common.	Very rare	Rare	CL≦OR; rarely CL>OR
Patterson Point formation	An_{51}	An_{43-74}	----------	An_{39}	None	None	None	CL≧OR
Little Sitkin dacite	An_{48}	An_{36-60}	An_{41}	An_{43}	Tridymite very rare.	Rare	None	CL>OR; rarely CL<OR
Pratt Point member	An_{58}	An_{34-86}	An_{40}(?)	An_{36}	Quartz common	None	Common	CL≦OR
West Cove member	An_{40}	An_{40-55}	An_{40}	An_{41}	None	Rare	None	CL>OR

[1] Calculated from data in table 2; includes normative orthoclase as albite.
[2] Hornblende rare in mapped areas of these rocks, abundant in intersertal inclusions in the rocks of the Double Point dacite, which are believed to be derived from the Williwaw Cove formation.

formation including the feeder dikes (pl. 23) contain plagioclase feldspar with an average composition of An_{55} and a range in composition of An_{40} to An_{75}. Plagioclase microlites have an average composition of An_{50}. Olivine is generally present, sometimes even visible in hand specimen, and there is no free silica. Oxyhornblende is rare in most rocks but abundant in the miarolitic inclusions contained in the lava of the Double Point dacite. In general, all rocks of the Williwaw Cove formation contain much more clinopyroxene than orthopyroxene. The index of refraction of the groundmass glass is only determinable in inclusions of the Double Point dacite where it ranges between N=1.498 and N=1.514 (?).

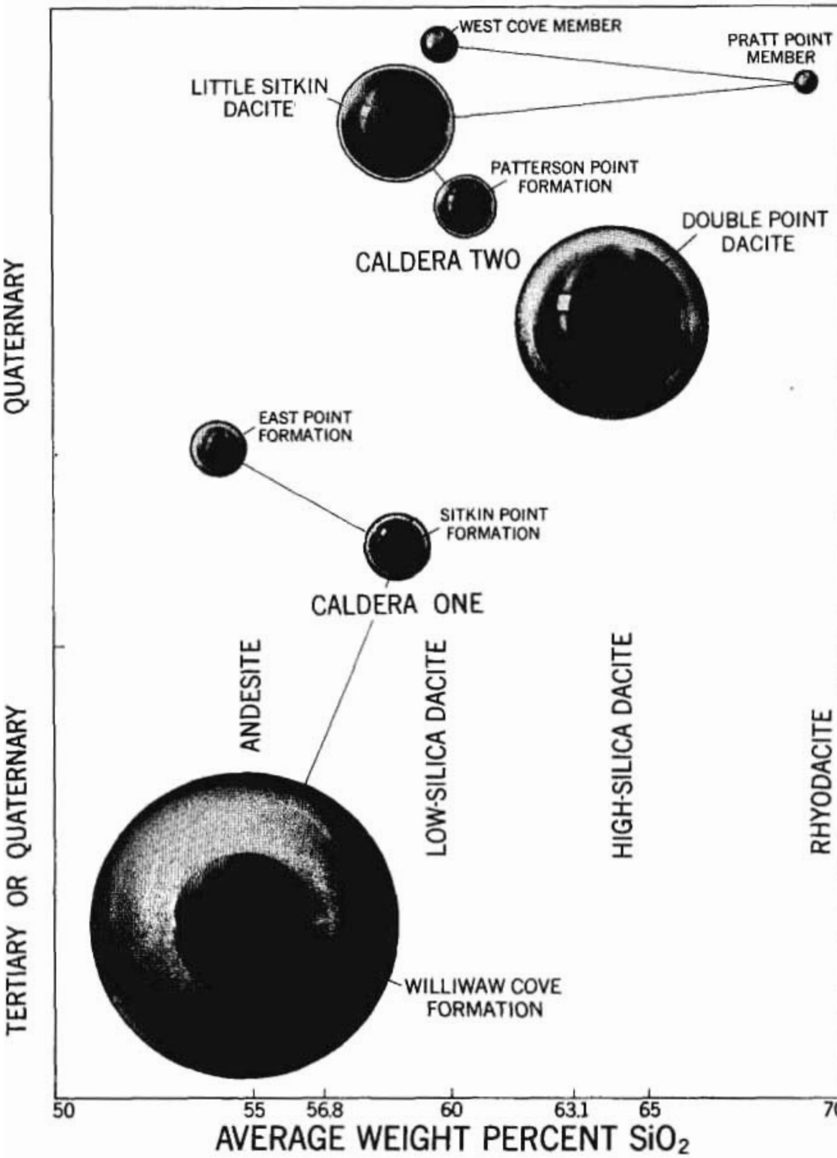
Petrographic knowledge of the Sitkin Point formation is limited to the study of several thin sections of lava blocks as shown in figure 40. The unconsolidated matrix has not been studied petrographically. Plagioclase phenocrysts have an average composition of An_{46}; microlites, An_{43}. Olivine and hornblende are present but uncommon and free silica is completely absent. Clinopyroxene and orthopyroxene are present in varying proportions.

The uniform flow units of the East Point formation contain plagioclase feldspar with an average composition of An_{59} and range in composition of An_{53} to An_{76}. Olivine is present and free silica and hornblende are absent. Clinopyroxene is much more abundant than orthopyroxene.

The high-silica dacite of the Double Point dacite contains plagioclase feldspar with an average composition of An_{42} and range in composition of An_{35} to An_{52}. Groundmass microlites have about the same composition as the large plagioclase phenocrysts. Tridymite is common as a groundmass mineral in many rocks; rare olivine and oxyhornblende have been observed in some others. In general the amount of clinopyroxene is less than or equal to the amount of orthopyroxene. Crystallites (longulites), skeletal crystals, and spherulites are common in a fluidal glassy groundmass which has an index of refraction from N=1.490 to N=1.504.

The main juvenile eruptive rocks in the Patterson Point formation are characterized by plagioclase feldspar with an average composition of An_{51} and range in composition of An_{43} to An_{76}. No free silica, olivine, or hornblende are known to occur. Clinopyroxene is present in amounts greater than or equal to the amount of orthopyroxene. Two determinations of the index of refraction of the glassy groundmass give N=1.504 and N=1.506.

The low-silica dacite of the Little Sitkin dacite contains plagioclase feldspar with an average composition of An_{48} and a range in composition of An_{40} to An_{60}. Plagioclase microphenocrysts have an aver-



GRAPH OF ROCKS OF LITTLE SITKIN ISLAND, SHOWING PERCENT SILICA AND VOLUME AS RELATED TO AGE

The volume of the inner sphere is proportional to the calculated present volume above sea level; the volume of the outer sphere is proportional to the estimated original volume as given in table 3. The "56.8" and "63.1" values of the abscissa indicate, respectively, the weighted average percent SiO_2 in rocks of the Little Sitkin Island, and the weighted average percent SiO_2 in rocks younger than the Williwaw Cove formation. The spheres connected by straight lines represent closely related volcanic formations, which were probably derived from the same magma.

age composition of An_{43}. Olivine is rare and tridymite was observed in only one specimen. No hornblende was found. In general, there is more clinopyroxene than orthopyroxene in the Little Sitkin dacite.

The Pratt Point member of the Little Sitkin dacite contains plagioclase feldspar with an average composition of An_{38} and a range in composition of An_{24} to An_{50}. The groundmass feldspar have about the same average composition as the phenocrysts. Oxyhornblende and corroded quartz are common and olivine is never present. In general, clinopyroxene is much less abundant than orthopyroxene. Crystallites (longulites), skeletal crystals, and spherulites are common in the rhyodacitic glass which has an index of refraction of N=1.488 to N=1.491.

The West Cove member of the Little Sitkin dacite has practically the same petrographic characteristics as the main body of the formation. The average plagioclase megaphenocryst has a composition of An_{49} and the range in composition is from An_{40} to An_{55}. Plagioclase microphenocrysts have an average composition of An_{40}. There is no free silica or hornblende. The few grains of olivine are surrounded by reaction rims of orthopyroxene and magnetite. Clinopyroxene is more abundant than orthopyroxene.

Comparison of table 1 with table 4 will show that, in general, the rocks low in silica contain plagioclase relatively high in anorthite content, olivine, and much more clinopyroxene than orthopyroxene, and that rocks high in silica contain plagioclase relatively low in anorthite content, quartz, and much more orthopyroxene than clinopyroxene. Intermediate rocks are intermediate in these respects. Oxyhornblende occurs abundantly in the most silicic and least silicic rocks and is rare or absent in the intermediate rocks. The index of refraction of the glassy groundmass also varies systematically from N=1.488 in the most silicic to N=1.514 (?) in the least silicic rocks. The more silicic rocks generally contain more glass and many skeletal crystals, crystallites, and spherulites.

Plagioclase is by far the most common phenocryst-forming mineral in nearly all of the rocks on Little Sitkin Island. Plagioclase phenocrysts constitute from 10 to 60 percent of the rocks; 20 to 30 percent is an average amount. Strong oscillatory zoning of plagioclase is universal and a few negative crystals in the feldspar contain two fluids. Albite and carlsbad twins are very common and pericline and baveno twins are present.

Pyroxene is the next most common mineral. Typically the maximum amount of pyroxene phenocrysts is 15 percent, but specimen 1 from the Williwaw Cove formation contains 43 percent augite megaphenocrysts. Hypersthene is the common orthopyroxene. Pleochroism in pale tints of pink and green characterizes the hypersthene and some of the clinopyroxene. No pigeonite was found.

Olivine constitutes as much as 5 percent of many rocks. Although this mineral is not in equilibrium with the rock as a whole (see norms, table 2), reaction rims are very rare. Euhedral outlines of some crystals suggest that the olivine was growing when the rock solidified. Several dikes cutting the Williwaw Cove formation contain masses of serpentine(?), probably altered from olivine.

Euhedral basaltic hornblende is common in the Pratt Point member of the Little Sitkin dacite, in the miarolitic inclusions of the Double Point dacite, and in the lithic blocks contained in the Patterson Point formation. Elsewhere hornblende usually occurs as anhedral remnants with reaction rims of hematite or magnetite. Strong pleochroism ranging from olive green and golden yellow to scarlet and deep brown is common.

Quartz makes up as much as 4 percent of the rhyodacitic Pratt Point rocks. Magnetite and ilmenite are present in amounts from a fraction of a percent to 5 percent. Tridymite lines cavities in many rocks of the Double Point dacite. Other accessory minerals include apatite and titanite(?). Alteration minerals include kaolin(?), leucoxene, serpentine(?), chlorite, and hematite. Introduced minerals include pyrite, chalcedony, zeolites, calcite, and sulfur. The secondary minerals are rare except in altered zones or active fumarolic areas (see pl. 23) where all but serpentine are abundant.

The following petrographic descriptions of the chemically analyzed rocks are based on studies of a single thin section of the particular rock, and of crushed fragments of the groundmass glass in immersion oils. Mineral percentages are based in part on Rosiwal analyses and in part on visual estimates. Bubbles or vesicles smaller than about 0.03 mm are included in the groundmass percentages. The color names and numerical designations used are based on the Munsell color system as shown in the rock-color chart printed in 1948 by the Rock-color Chart Committee of the National Research Council. The field location is given in general terms in the following descriptions and is also located exactly on plate 23.

Petrographic descriptions of chemically analyzed rocks

1. Basalt from Williwaw Cove formation on southeast coast 1 mile southwest of Pratt Point. (Chemical data given in column 1, table 2.) Color: light reddish gray (5*R* 6/1). Texture: holocrystalline, porphyritic, with large, diameter 15 mm phenocrysts of greenish black augite (5 *GY* 2/1). Plagioclase phenocrysts, 10–15 percent, range from An_{45} to An_{65} in individual and separate crystals and average An_{57}. Augite (nZ: 1.705, nX: 1.676) occurs as remarkably inclusion-free megaphenocrysts and as groundmass dust, making *40 to 45* percent

of the rock. Subhedral olivine, 2 percent, and magnetite-ilmenite, 1 percent, are accessory minerals. The groundmass is a microcrystalline aggregate of all the above minerals.

2. Andesite from typical inclusion in lavas of Double Point dacite. (Chemical data given in column 2, table 2.) Collected from small inlier of Double Point dacite about 1 mile west-northwestward of summit of Little Sitkin volcano. Similar inclusion from same area shown in plate 25. Color: dark gray (*N* 3). Texture: miarolitic intersertal. Pore space, miarolitic cavities: 20–30 percent. Plagioclase lathes, 45–55 percent, average An_{60} but range from An_{26} to An_{74}; megaphenocrysts, 3 percent, show fritted texture. Oxyhornblende, 14 percent, is pleochroic in deep brown and olive brown, occurs in needles with a length-width ratio of 15:1; many hornblende crystals have hollow centers. Orthopyroxene, 6 percent, occurs in euhedral needles with a length-width ratio as much as 30:1. Clinopyroxene, 4 percent, is present as stubby subhedral crystals. Magnetite, 4 percent, anhedrons have a length-width ratio as much as 10:1. Clear brown glass, 14 percent, in groundmass has N=1.498.

3. Andesite of Little Sitkin dacite from coast at stream mouth 0.8 mile south of terminus of crater flow of West Cove member. (Chemical data given in column 3, table 2.) Color: medium gray (*N* 5). Texture: hypocrystalline, porphyritic with feldspar phenocrysts as much as 4 mm in diameter, and pyroxene phenocrysts as much as 3 mm long. Plagioclase megaphenocrysts, 20–30 percent, range from An_{35} *to* An_{64} and average An_{47}; complex zoning and twinning common. Clinopyroxene, 8 percent, contains rare centers of orthopyroxene, 1 percent. Both unreacted olivine, 5 percent, and pyroxene are stained amber along joints. Magnetite, 2 percent, as anhedrons. Average composition of feldspar microlites in trachytic groundmass is An_{42}.

4. Andesite of Williwaw Cove formation from coast in Williwaw Cove near "Shack" (pl. 1). Color: medium light gray (*N* 6). Texture: holocrystalline, porphyritic with both feldspar and pyroxene phenocrysts as much as 4 mm long. Plagioclase, 45–60 percent, ranges in composition from An_{45} to An_{60} and averages An_{51}; complex oscillatory zoning and graphic fritting common within individual plagioclase grains. Subhedral clinopyroxene, 10 percent; euhedral orthopyroxene, 10 percent; and anhedral olivine, 1 percent, characterized by brown stains on some fractures. Anhedral magnetite, 5 percent, particularly abundant. Groundmass consists of mesh of feldspar and pyroxene microlites and magnetite dust. Groundmass plagioclase averages An_{43}.

5. Oxidized low-silica dacite of Little Sitkin dacite from thin boudinaged seam at contact of the rhyodacite in the Pratt Point member on coast half a mile north of Pratt Point. (Chemical data given in column 5, table 2.) Color: pale red (5*R* 5/2). Texture: porphyritic with plagioclase phenocrysts as much as 4 mm long. Plagioclase, 25–30 percent, ranges in separate and individually zoned crystals from $An_{29(?)}$ to An_{58} with an average composition of about An_{50}; many of the larger feldspars form a graphic "intergrowth" with dusty glass; some have a rim of clear feldspar in optical continuity with the fritted cores; two-fluid inclusions and small needles (0.002 mm by 0.04 mm) of apatite(?) or pyroxene(?) occur in feldspar. Orthopyroxene, 6 percent, occasionally cores clinopyroxene, 9 percent, crystals. Accessory minerals: magnetite, 3 percent, and tridymite, 1 percent. Fluidal groundmass highly charged with hematite dust.

6. Low-silica dacite of Little Sitkin dacite from interfingered contact zone on north side of rhyodacite of Pratt Point member about 0.9 mile south of East Point. (Chemical data given in column 6, table 2.) Color: medium gray

(*N* 5). Texture: hypocrystalline, massive. Plagioclase, 20 to 25 percent, ranges in composition from An_{55} to An_{72}; a few have fritted centers. Orthopyroxene, 2–3 percent, and clinopyroxene, 2–3 percent, both distinctly pleochroic in light pink and light green; a few orthopyroxene and clinopyroxene centers in differently oriented clinopyroxene crystals. One relict olivine grain, with a thick reaction rim of pyroxene and magnetite. No oxyhornblende xenocrysts although this mineral is plentiful in nearby thin laminae of rhyodacite. Groundmass brownish glass filled with magnetite dust and crystallites.

7. Low-silica dacite of Little Sitkin dacite from coast half a mile north of Pratt Point. (Chemical data given in column 7, table 2.) Specimen taken from within 6 inches of contact with rhyodacite of Pratt Point member. Color: grayish black (*N* 2). Texture: hypocrystalline, porphyritic with plagioclase as much as 5 mm in length. Most plagioclase megaphenocryst and microphenocrysts, 25–30 percent, group around An_{56} but range from An_{28} to An_{78}; complex oscillatory zoning common; many feldspars contain vermicular areas of dusty brown glass. Orthopyroxene, 8–10 percent, occurs as individual euhedrons and as cores in many clinopyroxene, 6 percent, crystals. Accessory minerals: magnetite, 2 percent, and oxyhornblende, 1 percent (xenocrysts?) Fluidal glassy groundmass contains angular crystal fragments, 3 percent, and euhedral rods of pyroxene(?).

8. Low-silica dacite of Little Sitkin dacite from crater flow of West Cove member 1 mile south of crater lake. Color: dark gray (*N* 3). Texture: hypocrystalline, porphyritic with prominent feldspar phenocrysts as much as 6 mm long. Plagioclase, 20–25 percent, ranges from An_{56} to An_{65} in individual zoned phenocrysts and between different crystals; average composition is about An_{50}; graphic fritting texture and two-fluid inclusions present in centers or selected zones of some feldspar crystals. Clinopyroxene, 6 percent, appears as reaction rims on some orthopyroxene, 5 percent, and olivine, 1 percent. Accessory: magnetite, 1–2 percent. Groundmass is clear brown glass choked with plagioclase (average composition, An_{45}) and acicular orthopyroxene(?) microlites. Index of refraction of an artificial glass of the powdered rock is greater than 1.540.

9. Low-silica dacite of the Patterson Point formation from stream cut 0.9 mile north of the summit of the 1,980-foot mountain. (Chemical data given in column 9, table 2.) Color: light brownish gray (5 *YR* 6/1). Texture: hypocrystalline, vesicular with "hairy" pumice developed locally, porphyritic with pyroxene and feldspar phenocrysts as much as 3 mm long. Plagioclase, 25–30 percent, varies from An_{44} to An_{70} and has an average composition of An_{51}; subgraphic areas of brownish glass and two-fluid negative crystals are included within the plagioclase. Clinopyroxene, 5 percent, and orthopyroxene, 4 percent, in part form agglomerations with magnetite-ilmenite, 1 percent. Groundmass consists of clear pink to brown glass (N=1.506) containing many small gas bubbles.

10. High-silica dacite of Double Point dacite from same locality as analysis 2. This rock is groundmass of plate 25. (Chemical data given in column 10, table 2.) Color: medium dark gray (*N* 4). Texture: hypocrystalline, porphyritic with blocky feldspar phenocrysts with maximum diameter of 5 mm. Eleven sections of the plagioclase, 25–30 percent, perpendicular to both albite twinning and basal cleavage give anorthite contents that appear to be distributed evenly from An_{23} to An_{58}; complex zones and intergrowths common; groundmass microlites may group around An_{17} but cannot be determined accurately; two-fluid inclusions from 0.004–0.02 mm in diameter occupy negative crystals in certain zones of the feldspar. Stubby euhedral hypersthene, 5–10 percent, is

pleochroic in light pink and light green. Accessories are clinopyroxene, 1 percent; magnetite, 2 percent; oxyhornblende, 1 percent; and tridymite, 1 percent. Fluidal groundmass glass has N=1.504(?).

11. High-silica dacite of the Double Point dacite located half a mile northeast of the summit of Little Sitkin volcano. (Chemical data given in column 11, table 2.) Color: brownish gray (5 *YR* 5/1). Texture: hypocrystalline, porphyritic with feldspar phenocrysts as much as 3 mm long. Zoned and twinned plagioclase, 25–30 percent, varies in composition from An[illegible] to An[illegible] and averages An[illegible]. Accessory minerals are euhedral orthopyroxene, 2 percent; subhedral clinopyroxene, 2 percent; magnetite, 1 percent; and tridymite, 1 percent. The fluidal glassy to cryptocrystalline groundmass carries pyroxene, magnetite and plagioclase microlites. The plagioclase microlites have an average composition of An[illegible].

12. Rhyodacite of Pratt Point member of Little Sitkin dacite from central part of mapped area (pl. 23) about 0.9 mile south of East Point. (Chemical data given in column 12, table 2.) Color: yellowish gray (5 *Y* 7/1) to medium light gray (*N* 6). Texture: hypocrystalline, vesicular with "hairy" pumice developed locally, porphyritic with hornblende phenocrysts as much as 7 mm long and feldspar phenocrysts as much as 4 mm long. Plagioclase, 15–20 percent, ranges in composition from An$_{37}$ to An[illegible] and averages An[illegible]; sometimes poikilitic with inclusions of hornblende. Accessory minerals: oxyhornblende, 3–4 percent; hypersthene, 2–3 percent; quartz, 2–3 percent; magnetite, 1 percent. The quartz is characterized by conchoidal fractures and is very susceptible to plucking during grinding. The groundmass is about half small bubbles and half clear pinkish glass (N=1.490). The few plagioclase microlites average An[illegible](?).

13. Rhyodacite lava from Pratt Point member of Little Sitkin dacite. Collected from within 6 inches of contact with rock represented by analysis 7. (Chemical data given in column 13, table 2.) Color: yellowish gray (5 *Y* 7/1). Texture: hypocrystalline, vesicular, porphyritic with plagioclase phenocrysts as much as 5 mm and hornblende phenocrysts as much as 3 mm long. Plagioclase megaphenocrysts, 15–20 percent, are complexly zoned from cores of An$_{55-60}$ to rims of An$_{35-45}$; several feldspars poikilitic with small hornblende inclusions, 0.09 by 0.2 mm; minute clinopyroxene rods, 0.01 by 0.05 mm; and two-fluid inclusions in cavities with a maximum diameter of 0.04 mm. Hornblende, 3–5 percent, is pleochroic in shades of olive green, reddish brown, and black; several crystals have deeper pleochroism at borders than at center. Hypersthene, 1–2 percent, is the only pyroxene megaphenocryst; two crystals have a core of oxyhornblende. Quartz, 1 percent, occurs in large phenocrysts with resorbed outlines and conchoidal fractures, which tend to aid plucking of this mineral during grinding of the thin section. Anhedral magnetite forms 1 percent of the rock. The groundmass consists of clear pinkish glass (N=1.491) containing numerous small vesicles.

GEOCHEMISTRY

Thirteen chemical analyses of representative rocks from Little Sitkin Island are presented in table 2 together with their CIPW norms and Rittmann values. Five spectrographic analyses of minor constituents of rocks representative of the chemical spread of the suite are also presented. The province is a silicic one; all rocks have normative quartz. Modal quartz is found only in the rhyodacite (tridymite

TABLE 2.—*Chemical composition, normative values, and Rittmann nomenclature for volcanic rocks on Little Sitkin Island*

	1[1]	2[1]	3[1]	4[1]	5[2]	6[2]	7[1]	8[3]	9[2]	10[1]	11[2]	12[2]	13[1]
Chemical analyses for major constituents													
Name used in this report	Basalt	Andesite	Andesite	Andesite	Low-silica dacite	Low-silica dacite	Low-silica dacite	Low-silica dacite	Low-silica dacite	High-silica dacite	High-silica dacite	Rhyodacite	Rhyodacite
SiO_2	52.74	55.02	55.35	55.37	58.47	58.63	59.21	59.94	60.38	64.74	65.04	68.79	69.43
Al_2O_3	11.99	17.91	17.72	18.02	16.91	17.04	16.85	16.79	16.93	16.25	18.47	15.00	15.17
Fe_2O_3	1.90	4.45	3.04	2.91	5.71	2.80	2.98	2.26	2.53	1.72	2.38	1.52	1.34
FeO	6.72	4.23	5.45	5.53	1.89	4.50	4.09	4.77	3.42	3.17	2.39	2.27	1.99
MgO	11.02	3.92	4.03	4.24	3.37	3.19	3.26	3.07	2.70	1.97	2.06	1.15	.94
CaO	12.49	8.58	8.77	8.70	7.32	7.15	7.26	6.89	6.08	5.07	5.13	3.44	3.41
Na_2O	1.78	3.11	3.28	3.03	3.40	3.37	3.49	3.49	3.72	4.13	4.06	4.30	4.48
K_2O	.64	1.09	1.00	.91	1.28	1.33	1.31	1.46	1.42	1.71	1.68	2.06	2.00
H_2O-	.01	.05	.07	.08	.17	.23	.05	.05	.17	.08	.05	.08	.00
H_2O+	.09	.41	.15	.06	.87	.71	.48	.17	1.39	.31	.08	.64	.52
TiO_2	.57	.85	.89	.87	.77	.75	.72	.77	.72	.53	.52	.38	.33
CO_2	.00	.00	.00	.01	.01	.01	.01	.00	.01	.00	.00	.01	.00
P_2O_5	.11	.15	.17	.16	.19	.15	.16	.16	.16	.15	.13	.11	.13
MnO	.17	.16	.17	.16	.15	.15	.15	.15	.13	.13	.12	.12	.11
Total	100.23	99.92	100.09	100.02	99.96	99.81	99.94	99.95	99.74	99.91	100.10	99.86	99.68
Spectrochemical analyses[1] for minor constituents [A. A. Chodos, analyst]													
Ni	0.02	----	0.001	0.0008	----	----	0.0008	----	----	----	----	----	----
Co	.005	----	.008	.003	----	----	.002	----	----	----	----	----	0.0004
Cr	.07	----	.002	.002	----	----	.002	----	----	----	----	----	.0001
Cu	.02	----	.006	.008	----	----	.008	----	----	----	----	----	.001
V	.03	----	.03	.02	----	----	.02	----	----	----	----	----	.005
Ga	.0008	----	.001	.001	----	----	.001	----	----	----	----	----	.001
Sc	.006	----	.002	.002	----	----	.002	----	----	----	----	----	.0002
Ba	.03	----	.03	.02	----	----	.05	----	----	----	----	----	.05
Sr	.1	----	.07	.06	----	----	.08	----	----	----	----	----	.04
Mo	----	----	.0002	----	----	----	.0002	----	----	----	----	----	.0003
Y	.003	----	.002	.002	----	----	.002	----	----	----	----	----	.001
Yb	.0008	----	.0002	.0003	----	----	.0003	----	----	----	----	----	.0002
Zr	.008	----	.008	.007	----	----	.008	----	----	----	----	----	.008
B	.001	----	.001	.001	----	----	.002	----	----	----	----	----	.002

Norms

Q	0.84	9.66	7.62	8.64	15.48	13.66	13.92	13.98	16.02	19.80	20.94	26.28	26.84
or	8.34	6.67	6.12	5.56	7.23	7.78	7.78	8.90	8.34	10.01	10.01	12.23	11.68
ab	15.20	26.20	27.77	25.68	28.82	28.30	29.34	29.34	31.44	35.11	34.58	36.15	37.73
an	23.07	31.41	30.58	32.53	27.24	27.52	26.69	25.85	25.30	20.85	21.68	15.57	15.57
wo	15.89	4.41	4.99	4.06	3.36	3.02	3.60	3.13	1.74	1.39	1.28	.35	.23
en	10.70	3.10	2.90	3.40	2.90	1.70	2.20	1.70	1.10	.80	.90	.20	.10
fs	3.96	0.92	1.85	1.45	----------	1.19	1.19	1.32	.63	.53	.28	.13	.13
en	16.90	6.70	7.20	8.20	5.50	6.30	5.90	6.00	5.70	4.10	4.20	2.70	2.30
fs	6.07	1.98	4.49	5.15	----------	3.96	2.90	4.49	2.64	3.17	1.45	2.38	2.11
mt	2.78	6.50	4.41	4.18	4.18	3.71	4.41	3.25	3.71	2.55	3.48	2.09	1.86
il	1.06	1.67	1.67	1.87	1.52	1.52	1.37	1.52	1.87	1.06	.91	.76	.61
ap	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34	.34
H_2O+	.09	.41	.15	.05	.37	.71	.43	.17	1.39	.31	.08	.64	.52
Total	100.24	99.97	100.09	99.91	[4] 99.82	99.61	100.07	99.99	99.62	100.02	100.11	99.82	99.82
Symbol [5]	III".5.4.4.	II.4(5).(3)4.4".	II.(4)5.(3)4.4".	II.(4)5."4.4".	II.4.3".4.	II.4".3".4.	II.4".3".4.	II.4".3".4.	"II.4.3.4.	(I)II.4.3.4.	(I)II.4.3.4.	I".4."3.4.	I'.4.(2)3.4.
Name [5]	Auvergnose	Bandose	Hessose	Hessose	Tonalose	Tonalose	Tonalose	Tonalose	Tonalose	Tonalose	Tonalose	Yellowstonose	Yellowstonose

Rittmann nomenclature

SiO_2	52.74	55.02	55.35	55.37	58.47	58.63	59.21	59.94	60.36	64.74	65.04	68.79	69.43
Al	10.79	16.12	15.95	16.22	15.22	15.34	15.16	15.11	15.24	14.62	14.82	13.50	13.65
Alk	3.31	5.76	5.92	5.46	6.23	6.39	6.55	6.70	7.00	7.91	7.77	8.50	8.69
CaO	12.49	8.58	8.77	8.70	7.32	7.15	7.25	6.89	6.08	5.07	5.13	3.44	3.41
FM	31.52	13.19	17.28	17.65	14.69	14.10	14.14	13.80	11.84	9.29	9.24	6.45	5.63
k	.19	.19	.17	.17	.19	.21	.20	.22	.20	.22	.22	.24	.23
an	.53	.47	.46	.50	.41	.41	.40	.39	.37	.30	.31	.23	.22
ca"	8.00	2.36	2.75	2.24	1.99	1.78	2.08	1.84	1.14	1.04	.90	.44	.43
Rittmann [6] name.	Basalt	Labradorite andesite or labradorite dacite (bandaite)	Pigeonite andesite or pigeonite labradorite andesite	Labradorite dacite (bandaite) or pigeonite labradorite andesite	Dacite	Dacite	Dacite	Dacite	Dacite	Dacite	Dacite	Rhyodacite	Rhyodacite
Occurs in:	Williwaw Cove formation	Double point dacite (inclusion)	Little Sitkin dacite	Williwaw Cove formation	Little Sitkin dacite	Little Sitkin dacite	Little Sitkin dacite	West Cove member	Patterson point formation	Double Point dacite	Double Point dacite	Pratt Point member	Pratt Point member

[1] Edythe E. Engleman, analyst.
[2] Harry M. Hyman, analyst.
[3] Looked for but not found: Pb, Be, Ag, Au, Pt, W, Ge, Sn, As, Sb, Bi, Cd, Tl, In, La, Nb, Ta, Th, U.
[4] Includes 2.88 percent hematite.
[5] See Washington, 1917.
[6] See Rittmann, 1952.

in the high-silica dacite). Olivine, which constitutes as much as 5 percent of some of the modes is not represented in the norms.

Because the phenocrysts and groundmass minerals differ chemically, Rittmann names (based on bulk chemical analyses) are used in the discussion that follows. The most basic member is basalt; the most acid one, rhyodacite. Both rocks occur in minor amounts. The great mass of rock material is andesite, bandaite, or dacite. A further subdivision of Rittmann's names seems desirable within the dacite range. One group of rocks, referred to as "low-silica dacite", contains about 60 percent SiO_2; and another, referred to as "high-silica dacite", contains about 65 percent SiO_2. The terms "high-silica" and "low-silica" have no relation to Rittmann's adjectives "light" and "dark", which describe the quantity of iron and magnesium.

The oxide constituents of the chemical analyses are plotted on a standard silica-variation diagram, figure 42, which shows that the suite from Little Sitkin has an alkali-lime index of 63.5—that is, the silica percentage at which the sum of the alkalies equals the lime (Peacock, 1931, p. 54–67). The alkali-lime index is comparable to that of the Katmai province, 63.8 (Peacock, p. 62); to the Adak-Kanaga province, 63.0 (Coats, 1952, p. 493); and to the Buldir province, 64.5, extrapolated (Coats, 1953, p. 18).

Except for specimen 1, the variations shown by the chemical analyses plotted on figure 42 are linear. Rectilinear variation diagrams of this sort have been discussed before (Fenner, 1926, p. 704–772, especially p. 760–771; 1938, p. 1467–1481; Wilcox, 1944, p. 1067–1073; Barth, 1952, p. 167, 168; Reynolds, 1954, p. 582) and they present a petrogenic problem. If all the trends are linear and successively younger rocks become progressively more siliceous, then there must be very stringent requirements for their mode of derivation. If the younger rocks become more siliceous owing to removal of basic minerals from a magma, then the composition of these minerals must have remained constant or changed systematically. These minerals must be removed from beginning to end of the series and no other minerals can be removed at any intermediate point in the series or the trends on the variation diagram would not be linear. Because these linear trends are inconsistent with the Bowen reaction series these rocks probably did not evolve by crystal differentiation.

With this particular series the hypothesis that the more acid members are derived from the more basic members is also refuted by the actual time relationships of the members involved. Although the rocks of Little Sitkin became, on the whole, more siliceous with succeeding eruptions, considerable fluctuations in composition occurred (fig. 43).

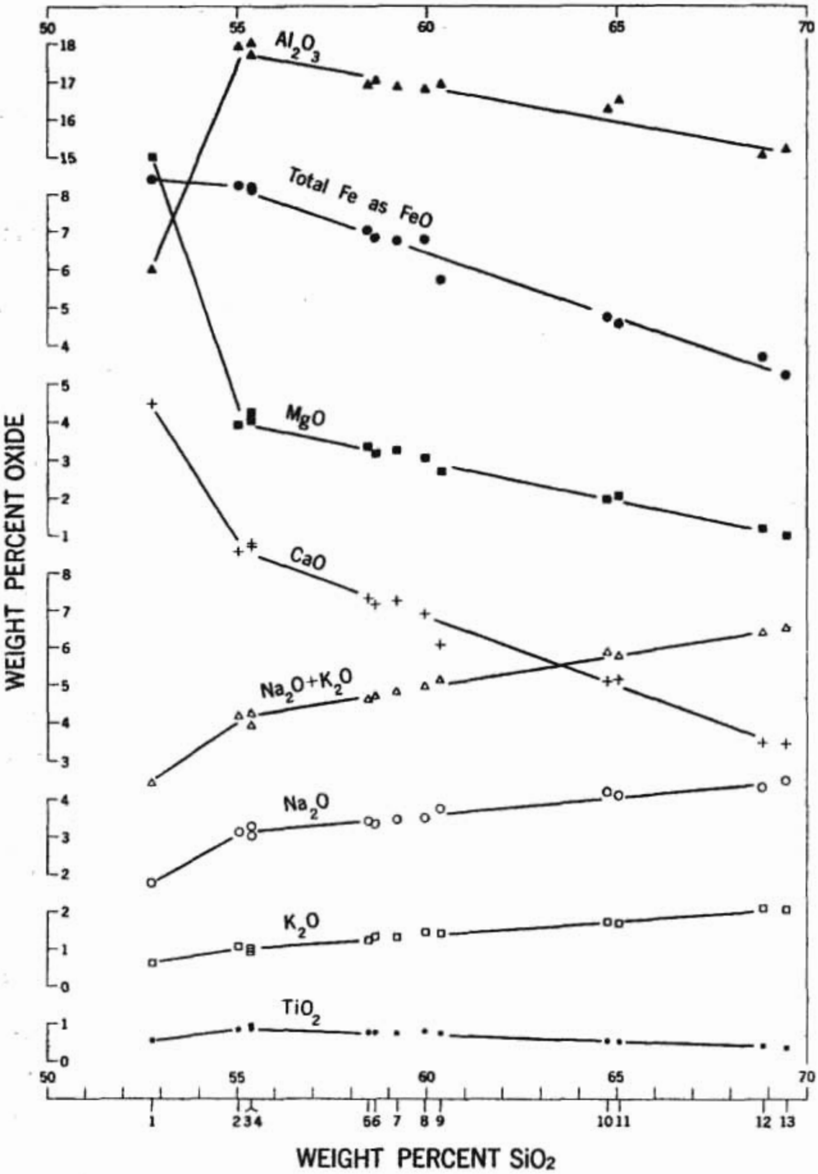


FIGURE 42.—Silica-variation diagram of rocks of Little Sitkin Island. Lines drawn by inspection. Analyses numbers correspond with column numbers in table 2.

Rectilinear variation diagrams can also be explained as the mixing of two end members, namely: the mixing of acid and basic magmas; the incorporation and dissolution of basic inclusions in an acid magma; the incorporation and dissolution of acid inclusions in a basic magma; or the formation of discrete magmatic melts in various parts of a zone where there has previously been mixing of rock by other geologic processes.

An accurate knowledge of the volume and composition of the various rocks on Little Sitkin Island would be helpful in evaluating their mode of origin. Table 3 is an attempt to calculate the volume. Column 1 of table 3 gives the calculated volume of all the mapped formations above sea level at the present time. These figures were determined by the combined use of the topographic and geologic map. The contour lines of a "restored topography" were drawn from the margin of a particular formation beneath it to the corresponding contour line on the opposite margin. Control in the placement of these contour lines was provided by the relict constructional topography of both the younger and older land surfaces; the internal structure, that is, bedding of the formation involved; the external structure, for example, steep caldera faults, which control one or more margins of the formation. It is obvious that such control is best for the youngest formations and progressively less reliable for successively older sequences of rock. After drawing the contours, a 1,000-foot square grid was placed over the map. At each grid intersection the thickess of the formation was noted by obtaining the difference in the elevations shown by the two sets of contours at that point. If each grid square is regarded as the approximation of a prism in three dimensions, then the volume of this prism can be estimated by multiplying the area of the square by the average of the thickness values at each corner. Summing the volumes of the prisms gives the volume of the formation.

Volume calculated by the above method is less than the original volume of the extrusive material for three reasons: since extrusion the rocks have been partially eroded; since extrusion some of the rocks have been downfaulted during episodes of caldera formation, and during extrusion the lavas involved may have flowed into the sea. But losses due to erosion can be minimized by utilizing the relict constructional topography to reconstruct the original constructional topography, the precaldera structure can be reconstructed to compensate for losses due to faulting, and the amount of lava that flowed into the sea may possibly be calculated by a study of the submarine topography (see pl. 22, Snyder, 1957). The volcanic structure of Little Sitkin appears to have been built on a wide flat platform at about 300 feet below sea level, the "Ridge Shelf" of Gates and Gibson, (1956, p. 134). The steepening of slope above this level in some areas, notably off Prokhoda Point, appears to be more or less continuous with the relict constructional slopes of the basement rocks. From this evidence it is postulated that the volcanic rocks of Little Sitkin Island have been deposited above a −300-foot platform. This is used as the base for the estimated original volume which is presented in column 2 of table 3. The volume should be considered only as an estimate, for large errors are possible in some of the figures. Despite this uncertainty the data may be useful, at least in a scrutiny of orders of magnitude. The estimated original volume of the Williwaw Cove formation is the approximate volume of a single volcanic mountain whose outer limits are the present −300-foot contour and whose slopes are comparable to those of the single volcanic mountain of Segula Island.

TABLE 3.—*Volume, weight, and percent weight for volcanic rocks of Little Sitkin Island*

	1	2	3	4	5	6
	Calculated volume above sea level at present time [1] (cu ft×10^9)	Estimated original volume above −300 ft before erosion and caldera faulting [2] (cu ft×10^9)	Average rock specific gravity	Estimated original weight (tons×10^6)	Estimated original weight percent of rocks younger than Williwaw Cove formation (percent)	Estimated original weight percent of all rocks of Little Sitkin Island (percent)
West Cove member	3	3	2.49	234	0.48	0.10
Pratt Point member	.5	.5	2.18	34	.07	.015
Little Sitkin dacite	90	100	2.50	7,800	15.5	3.5
Patterson Point formation	10	12	1.93	717	1.4	.32
Double Point dacite	260	500	2.50	39,000	77.5	17.4
East Point formation	5	10	2.91	905	1.8	.40
Sitkin Point formation	10	20	2.60	1,620	3.2	.72
Williwaw Cove formation	205	2000	2.79	174,000	-------------	77.6

[1] Total calculated present volume of all formations=588.5 by 10^9 cu ft=approximately 4 cu miles.
[2] Total estimated original volume of all formations=2,645.5 by 10^9 cu ft=approximately 18 cu miles.

Specific gravity listed in column 3 of table 3 is determined with a Jolly balance using small hand specimens that included vesicles, miarolitic cavities, and other pore space. Column 4 is computed from the product of columns 2 and 3, multiplied by the weight of a cubic foot of water. Columns 5 and 6 present the relative weight of each formation given as percent of the total weight. From these figures it can be seen that the Little Sitkin dacite, the Double Point dacite and the Williwaw Cove formation include more than 98 percent of the rocks.

Table 4 lists the weighted chemical composition of each of the rock sequences on Little Sitkin Island. These data are used with that in columns 5 and 6, table 3 to calculate the average composition of all rocks younger than the Williwaw Cove formation, and the average composition of all rocks extruded on the present minus 300-foot bench. Composition of the minor amounts of the East Point and Sitkin Point formations, for which chemical analyses are lacking, are assumed from analyses of similar rocks. Plate 26 combines graphically the calculations given in tables 3 and 4 with the relative position of each rock sequence in time.

TABLE 4.—*Weighted chemical compositions for volcanic rocks of Little Sitkin Island*

	West Cove member [1]	Pratt Point member [2]	Little Sitkin dacite [3]	Patterson Point formation [4]	Double Point dacite [5]	East Point formation [6]	Sitkin Point formation [7]	Williwaw Cove formation [8]	Average of volcanic rocks younger than Williwaw Cove formation [9]	Average volcanic rock of Little Sitkin Island [10]
SiO_2	60.00	69.23	58.89	60.63	64.40	54.38	58.89	54.98	63.1	56.8
Al_2O_3	16.81	15.12	17.04	17.00	16.44	15.97	17.04	17.38	16.6	17.2
Fe_2O_3	2.25	1.43	2.66	2.54	2.17	3.09	2.66	3.50	2.3	3.2
FeO	4.77	2.13	4.57	3.44	2.85	5.49	4.57	5.06	3.2	4.7
MgO	3.07	1.05	3.31	2.71	2.11	6.39	3.31	4.77	2.4	4.3
CaO	6.90	3.44	7.33	6.11	5.27	9.92	7.33	9.04	5.8	8.3
Na_2O	3.49	4.39	3.43	3.74	4.05	2.64	3.43	2.94	3.9	3.1
K_2O	1.46	2.03	1.30	1.43	1.67	0.88	1.30	0.96	1.6	1.1
H_2O+	0.17	0.58	0.39	1.40	0.21	0.18	0.39	0.22	0.3	0.2
TiO_2	0.77	0.36	0.76	0.72	0.55	0.76	0.76	0.83	0.6	0.8
P_2O_5	0.15	0.12	0.16	0.16	0.14	0.14	0.16	0.15	0.1	0.2
MnO	0.15	0.12	0.15	0.13	0.13	0.16	0.15	0.16	0.1	0.2
Total	99.99	100.00	99.99	100.01	99.99	100.00	99.99	99.99	100.0	100.1

[1] Analysis 8.
[2] Average of analyses 12 and 13.
[3] Average of analyses 5 (except on Fe_2O_3 and FeO), 6, 7, and 8, recomputed to contain 10 percent of analysis 3.
[4] Analysis 9.
[5] Average of analyses 10 and 11, recomputed to contain 5 percent of analysis 2.
[6] Average of analyses 1, 2 and 4.
[7] Average of analyses 5 (except on Fe_2O_3 and FeO), 6, 7 and 8, recomputed to contain 10 percent of analysis 3.
[8] Average of analyses 2 and 4, recomputed to contain 10 percent of analysis 1.
[9] Computed from data in this table and in column 5, table 3.
[10] Computed from data in this table and in column 6, table 3.

Can information of the sort presented in plate 26 be used to decide the relative importance of the various end-member-mixing hypotheses which were formulated to explain the rectilinearity of the variation diagram? I think so. Mixing of acid and basic magmas can be ruled out because the quantity of rhyodacite or more acid material necessary to form the abundant dacite by admixture with the andesite is insufficient. For example, to form a magma of the composition of the Double Point dacite by admixture of magmas of the composition of the Williwaw Cove formation and the Pratt Point member would require over 750 times more rhyodacite than is known to exist. Incorporation and dissolution of basic inclusions in an acid magma can be excluded for the province as a whole for the same reason, but may have caused internal variations in a formation. For example some low-silica dacite in the Little Sitkin dacite may have been derived by mobilization of basic inclusions in high-silica dacite magma of the composition of the Double Point dacite. To form all the rocks of the Little Sitkin dacite in this way would require an inclusion-magma ratio of 3:2; the observed ratio in the Double Point dacite is only 1:20, which suggests that only one-thirtieth of the low-silica dacite could have formed by dissolving inclusions. The third mechanism, incorporation and dissolution of acid inclusions in a basic magma, is not supported by field evidence. No acid inclusions have been found in the rocks of Little Sitkin Island. The fourth mechanism, magmatic melting in a zone where the rocks are mixed, for example, by tectonic processes, is permissible on the basis of known evidence. Such a mechanism reconciles the chemical linearity with the volumetric relationships and is supported by the small scale inhomogenieties observed in the field (layered bombs, composite flow).

This belief in local crustal melting is supported by the current work of Powers (1955, p. 77–107) who has recently made an exhaustive survey of the chemistry of Hawaiian rock, in which he concludes that locally derived magmas are responsible for building up the primitive volcanic shields of the islands. The source of energy for the melting process, according to Powers, is friction produced by a cyclic kneading of the equatorial bulge of the earth's crust. This would only be applicable for regions within the earth's equatorial bulge but, for the Little Sitkin area, a tectonic kneading (not necessarily cyclic) along the Aleutian welt might be an even more efficient source of energy. Powers' remarks (1955 p. 101) in this connection are pertinent:

> The proposed process of volcanism, if valid, should be applicable in part only to volcanoes situated along the equatorial bulge. However, its operation probably would be completely obscured by the processes of volcanism associated with great structural deformation in regions where the equatorial bulge is coincident with zones of Cenozoic mountain-building. Also different lava types would be expected where the bulge crosses the great blocks of sial. . . .

Other authors are concerned with magma mixing or sialic contamination in the origin of the intermediate lavas in orogenic areas. Because of their simultaneous extrusion with floods of uniform basalt on either side, Waters (1955, p. 712, 713) theorizes that andesites from the Cascade Range of Oregon and Washington have been formed by the mixing of geosynclinal sediments with tholeiitic magma in tectogene roots. From an extensive study of numerous xenocrysts and from the close field association of many lava types Larsen and others (Larsen, Irving, Gonyer, and Larsen, 1938, p. 429) have concluded that the lavas of the San Juan volcanic field have been derived from intimately mixed magmas of diverse original composition.

Tilley (1950, p. 37, 58, 59) has tentatively concluded from a review of the world literature that andesitic rocks of the orogenic zones evolve from basaltic magma modified by sialic contamination.

In this report the author accepts the hypothesis that tectonic kneading may have been the cause of local crustal melting. Possibly this same tectonic kneading may have been the cause of the mixing of a crustal sialic component and an oceanic, or subcrustal, periodotic component which, when melted in magmas, could give rise to lava compositions that would produce rectilinear variation diagrams. Incomplete local tectonic mixing and the random migration of the loci of magma formation would explain both the random variation of the composition of rock formations through time and the second and third order inhomogeneities. All this would be dependent upon the constant composition of the contributed sialic and oceanic material, a condition that might be met only rarely. This would be consistent with the rarity of rectilinear variation diagrams.

GEOLOGIC HISTORY

The geologic history of Little Sitkin Island begins with probable middle Tertiary uplift of the Aleutian Islands arc (Gates, Fraser and Snyder, 1954; Gates and Gibson, 1956, p. 130) when Amchitka, Rat, and Kiska Islands were uplifted, and the general shape of the crest of the Aleutian Ridge and Bowers Bank were determined. Possibly the platform beneath Segula and Little Sitkin Islands was also formed. By this time also the great fissures that later became magma channels for the eruptions that produced Little Sitkin Island had been formed. At a depth of several miles in the earth andesitic magma began to flux, stope, or force its way to the surface during latest Tertiary or earliest Quaternary time. This magma, like the others to follow, was quite inhomogeneous. Parts of it were as basic as augite basalt; parts were as acid as dacite; most of it was close to the border between andesite and bandaite. With the first outpourings of this magma on the Segula-Sitkin platform the record decipherable from the rocks begins. Figure 43 gives a diagrammatic account of the geologic history.

The magma that formed rocks of the Williwaw Cove formation must have been rich in volatile material. Explosive eruptions were common and much ash and pyroclastic debris were buried with the massive flows. Although some fissures fed flows on the flanks of the growing composite cone, most of the eruptive products were distributed from a central vent. A volcano, perhaps 7,000 or 8,000 feet high, was built. A long period of erosion followed this eruptive activity. Probably mid-Pleistocene glaciers blanketed the slopes and

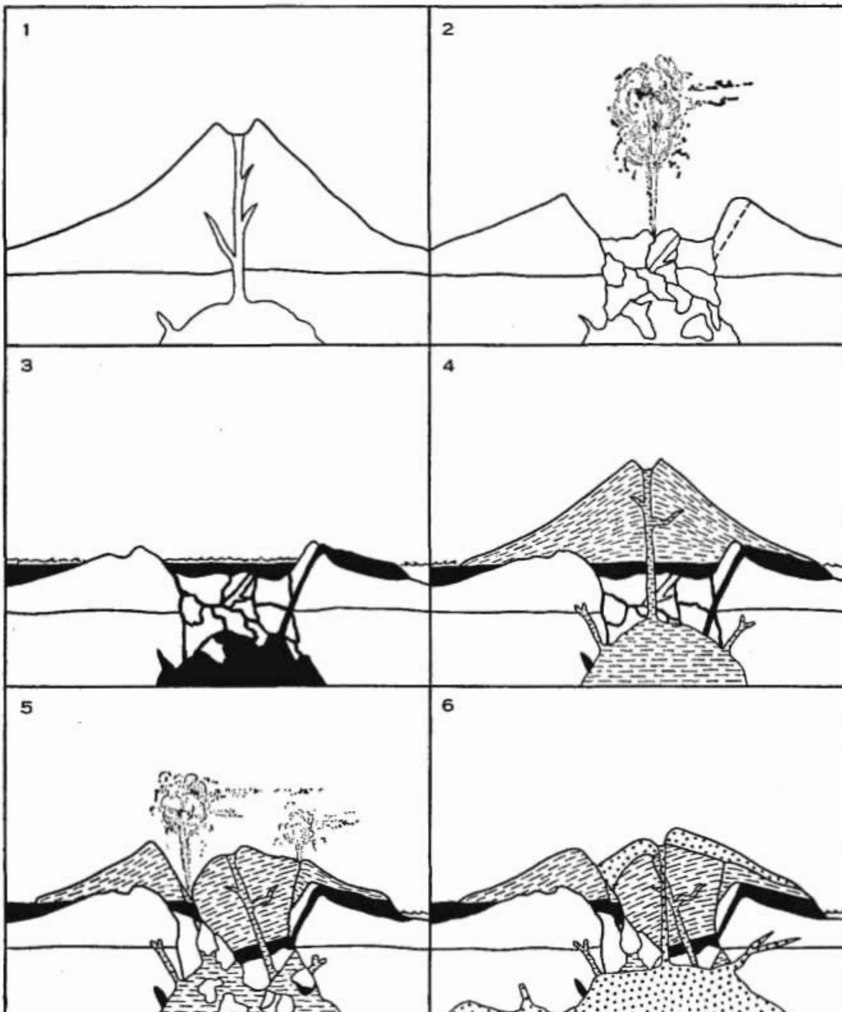


FIGURE 43.—Diagrammatic review of geologic history of Little Sitkin Island. (1) Erection of andesitic composite cone on platform 300 feet below sea level in late Tertiary or early Quaternary time. (2) Formation of Caldera One after long period of erosion. (3) Deposition of Sitkin Point formation in offshore basin and in caldera lake and extrusion of flow sequence of East Point formation. These flows probably represent the last extrusion of the andesitic magma. (4) Erection of high-silica dacite lava-flow cone of Double Point dacite in late Pleistocene or early Recent time. All lava of this magma contains inclusions of solidified andesitic conduit rock. (5) Formation of Caldera Two with attendant nuée ardente eruptions. A large block of the Double Point dacite (size exaggerated) has dropped only a small amount into the caldera. (6) Extrusion of low-silica dacite lava continuing to the present. The Little Sitkin dacite here represented contains a composite dacite-rhyodacite flow.

accelerated the disintegration of the land, although most if not all of the deposits of this ice are now beyond the island margins. While the land was being denuded pressures were gradually building up inside the volcano. Finally a gigantic eruption occurred and a large part of the mountain collapsed. Possibly Prokhoda Scarp, between Little Sitkin Island and Semisopochnoi Island, was formed at this time. The remaining mountain was lowered relative to sea level; a caldera lake was formed; and the margins of the mountain were inundated. Explosive eruptions continued for some time and tuffs and breccias, partly andesitic and partly dacitic, were deposited in offshore basins and in the caldera lake.

After the deposition of these tuffs and breccias (the Sitkin Point formation), the island was uplifted relative to sea level and the tuffaceous graywacke and tuff-breccia deposits were subjected to subaerial erosion. At about the same time a new vent was formed on the northeast side of the island and a thick series of fluid basalt and andesite (the East Point formation) was extruded. The volume of these post caldera pyroclastic deposits and flows was small compared to the huge mass of rock in the original mountain. Probably these deposits represent the last extrusion of the andesite magma.

Probably in latest Pleistocene or earliest Recent time, immediately following extrusion of the East Point formation, a new magma was formed. This magma, the source of the Double Point dacite, was more silicic than the previous magma and formed high-silica dacite with minor amounts of more basic and more acidic material. One distinctive characteristic of the magma was the presence of unique andesitic inclusions. Texturally these inclusions resemble none of the earlier rocks, but they are chemically similar to the original magma of the present Williwaw Cove formation and were probably torn from the conduit walls at shallow depth by the silicic magma. The magma of the present Double Point dacite was relatively poor in volatile materials compared to the previous magma. Pyroclastic materials were subordinate and most eruptions were thick massive flows. A large central cone was constructed from these flows within the remaining shell of Caldera One. The lavas from this cone reached the sea on the southwest and northeast coasts of the island.

The volcanic cone that formed in Double Point time was then somewhat eroded. During the erosion period gas pressure was again building up and a new magma was forming, possibly partly by mixture with the inclusion-containing magma of the Double Point dacite. Movements on the Prokhoda Scarp fault zone may have triggered a cataclysmic eruption that resulted in the formation of another caldera. The part of the volcano formed during Double Point time that was nearest the extension of the Prokhoda Scarp fault was shattered and sank in the abyss of Caldera Two. The northern third of the volcano, however, was only tilted slightly south into the caldera. Meanwhile voluminous nuée ardente eruptions from the new magma blanketed the island with low-silica dacite ash, and a thick deposit of welded ash accumulated on the northwest side of the island. Minor inhomogeneities in the magma formed "marble cake" bombs that were incorporated in the welded deposit. The initial nuée ardente phase was soon succeeded by a vulcanian phase in which relatively cold ash and a minor amount of angular lithic debris was erupted. Some lava flows, the lower part of the Little Sitkin dacite were possibly extruded at this time.

After the Caldera Two eruption, the magma that formed the Little Sitkin dacite approached closely to the surface in a number of places along a zone trending N. 67° W. across the island. Rocks in this zone were altered by fumarolic activity. Lava eruptions occurred slightly east of the center of the island on the south flank of the remainder of the cone that formed in Double Point time. Volatile content in the magma was low so that only lava flows were extruded. These lavas were predominantly low-silica dacite but several andesitic flows were extruded and, in the Pratt Point member, a considerable quantity of mixed low-silica dacite and rhyodacite were extruded from the same vent. About a half centry ago, two aa flows were extruded, one from the breached central crater and one from a fissure of Caldera One in the west central part of the island. Some faulting was probably associated with the eruptions. Both flows have been completely altered to clay in areas where they have crossed active fumarolic centers. A small amount of native sulfur was deposited in the fumarolically altered area of the crater flow. Two small avalanche deposits on the north coast may have been instigated by earthquakes associated with this last eruption of Little Sitkin volcano.

ECONOMIC GEOLOGY

Sulfur is the only economic mineral available in potentially commercial quantities on Little Sitkin Island. A large deposit of sulfur riddled with active fumaroles occupies an area of about 10 acres on the south side of the present breached crater where it replaces low-silica dacite of the crater flow. Traces of native sulfur have been observed around the fumarolic area south of the 1,303-foot mountain. In the crater area all rocks are bleached and altered to white kaolinitic(?) clay. The sulfur occurs as veins and vug linings in this clay. Usually the entire surface deposit is composed of massive, mammillary aggregates of sulfur crystals without much rock clay.

Sulfur replacement presumably decreases markedly with depth. Small amounts of H_2S gas are always present in the abundant quantities of water vapor being emitted. Sulfur is probably being deposited primarily as the result of near-surface partial oxidation of this gas and secondarily as a sublimate.

A sample collected in the central part of the deposit contained 95.8 percent sulfur by weight. Assuming that the deposit averages this grade throughout a surface zone 10 feet thick, 200,000 tons of sulfur is present. Probably this estimate is too large. Estimates of the amount of sulfur in the fumarolic deposit atop Makushin Volcano on Unalaska Island (roughly the same size or slightly smaller than the deposits on Little Sitkin Island) range from 33,500 to more than 77,000 tons of recoverable sulfur (Maddren, 1919, p. 291, 292; Sweeny and Myers [1]).

Recovery of the sulfur on Little Sitkin Island is favored by a source of heat and energy at the fumarole, and by a source of pure snow water at the crater lake. Other factors hinder recovery: great shipping distance from the world market, absence of a suitable harbor for ships, rugged terrain between coast and crater deposit, generally inclement weather. In the face of these difficulties it does not seem probable that the sulfur deposit on Little Sitkin Island will be exploited in the near future. In the Andes, however, similar volcanic deposits subject to rigorous climate and altitude conditions are being commercially utilized at the present time (Cooke, 1954, p. 44–48, 71).

REFERENCES CITED

Arctic Weather Central, 11th Weather Squadron, 1950, Climate, weather and flying conditions of Alaska and eastern Siberia: Elmendorf Air Force Base, Alaska, p. 1–52.

Barth, T. F. W., 1952, Theoretical petrology: New York, John Wiley & Sons, Inc., 387 p.

Coats, R. R., 1950, Volcanic activity in the Aleutian Arc: U. S. Geol. Survey Bull. 974–B, p. 35–49.

———1952, Magmatic differentiation in Tertiary and Quaternary volcanic rocks from Adak and Kanaga Islands, Aleutian Islands, Alaska: Geol. Soc. America Bull., v. 63, no. 5, p. 485–514.

———1953, Geology of Buldir Island, Aleutian Islands, Alaska: U. S. Geol. Survey Bull. 989–A, p. 1–26.

———1956, Geology of northern Kanaga Island, Alaska: U. S. Geol. Survey Bull. 1028–D, p. 69–81.

Collins, H. B., Jr., Clark, A. H., and Walker, E. H., 1945, The Aleutian Islands: Their people and natural history: Smithsonian Inst., Washington, War Background Studies, no. 21, p. 1–131.

Cooke, H. R., Jr., 1954, How high can mining go?: World Mining, v. 7, no. 9, p. 44–48, 71.

[1] Sweeny, H. P., and Myers, D. B., 1908, The sulfur deposit of Mount Makushin, Unalaska: unpublished undergraduate thesis, Massachusetts Inst. Technology, p. 14–17.

Fenner, C. N., 1926, The Katmai magmatic province: Jour. Geology, v. 35, no. 7, pt. 2, p. 673–772.

———1938, Contact relations between rhyolite and basalt on Gardiner River, Yellowstone Park: Geol. Soc. America Bull., v. 49, p. 1441–1483.

Gates, Olcott, Fraser, G. D., and Snyder, G. L., 1954, Preliminary report on the geology of the Aleutian Islands: Science, v. 119, no. 3092, p. 446–447.

Gates, Olcott and Gibson, W. M., 1956, Interpretation of the configuration of the Aleutian Ridge: Geol. Soc. America Bull., v. 67, no. 2, p. 127–146.

Gibson, W. M., and Nichols, Haven, 1953, Configuration of the Aleution Ridge, Rat Islands—Semisopochnoi I. to west of Buldir I.: Geol. Soc. America Bull., v. 64, no. 10, p. 1173–1187.

Larsen, E. S., Irving, John, Gonyer, F. A., and Larsen, E. S. 3d, 1938, Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colorado: Am. Mineralogist, v. 23, no. 7, p. 417–429.

MacGregor, A. G., 1952, Eruptive mechanisms—Mt. Pélee, the Soufrière of St. Vincent [West Indies] and the Valley of Ten Thousand Smokes [Alaska]: Bull. Volcanologique, ser. 2, v. 12, p. 49–74.

Maddren, A. G., 1919, Sulphur on Unalaska and Akun Islands and near Stepovak Bay, Alaska: U. S. Geol. Survey Bull., 692–E, p. 283–298.

Peacock, M. A., 1931, Classification of igneous rock series: Jour. Geology, v. 39, no. 1, p. 54–67.

Powers, H. A., 1955, Composition and origin of basaltic magma at Hawaii: Geochimica et Cosmochimica Acta, v. 7, p. 77–107.

Reynolds, D. L., 1954, Fluidization as a geological process, and its bearing on the problem of intrusive granites: Am. Jour. Sci., v. 252, no. 10, p. 577–613.

Rittmann, A., 1952, Nomenclature of volcanic rocks: Bull. Volcanologique, ser. 2, v. 12, p. 75–102.

Snyder, G. L., 1957, Ocean floor structures, northeastern Rat Islands, Alaska: U. S. Geol. Survey Bull. 1028–G, p. 161–167.

Tilley, C. E., 1950, Some aspects of magmatic evolution: Quart. Jour. Geol. Soc. of London, v. 56, part 1, p. 37–61.

Tröger, W. E., 1952, Tabellen zur optischen Bestimmung der gesteinsbildenden Minerale: 147 p., Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung (Erwin Nägele) p. 113.

U. S. Coast and Geodetic Survey, 1947, United States coast pilot, serial no. 680, Alaska, Pt. 2, Yakutat Bay to Arctic Ocean, p. 1–659; or serial no. 659, Alaska, Aleutian Islands, p. 1–147.

Waters, A. C., 1955, Volcanic rocks and the tectonic cycle: Geol. Soc. America Special Paper 62, p. 703–722.

Washington, H. S., 1917, Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99.

Weather Central, Alaska, 11th weather region, A. A. F., 1945, The climate, weather behavior, and topography of selected Alaskan and Aleutian stations: p. 1–59.

Wentworth, C. K., and Macdonald, G. A., 1953, Structures and forms of basaltic rocks in Hawaii: U. S. Geol. Survey Bull. 994, 98 p.

Wilcox, R. E., 1944, Rhyolite-basalt complex on Gardiner River, Yellowstone Park, Wyo.: Geol. Soc. America Bull., v. 55, no. 9, p. 1047–1079.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—an introduction to the study of rocks in thin sections: San Francisco, W. H. Freeman and Co., 406 p.

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