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THE TABLE, A FLAT-TOPPED VOLCANO IN SOUTHERN BRITISH COLUMBIA

W. H. MATHEWS

ABSTRACT. The Table, a steep-walled mass of lava, is made up of a core of thick, flat-lying layers partly surrounded by thin, nearly vertical sheets adhering to the core like icing on the sides of a layer cake. Field evidence suggests that eruptions took place while land in the vicinity of the vent was covered by Pleistocene ice. An intraglacial origin for the volcano is assumed, as follows: (1) volcanic heat led to the thawing above the vent of a vertical pipe in the ice sheet; (2) lava repeatedly flooded the floor of the pipe, spread laterally until it reached the ice walls, chilled first along the contact to form a solid ring, then the still-molten material, ponded within the ring, acquired a tabular form and a level upper surface; and (3) molten lava locally overflowed down into narrow spaces between the solidified lava core and the ice, giving rise to the vertical sheets surrounding the horizontal layers.

INTRODUCTION

A series of volcanic centers exists in the southern Coast Mountains of British Columbia, and extends northwesterly along the central part of this mountain chain from the vicinity of Mount Garibaldi, 40 miles north of the city of Vancouver (fig. 1). A considerable number of these centers were examined during the geological mapping of 380 square miles in the Mount Garibaldi map-area in 1946 and 1947[1]. Remnants of original surfaces remain on many of the volcanoes as evidence of their relatively recent origin, but almost all bear marks of the Cordilleran ice sheet which buried most of the map-area during Wisconsin time. Eruptions took place throughout a considerable part or perhaps all of the Pleistocene epoch. The volcanic rocks are clearly distinct from the Mesozoic(?) metamorphic and plutonic rocks on which they have been deposited. The relatively restricted distribution of the young volcanic rocks in both space and time suggests that they are a well defined natural unit.

Abnormal internal structures are present in several of these young volcanic masses and unusual external form is apparent in others. Of all the volcanoes, however, the flat-topped mass known as The Table, 3½ miles north of Mount Garibaldi, is the most striking both in external form and in internal structure.

[1] Geology of the Mount Garibaldi map-area—unpublished PhD thesis, University of California Library, Berkeley, California.

DESCRIPTION

The Table is a pillar of black dacite[2] rising in sheer cliffs, several hundred to almost 1,000 feet high, to a nearly hori-

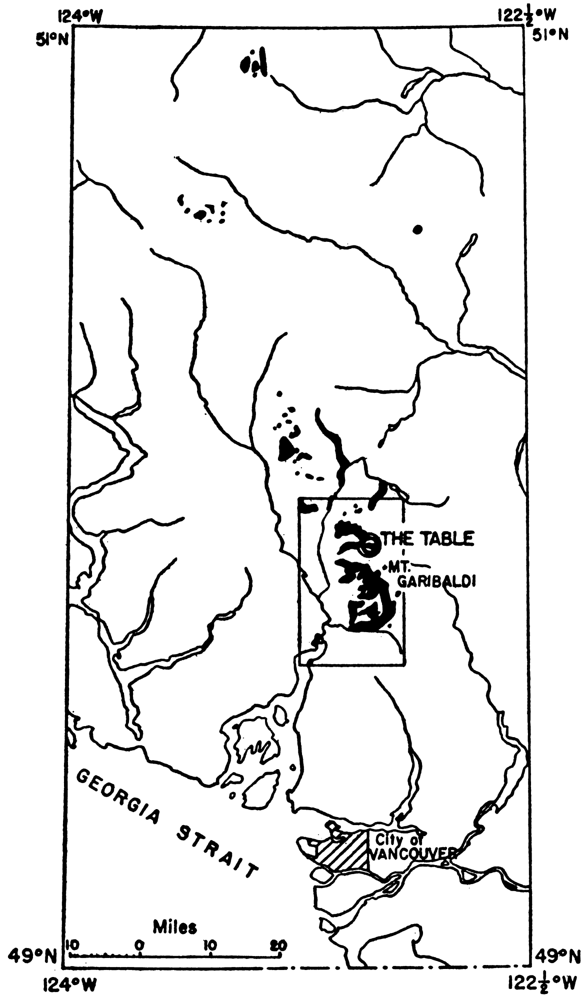

Fig. 1. Index map showing the location of The Table (circled), the outline of the Mount Garibaldi map-area (rectangle), and known occurrences of Quaternary volcanic rocks (solid black) in the southern Coast Mountains of British Columbia.

[2] The term dacite has been applied to this rock because it contains slightly more than 57.2% SiO_2, the amount of silica corresponding to 10% normative quartz in this suite of igneous rocks. On the basis of mineralogical analysis alone the rock would probably be regarded as an andesite.

zontal summit surface 1,000 feet long and about 750 feet wide (fig. 2, and plate 1). A distinct horizontal layering of its core is revealed in places, but elsewhere sheets of lava coat the almost perpendicular surface of this core much as icing coats the surface of a layer cake. Its outstanding exposures and unusual structure command attention. Repeated showers of rock falling from its precipitous faces also command respect, and, together with the inaccessibility of so much of the mass, add to the difficulties of its investigation.

Only two types of rock are exposed in the vicinity of The Table: (1) Mesozoic(?) quartz diorite, forming the foundation on which the mountain is built, and (2) a complex of gray dacite domes and flows. The quartz diorite is exposed up to altitudes of 5,100 and 5,400 feet above sea level at the western and northwestern base of the mountain but is concealed on the southeastern and northeastern slopes by the gray dacite. The summit and northern face of a plateau a half-mile north of The Table represent the slightly dissected upper and lateral surfaces of a dacite flow. Elsewhere radial aggregates of lava columns represent partially preserved dome-shaped protrusions or lava lobes. The preservation of some of the original topographic expression of these dacite masses is evidence of their youth, but the presence of fresh erratics on them up to an altitude of at least 6,400 feet indicates that they were extruded during or before the latest maximum of Pleistocene glaciation.

The uppermost limits attained by the Cordilleran ice in the immediate vicinity of The Table was at least 6,800 feet above present sea level if the ice surface sloped uniformly between the highest known traces of regional glaciation 4 miles to the north and 18 miles to the south. Whether or not The Table itself was glaciated is not known, for no glaciated surfaces remain on its slopes and these slopes are too steep to bear erratics. Its summit has not been examined for traces of the ice sheet. The well defined striae on the gray dacite north of The Table and the lithology of the nearby erratics, indicate that the latest ice movement in the vicinity of The Table was south 60 degrees west.

Talus, derived directly from The Table, surrounds the mountain on all sides. This talus generally forms smooth aprons except at the mouths of the narrow gullies, which

PLATE 1

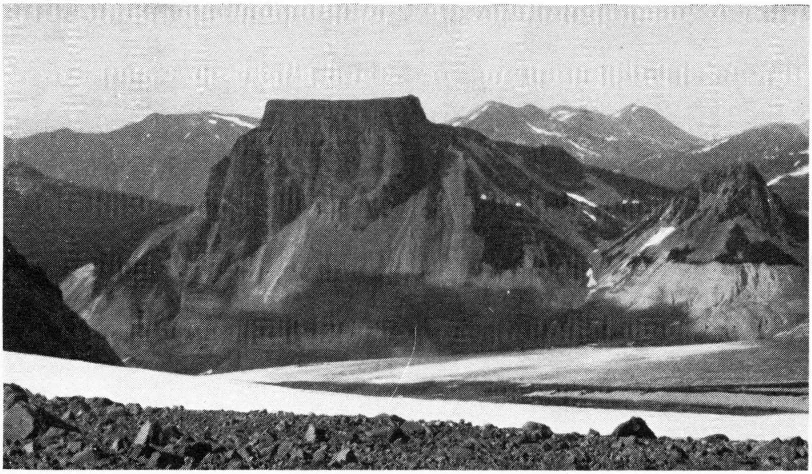

Fig. 1. The Table from the south. The height of the Warren Glacier in the 19th century is marked by the top of the barren slopes, 500 feet above the glacier surface in 1946.

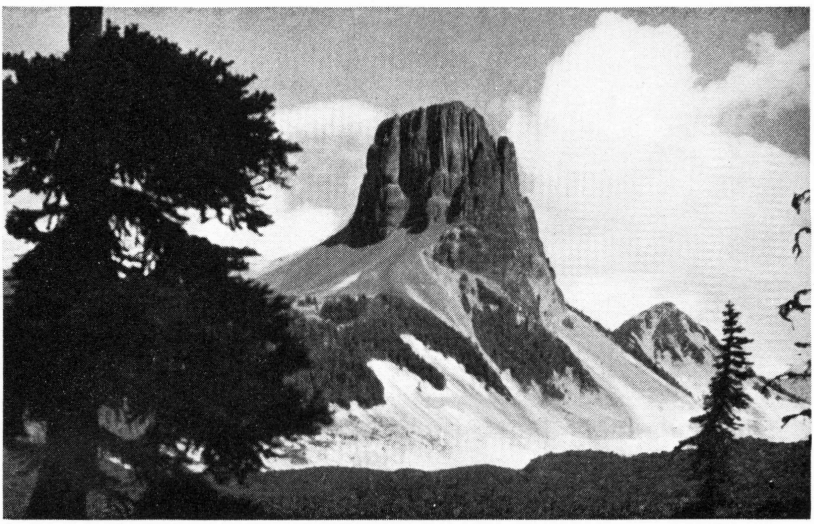

Fig. 2. The Table from the west. Horizontal layering is locally apparent on the northwest face.

score the upper slopes of the mountain; here the debris accumulates as steep-sided cones. To the northwest of the mountain, however, the surface of the talus has an abnormally low slope and is distinctly hummocky, broken by irregular ridges and pits with a local relief of 10 to 20 feet. This part of the talus may have been deposited on wasting glacial ice of Pleistocene age which, on disappearing, left a kettle topography, or it may have been formed in a single large-scale rock-fall which developed landslide topography.

The contacts of The Table with surrounding rocks have been concealed by this talus at all but two points. At the southwestern end of the mountain a steep flow derived directly from the upper part of The Table is separated from the underlying quartz diorite (fig. 2, altitude 5,100 feet) by an undisturbed mantle of glacial till. It is significant that this till, even a fraction of an inch below its upper surface, is totally unweathered. Evidently this flow is of glacial age or was laid down so soon after the disappearance of the ice that atmospheric agencies had no opportunity to modify the glacial debris. The other point at which a contact between the black dacite of The Table and the adjoining rocks is exposed lies at an altitude of 6,200 feet on the eastern side of the mountain about 400 feet below and 600 feet south of the crest of the east ridge. The contact at this point strikes northerly, parallel to the present face of the mountain, and dips at an angle close to 90 degrees. Black dacite of The Table contains fragments of both gray lava and quartz diorite up to several inches in diameter. The black dacite itself is locally glassy, and a few feet from the contact it displays well developed joint columns whose axes are nearly horizontal and trend east-west. The contact clearly indicates an intrusive relationship of The Table dacite into the adjoining gray lavas. As indicated below, however, this contact must have originally lain at no great distance below the surface.

The central part of the black dacite pillar is composed of a succession of flat-lying layers approximately 10 feet thick, characterized by stout vertical joint columns, alternating with layers 100 to 250 feet thick, characterized by slender joint columns. The stout joint columns average about 18 inches in diameter and the slender columns about 6 to 9 inches. Each pair of layers is interpreted as a single flow unit con-

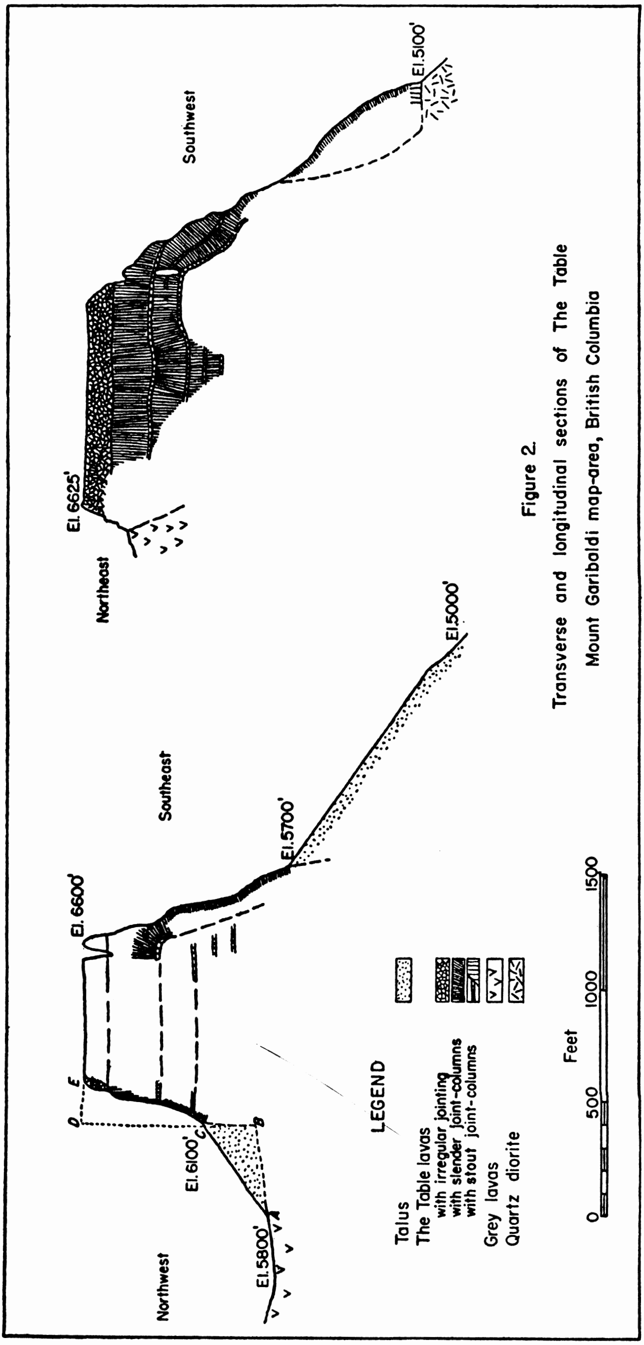

Figure 2.
Transverse and longitudinal sections of The Table
Mount Garibaldi map-area, British Columbia

sisting of a slowly cooled basal layer with fairly widely spaced polygonal joints and a more rapidly cooled upper layer with closely spaced joints. Similar joint patterns are commonly developed in lavas in many parts of the world, for example in the flows of the Giant's Causeway in Ireland. Tomkeieff (1940) has recognized in the flows of the latter locality a basal layer of stout columns, which he refers to as the "colonnade", on which is superimposed a layer of slender columns, the "entablature." A zone of stout "pseudocolumns" above the entablature in several of the Giant's Causeway flows is not represented at any place in the Mount Garibaldi map-area. In most flows the ratio of the thickness of the entablature to that of the colonnade is between 1:1 and 2:1, not 10:1 to 25:1 as in The Table. This relationship is here interpreted as signifying that heat loss through the top of the flow units of The Table is from about 10 to 25 times the heat loss through the bottom. By contrast the heat loss through the upper surface of most flows appears to be rarely more than twice the loss through the basal surface. This may in turn signify either that each of the flow units of The Table was deposited on still-warm lavas or that their upper part was subject to unusually rapid loss of heat for some undetermined reason.

One unusual feature in the layering is displayed on the northern face of The Table near its western end. Here a zone of stout columns well defined at the western end of the face dies out 100 feet to the east(fig. 2) and adjacent zones of slender columns above and below here merge into a single unit. Apparently a double upwelling of lava gave rise to distinct superimposed flow units in the outer part of The Table but toward the central part of the mass the same lava cooled and fractured as a single unit.

Flow units, though slightly irregular in detail, are essentially horizontal throughout the greater part of the mountain. The upper surface of the highest flow dips very gently toward the center of the mass in the form of a broad saucer with a relief of not more than 25 feet. Flow contacts lower in the mass have somewhat greater irregularity and any shallow basin-shaped form, like those so conspicuous in the top surface, is masked but the gentle dips clearly prevail. At several places around the periphery of the mass, however, the layers are bowed sharply downward and individual flow units assume a vertical attitude (fig. 2). The joint columns, which are consistently perpendicular to the adjoining flow contacts and which are upright in the higher slopes of the mass and in the deeper gullies, lie at low angles where exposed on the lower slopes and spurs of the mountain. Whether these flow units poured down the flanks of the pillar as continuous sheets, like tablecloths draped over tables, or as isolated lobes, like dribbles of wax down the side of a candle, is problematical, but local irregularities in both the direction and angle of pitch of the column favors the latter picture. Certainly the flow unit that poured off the southwestern end of The Table down to the 5,100 foot level is a distinct lobe with clearly defined cooling surfaces on three sides.

DISCUSSION

A rough measure of the cliff recession that has taken place since the ice age is given by the volume of detritus distributed around the base of the mountain. On the south face, where talus descends to Warren Glacier, some of this debris may have been removed by ice transport; on the north slope, however, all the coarser debris accumulated in post-Pleistocene time remains on an undisturbed layer of till. The volume of talus below this face of the mountain can be estimated, assuming the till-covered surface continues beneath the talus with no sharp change in slope as far as the buried face of The Table itself. This volume of talus, proportional to the area of the triangle ABC in figure 2, should be approximately the same as the volume of material lost from the upper slopes of the mountain, a volume similarly proportional to the area of the triangle CDE in the same figure. On this basis it can be surmised that when talus development began the north face of The Table was essentially vertical through a range of 800 feet. Cliff recession at the top of this face may have averaged 150 feet since that time, and a shorter distance at lower levels, the general slope declining with this recession from an original value of approximately 90 degrees to the present value of slightly more than 70 degrees. The volume of talus lying against the south face of the mountain is so large that cliff recession amounting to at least several tens of feet must be presumed. Circumstances do not, however, favor as satisfactory an estimate of recession on this face as was possible on the north side.

Parts of the present surface on both the north and south sides of the mountain near the top of the talus are parallel with if not coincident with original cooling surfaces. In places flat-lying flow units display nearly horizonal joint columns which must have developed by cooling from the sides rather than the tops of the flows. Cliff recession here since deposition of the lava has almost certainly been less than the thickness of the entablature of individual flow units, that is less than 100 to 250 feet. Higher on the slopes, where cliff recession seems to have exceeded 100 to 150 feet, these laterally cooled parts of the flow units no longer remain. The original thickness of a lava sheet which poured down over the south face of the mountain near its eastern end is not certain, but cliff recession has been insufficient to interrupt its continuity across a width of several hundred feet and throughout this distance the joint columns are perpendicular to the present surface. It seems that the surface that would be obtained were the talus fragments restored to their original positions in the upper part of the mountain would be the original surface and not just a surface exposed at the time of deglaciation.

At the time of its origin The Table was apparently elliptical in plan with a major axis at the summit 1,200 feet long, trending about south 70 degrees west, and a minor axis about 1,000 feet long. Its north wall was essentially vertical and its south face steep to vertical. The eastern and western ends of the mountain sloped at angles somewhat greater than at present and probably not less than 70 degrees. Except at the eastern end of the mountain where the dacite intrudes gray lava there is no trace of a pre-existing rock mass or ash cone that could have prevented the spread of the lavas from The Table, and the fact that these lavas could pour freely down the sides of the pillar at several places shows that no such rock retaining wall existed.

The problem arises of explaining the peculiar behaviour of the lava, whereby in the core of the pillar it was sufficiently fluid to form flat-lying layers, and yet at the flanks of the mass it was so viscous that it could come to rest on almost vertical slopes. This relatively abrupt change in the character of single flows can be due only to abrupt changes in external conditions, possibly in the rate of cooling. The residual heat of the underlying flows may well have maintained a higher fluidity in the central part of the next higher flow in the succession than at its more exposed flanks. If such a condition alone prevailed, one would expect the cooling rates and viscosity at any time to increase progressively from center to margin of the flow units rather than change abruptly. One would expect, too, a dome-shaped pile of lava, an "exogenous dome," to be formed in this way and not a structure like The Table.

The answer to this problem cannot be deduced from the available information, but it is possible to reconstruct a hypothetical set of conditions to account for the observed features. The relationship of the lava at the western base of The Table to the underlying till suggests that the black dacite may have been extruded during a period of glacial occupation. No direct evidence has been found, such as the presence of erratics released from overhanging ice and embedded in the upper part of a flow, to prove the coexistence of glacial ice and molten lava, but with the data on hand such a possibility cannot be denied. It remains, therefore, a possibility worthy of further investigation.

Products of eruptions under and through ice sheets have been described both in Iceland (Noe-Nygaard, 1940; Nielson and Noe-Nygaard, 1936; and others) and in northern British Columbia (Mathews, 1947), but The Table differs from any of these. Granulated lava, palagonite breccias, and pillow lavas have been developed in the described occurrences of subglacial and intraglacial eruptions, but such material is considered to have been formed by contact of lava with melt-water or with water-soaked debris and not necessarily with the ice itself. Koto's notes (1916) on the subaqueous lava of Sakurajima indicates that rapid quenching of lava does not necessarily result in such breccias and pillow structures; hence their absence cannot be regarded as evidence against subglacial extrusion of lava. The fact that some subaqueously chilled lavas develop breccias and others pillows is evidence itself that varying though undetermined physical properties of the lava can have a very marked influence on the products developed by quenching.

The shape of cavities melted into glacial ice during a volcanic eruption also varies with circumstances. Descriptions of historic subglacial and intraglacial eruptions in Iceland (Nielsen, 1937; Noe-Nygaard, 1940) indicate that broad areas of ice can be affected by a single central eruption. At Grimsvötn, for example, a mass of ice estimated to have been 5 by 10 kilometers (3 by 6 miles) in extent and probably not less than 200 meters (almost 700 feet) deep was melted. The presence of the upper layers of the ice within most of this area after the eruption had ceased indicates that it was the basal layers which had been melted. The volcanic heat had thus created a mass of subglacial meltwater, presumably within a lens-shaped chamber around the vent, and the sudden drainage of this meltwater had permitted the collapse of the still-frozen roof. Northwest of Hagöngur a large saucer-shaped collapse depression was created in the surface of the ice apparently by a subglacial eruption which never broke through to the surface. A marked contrast to these two examples is provided by the deep cylindrical pit thawed through névé in the summit of Mount Baker, Washington, by the heat from a central fumarole. In the first instance the thawing of the ice was apparently aided by warmed, pent-up, and circulating waters; in the last, the thawing has been effected by warm rising vapors. The difference in the means of heat-transfer, or perhaps in the opportunity for circulation of the fluids, may, therefore, largely determine the shape of the cavity, and no predictions should be made as to whether a broad lens-shaped chamber or a vertical pipe would be created by thawing under an unknown set of circumstances. Conceivably, too, a long and relatively narrow tunnel might equally well be created by water flowing continuously along a particular course under the ice from the site of the vent.

Water may persist in the subglacial or intraglacial cavities until the lava has been extruded or, on the other hand, the cavity may be partly or completely drained before lava flows from the vent.

Because of possible variations in (1) the physical characteristics of the lava, (2) the shape of the chamber formed by thawing, and (3) the amount of water persisting in the chamber at the time of extrusion, a large number of subglacial and intraglacial volcanic forms can be anticipated. The Table may be one of these.

Let us assume that a vertical pit, larger than but otherwise similar to that of Mount Baker, was thawed through the ice at the site of The Table, or more particularly near its north-eastern end where the observed intrusive contact, and presumably the vent, is located. Let us assume, too, that the pit was almost completely drained of meltwater, even though it is not certain that this assumption is either necessary or valid. Lava flooding into the floor of the pit would spread laterally until it came in contact with the ice. With its motion retarded and its cooling accelerated the magma could solidify against the ice to form an annular ring within which would be ponded the still-molten lava. Such a mass would cool to form a roughly circular steep-walled flow unit with a flat upper surface, "the lowest layer in the cake." Successive extrusions of lava would repeat this history, adding successive layers to "the cake." Locally the lava might break over or through the solid ring and, pouring down into the gap thawed between the cooling pile of lava and the ice, would chill and come to rest like "the icing on the cake." Thus a structure having the essential characters of The Table, with flat-lying layers in its central portion and steeply dipping layers on its sides, could form. If such, indeed, were the origin of The Table, it would seem that the cavity thawed in the ice sheet was filled to within about 200 feet of the glacier surface, for the top of The Table lies within this distance of the highest limit known to have been attained by the ice. The process of filling this pit with repeated floods of lava would require time, and the glacier would not remain static during the interval but would be constantly encroaching on the cavity. A continued supply of volcanic heat from the vent and lava pool would thaw this encroaching ice, and the relative rates of supply of ice and of heat would determine changes in size and shape of the pit. The rate of ice movement toward the pit would be greatest on its upstream side and least on its downstream side if, indeed, the ice could reverse its direction of flow here. The pit would, therefore, become gradually elongated downstream from the vent and lava pools. The direction of ice movement near The Table, as indicated previously, was south 60 degrees west. It seems more than a coincidence that The Table itself is elongated in almost precisely this direction. It seems more than a coincidence, too, that the observed intrusive contact is at the northeastern end of The Table, the upstream face, and the latest known flow to pour down off the upper part of the mass is at the opposite end.

References

Koto, B., 1916. The great eruption of Sakura-jima in 1914: Tokyo Imp. Univ., Jour. Coll. Sci., vol. 38, art. 3, pp. 1-237.

Mathews, W. H., 1947. "Tuyas," flat-topped volcanoes in northern British Columbia: Am. Jour. Sci., vol. 245, pp. 560-570.

Nielsen, N., 1937. A volcano under an ice-cap, Vatnajökull, Iceland, 1934-36: Geog. Jour., vol. 40, pp. 6-23.

———, and Noe-Nygaard, A., 1936. Om den islandske "Palagonitforma-tion's" Oprindelse (with German summary): K. danske Geog. Selsk., Geog. Tidsskr., vol. 39, pp. 89-122.

Noe-Nygaard, A., 1940. Sub-glacial volcanic activity in ancient and recent times (studies in the palagonite-system of Iceland, No. 1): K. danske Geog. Selsk., Folia Geog. Danica, vol. 1, no. 2.

Tomkeieff, S. I., 1940. The basalt lava of the Giant's Causeway district of northern Ireland: Bull. volcanologique, ser. II, vol. 6, pp. 89-144.

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA