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ORIGIN OF THE SALTON VOLCANIC DOMES, SALTON SEA, CALIFORNIA

V. C. KELLEY AND J. L. SOSKE
California Institute of Technology

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ABSTRACT

The location of the Salton volcanic domes and the alinement of the associated mud volcanoes strongly suggests their affiliation with the buried extension of the San Andreas fault. Two surface trends are evident—the northeastward locus of the volcanoes, and the northwestward line of mud geysers. The latter coincides almost exactly with a southeastward extension of the San Andreas fault from 15 miles to the northwest. A detailed magnetic survey indicates that the subsurface material is not confined to the immediate vicinity of the domes. Steep magnetic gradients observed over the flats some distance from the line of volcanic hills are interpreted as the magnetic effect of the sloping surface of the underground igneous mass. In consequence of wind-directed wave attack during the presence of Lake Cahuilla and Salton Sea the lighter pumiceous materials have been concentrated to the lee of the hills in wave-built terraces or "tails," which at the southernmost volcano have accumulated in sufficient quantities to be of commercial importance. At this same volcano a peripheral distribution of obsidian with relation to pumice leads to a unique interpretation of its structure and origin. Fumarolic carbon dioxide gas trapped in the valley sediments to the northeast of the domes has been recently exploited for the manufacture of "dry ice."

The Salton volcanic domes lie very near the bottom of the inland depression which structurally constitutes the northern extension of the Gulf of California. This sub-sea-level portion of the Gulf trough includes in a broad way three better-known geographic units, namely, Coachella Valley, Salton Sea, and Imperial Valley. Salton Sea, occupying the center of the basin, separates Coachella Valley on the north from Imperial Valley on the south. However, the separation is not purely geographical inasmuch as the Coachella Valley is a comparatively narrow structural basin whereas the Imperial Valley is considerably broader and probably includes several parallel depressed and waste-covered fault blocks. The principal structural feature of this region is the San Andreas fault, which practically coincides with the east side of the Coachella Valley. Southeastward it probably passes beneath the Salton Sea and under the Imperial Valley.

THE VOLCANIC DOMES

There are 5 volcanic domes lying roughly parallel to the southeastern shore of the Salton Sea. The length of the line of volcanoes

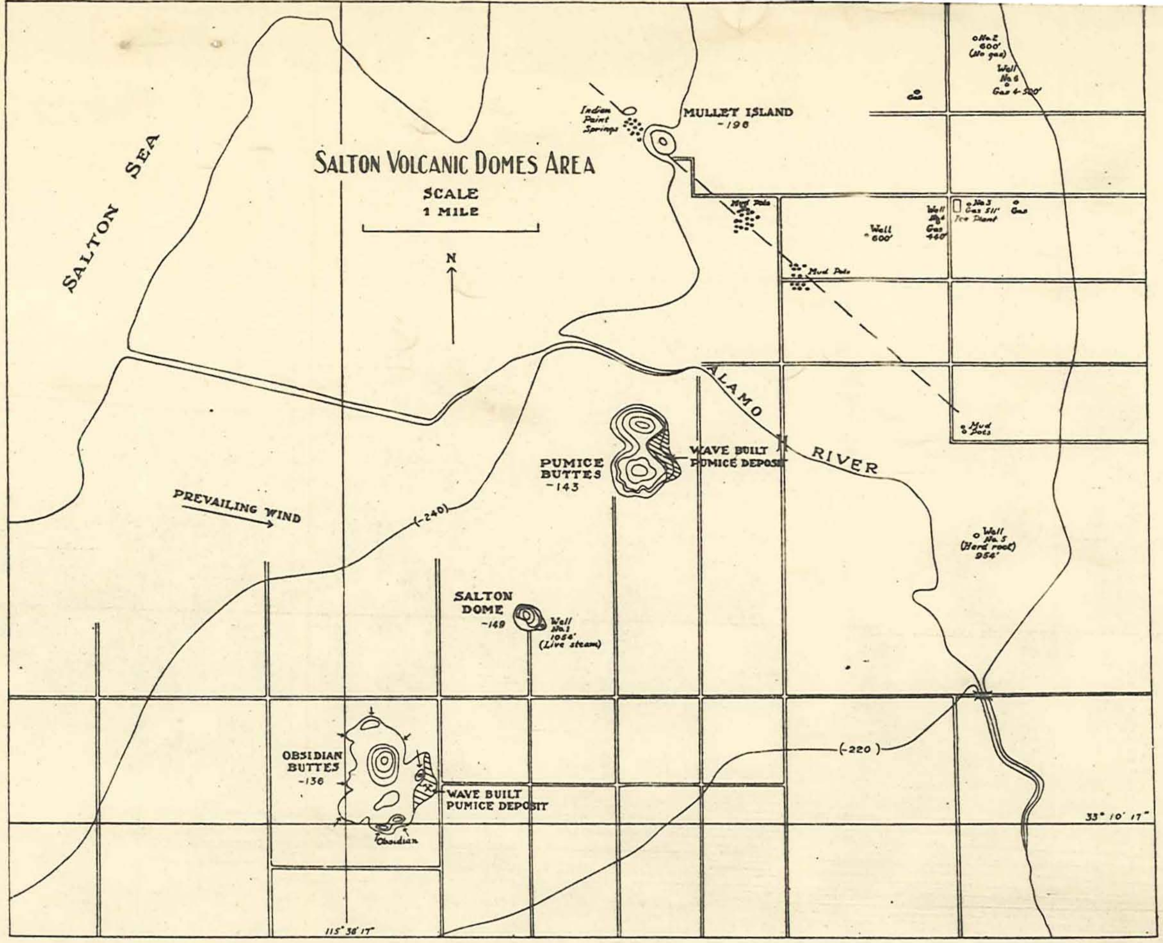

FIG. 1.—Salton volcanic domes showing the locus of the mud pots and the wave-built pumice deposits on the east side of the hills

is about 4 miles. As late as 1914 the hills stood as islands in the Salton Sea (Fig. 2), but by the spring of 1935 the shoreline of the sea had receded about 1½ miles from the volcanic cones. None of the hills rises more than 100 feet above the level valley floor which at this point is 240 feet below sea-level.

Rogers[1] has briefly described the rocks of these hills as "rhyolitic obsidians and pumices and their alteration products." He was especially interested in Mullet Island, where he found that the original rhyolitic material had been altered to a metamorphic rock composed essentially of tridymite and feldspar. Here, as in the case of many viscous rhyolitic extrusions, the flow structures are arched into a gentle dome. But, although the structure as exposed is quaquaversal, the igneous mass as a whole is probably mushroom shaped, as a well drilled on the flank of the dome reached sedimentary material in a few tens of feet.

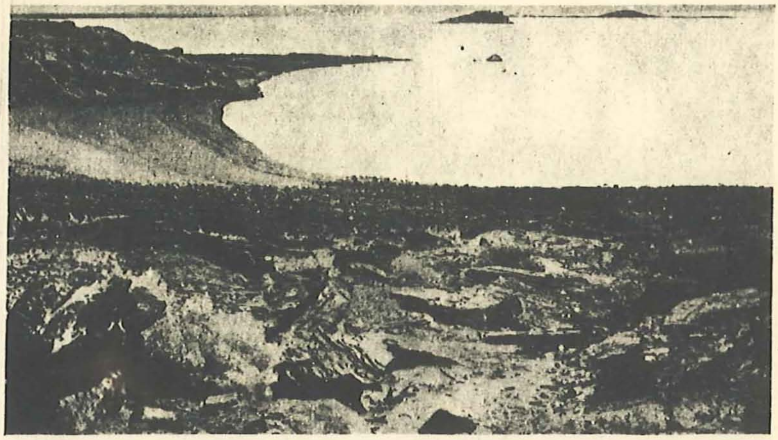

FIG. 2.—Looking southwest from Pumice Buttes Island. Salton Dome and Obsidian Buttes in distance partly inundated by Salton Sea. Photograph by MacDougal, 1912.

Mullet Island has attracted much attention locally because of the nearby hot springs and mud "pots" which discharge considerable quantities of steam, carbon dioxide, some hydrogen sulphide, and water laden with sodium chloride. Much iron oxide forms in some of

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[1] A. F. Rogers, "Salton Volcanic Domes of Imperial County, California," *Geol. Soc. Amer. Proceedings for 1934*, p. 328.

the muds, perhaps as the result of the extreme oxidizing action of the gases on the sediments.

Pumice Buttes, about 2 miles south of Mullet Island, are two small coalesced volcanic cones or domes as shown in Figure 1. The structure of the north hill is markedly quaquaversal and like Mullet Island the igneous mass is probably mushroom shaped with the outer margin of the body partly covered by valley fill. The south hill is almost entirely covered with mud flows and terrace deposits. Erosion by wind and waves has partially exhumed the once more extensive mud flows on the west side, producing steep cliffs in which the texture and crude bedding of the consolidated mud flows are well exposed.

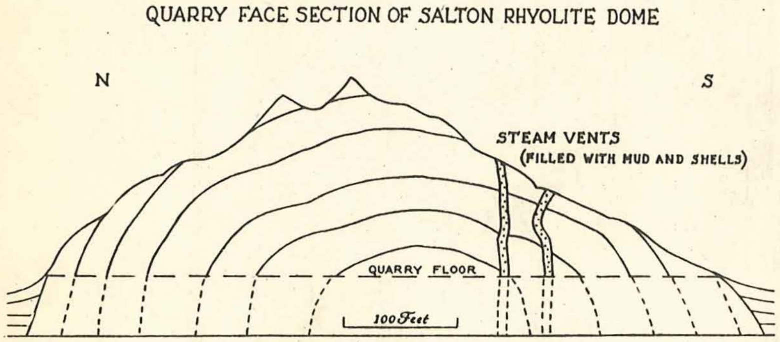

Fig. 3.—Quarry face section of Salton Dome

Salton Dome is interesting chiefly because of the excellent exposure of its internal structure in a quarry on its west side. The flow structures of the dome are nearly vertical on the flanking limbs and in this respect the mass has a plug-like form in contrast to the mushroom forms of the previously described volcanic cones. Numerous small open vents from which continued slow exhalations of steam escape are present among the craggy outcrops. In the quarry face are exposed two of these vents filled with mud and small shells deposited during the existence of Lake Cahuilla.

The name Obsidian Buttes given to the southernmost of the volcanic hills is not apt in that most of the rock is pumice. The name presumably arose from the several small buttes of obsidian which are distributed around the periphery of the nearly circular pumice field (Fig. 1). The volcanic cone is composed of a central dome-like hill surrounded by a lower field of pumice with buttes of obsidian at the outer margin.

The magma which rose to form Obsidian Buttes was exceedingly rich in gases. During the rise of the lava to the surface, and before it had congealed, most of the gas-rich material had separated and risen to the top of the lava column. Once at the surface the gas-rich upper part rapidly expanded and cooled to form the highly cellular and light pumice. Below it was molten gas-lean material which was effectively capped temporarily by the brittle but light pumiceous material. However the magmatic pressures were not entirely relieved at this stage and additional surges from below found much easier avenues of escape by flowing laterally to the edge of the pumice cap where the molten material rose nearly vertically to the surface and congealed to form the small obsidian buttes. Several of the buttes rise very abruptly above the outer flat valley floor and the inner pumice area (Fig. 5). The flow lines are usually tangential to the pumice field, but may be very much contorted. Such an occurrence is unique, so far as the authors are aware, and probably would form only under specialized conditions obtained with a rather complete segregation between the gas-rich and gas-lean phases of a rhyolitic lava.

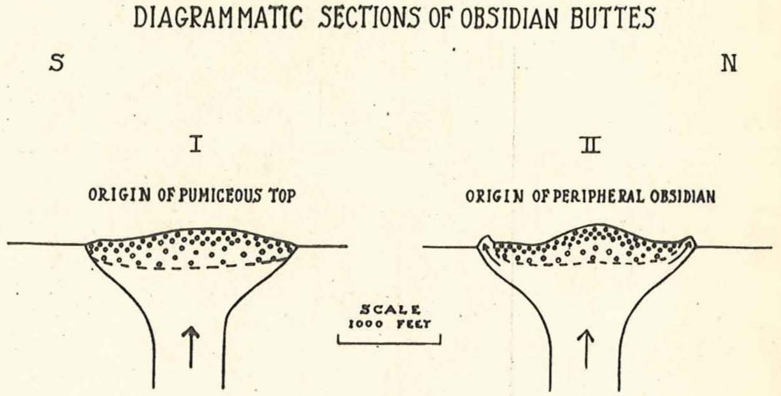

FIG. 4.—Diagrammatic section of Obsidian Buttes

SIGNIFICANCE OF THE VOLCANIC CONES

The Salton volcanic domes are undoubtedly of Quaternary age, very young, for the fading stages of volcanism are still evidenced by the mud pots and steam geysers. It is probable that molten rock lies not over a few thousand feet below the valley floor. One is immediately struck by the isolation of the volcanic cones on the apparently undisturbed level floor of the basin and by their linear distribution, which suggests some underlying structural control. This alinement prompted a magnetic investigation on the expectation of finding a buried fault or underground igneous mass. The completed magnetic survey indicates the latter, but its emplacement may have been determined by an earlier fracture.

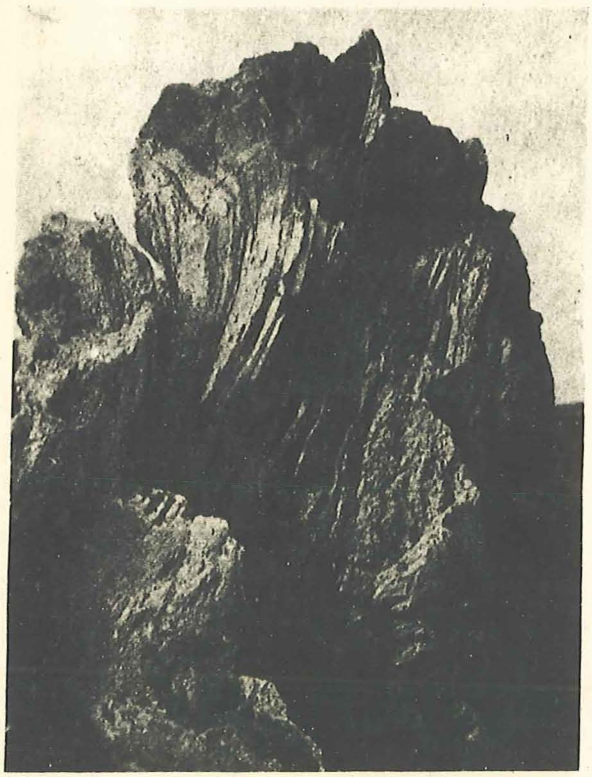

FIG. 5.—Obsidian outcrop covered with calcareous tufa, near the top of one of the peripheral extrusions at Obsidian Buttes.

The position of the volcanic cones is roughly on the extended strike of the San Andreas fault, but their alinement makes a large angle with the regional trend of the fault. Nevertheless, their position directly in line with the San Andreas rift appears to be more than fortuitous.

Even more convincing evidence for a buried fracture was obtained by mapping the positions of the mud pots in the vicinity of Mullet Island. It was found that there are four groups of mud geysers in a straight line striking N. 45 W. (Fig. 1). This is also the regional trend of the San Andreas fault 20 miles to the northwest, and furthermore, their loci are exactly in line with this major fracture. It is also interesting to note in this connection that on the west side of Volcano Lake in Lower California a more prominent and active group of mud geysers occurs directly in line with the more active San Jacinto fault. A magnetic profile also indicates its buried expression along this line. Thus the alinement of the mud geysers near Mullet Island for almost 3 miles is as good evidence as has been found for the southeastward extension of the buried San Andreas rift.

THE CARBON-DIOXIDE GAS FIELD

Carbon dioxide has been known to issue from the boiling springs and geysers around Mullet Island for many years. About seven years ago a well was drilled in the altered rhyolite on the flank of the hill. It blew considerable gas and subsequently more than a dozen wells have been drilled in the vicinity in quest of carbon dioxide. One was drilled on the flank of Salton Dome and after penetrating sediments for over a thousand feet parallel to the neck encountered live steam. Finally, after drilling again into live steam and high pressure underlying the north hill at Pumice Buttes, attempts to obtain carbon dioxide directly over the volcanic cones were abandoned. The later wells have been drilled on the flats east of the cones.

All of the producing wells are located in a small area about 2 miles directly east of Mullet Island and north of the line of mud geysers. The principal producing horizon appears to be between depths of 400 and 500 feet. The initial pressures, usually between 200 and 300 pounds per square inch, decrease after some production.

The general opinion among the operators in the district is that the carbon-dioxide gas has resulted from the action of superheated steam and other gases on the sedimentary carbonate rocks. They note that "lime" rocks are present near the producing horizons. On the other hand, the emanation of carbon dioxide from volcanoes is well known. The Salton volcanoes themselves give off carbon dioxide and other gases, and it appears more probable that the producing horizons are sedimentary structural traps into which the juvenile magmatic carbon dioxide has migrated.

THE WAVE-BUILT PUMICE DEPOSITS

The pumice deposits are wave-built terraces, but their position in relation to the wave cutting is not the usual one. A complete understanding of the wave-built pumice deposits necessitates a review of the recent physiographic history of the basin.

Prior to the last outbreak of the Colorado River and the flooding of the basin during the period 1904–7, the area now occupied by the Salton Sea was a dry playa with local saline accumulations. The basin had been dry continuously since the coming of the white man. However, older and higher shorelines furnish evidence of an earlier water body, and Indians of the region tell of this lake and its gradual disappearance.

The name Salton Sea applies only to the twentieth-century inundation of the basin. The earlier water body has been referred to as Lake Cahuilla. Buwalda and Stanton[2] have pointed out that the pre-Salton Sea lakes of Quaternary time were fresh water, and that the prominent high-water shoreline was formed by Lake Cahuilla and not by an extension of the Gulf of California. Moreover, the sub–sea-level depression of the Salton basin took place after or concurrently with the establishment of the Colorado River cone as an effective dike against the Gulf of California.

It is possible that the sinking of the basin may have initiated the volcanic activity. That the volcanoes are not older than Quaternary is evidenced by their very young aspect and their very slight dissection. Prior to the building of the Colorado River cone most of the region was above sea-level and was undergoing erosion with drainage

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[2] John P. Buwalda and W. Layton Stonton, "Geological Events in the History of the Indio Hills and the Salton Basin," *Science*, Vol. LXXI, p. 105.

to the gulf. That the volcanoes were formed after the early stages of Lake Cahuilla is shown by the fact that only the very outer margins of their surface forms are covered by lake deposits. That the volcanoes were present during at least the later stages of Lake Cahuilla is indicated by the shorelines above those formed by the Salton Sea. That a considerable time elapsed between the last desiccation of Lake Cahuilla and the appearance of Salton Sea is shown by the pronounced dissection of the Cahuilla wave-cut cliffs and pumice terraces.

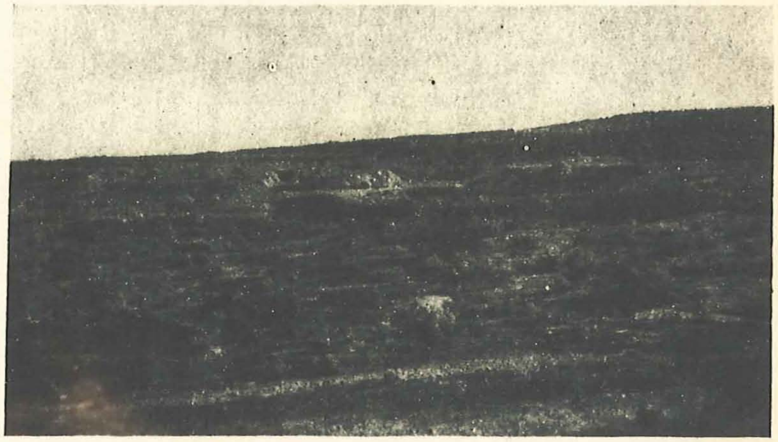

FIG. 6.—Details of the wave-built terraces at Pumice Buttes

Thus, the Salton volcanic cones were formed some time after the building of the Colorado delta dike and during the Lake Cahuilla stages. When the Colorado River flowed into Lake Cahuilla and kept it filled to its maximum, some 30 feet above sea-level, the tops of the cones were covered by more than 150 feet of water. At other times when the river was diverted directly to the gulf, Lake Cahuilla continuously shrank, and if the diversion continued 50 years or more the lake practically disappeared. The lake-level rarely remained stationary except when overflowing to the gulf, at which times the action of the waves was above the cones. Since at other times the level of the lake was either rising or sinking, the periods of effective wave action on the volcanoes were comparatively short.

Nevertheless, at times they were subjected to wave attack, the effectiveness of which varied with the type of rock. Mullet Island, composed of altered but resistant rhyolitic material, and Salton Dome composed of relatively dense rhyolite, were beveled only slightly. Pumice Buttes, with their partially consolidated mud flows and Obsidian Buttes, composed of light frothy pumiceous material, were easy prey to the wind-directed wave attack. The prevailing winds in this part of the valley are from the west. The soft and light pumiceous materials eroded from the western (windward) side of the islands were sorted, buffeted, and carried to the eastern (lee) side of the islands. This resulted in a natural selection and concentration of high-grade pumice in the terraces or "tails" which formed to the lee of the islands. The combination of wave-cutting on one side and terrace-building on the other side has given some of the hills a noticeable asymmetrical profile.

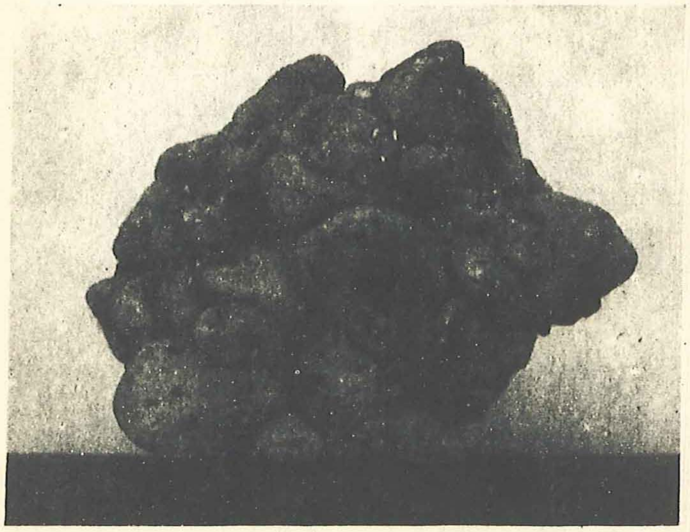

FIG. 7.—A fossiliferous pumice conglomerate from the wave-built terrace at Obsidian Buttes. Numerous small fresh-water gastropods occur in the calcareous tufa cement. $\times\frac{3}{4}$.

At Pumice Buttes this selection was largely from the tuffaceous material of the mud flows which does not contain so much high-quality pumice as Obsidian Buttes. At the latter volcanic cone the top of the flow contained the "cream" of the pumice. It was exceedingly cellular and light, and the buoyant material was spread far and wide over the valley. The ancient beach line many miles to the east contains much of this material. However, large quantities of excellent pumice were waterlogged or otherwise deposited in the "tail" at Obsidian Buttes. Here the deposit is mined and water-sorted for the highly cellular glass which is used in the manufacture of certain acoustic plasters and polishing blocks. The larger fragments often contain cavities 2 or 3 inches in diameter spun across with fine tubular threads. The present erosion surface shows none of the very high-grade pumice found in the sedimentary deposit, indicating that the original surface of the extrusion was much more frothy than the material uncovered by erosion.

THE MAGNETOMETRIC RESULTS

That the volcanic domes occur along a slightly curved line suggests a possible common fissure along which the extrusive material reached the surface at the various points. With this in mind, several magnetic profiles were made across the curve joining the buttes, but no striking anomalies were observed. Next, a detailed vertical intensity map of the entire area was made in an effort to determine the extent of the subsurface igneous material. This was done by placing observation stations over the area about every half-mile, but where the magnetic gradients were found to be steep the stations were placed much closer together in order to obtain a more accurate representation of the magnetic features associated with the buttes.

In the immediate vicinity of the volcanic cones the stations were only a few hundred feet apart because it is in these areas that the magnetic intensity has the greatest lateral variation. In all, observations were made at about 200 stations during the survey. The presence of swamps in the vicinity of the Alamo River prevented a magnetic survey of this part of the area.

The method used during the investigation is very similar to the conventional system of making a barometer survey for elevation. A Schmidt type of vertical intensity variometer was used as a combined field and stationary recording instrument. Stationary observations are necessary to obtain the background reading so the field observations may be corrected for diurnal and other variations which may affect the magnetic component being studied. Instead of making a stationary continuous reading of the component, the variometer was read at a conveniently located station at brief intervals of time during the field survey. In this manner a continuous approximation of the variations was obtained by interpolation methods. This procedure gave the necessary data for the correction of the routine field observations for diurnal effects. Temperature corrections and adjustments were made for the normal variations of the vertical intensity component and for changes in latitude and longitude. The resulting values were reduced in such manner that if any variation was noted it could be attributed to geological conditions associated with areal changes of magnetic susceptibility. These values were then plotted on a map and isonomalic lines were drawn (Fig. 8).

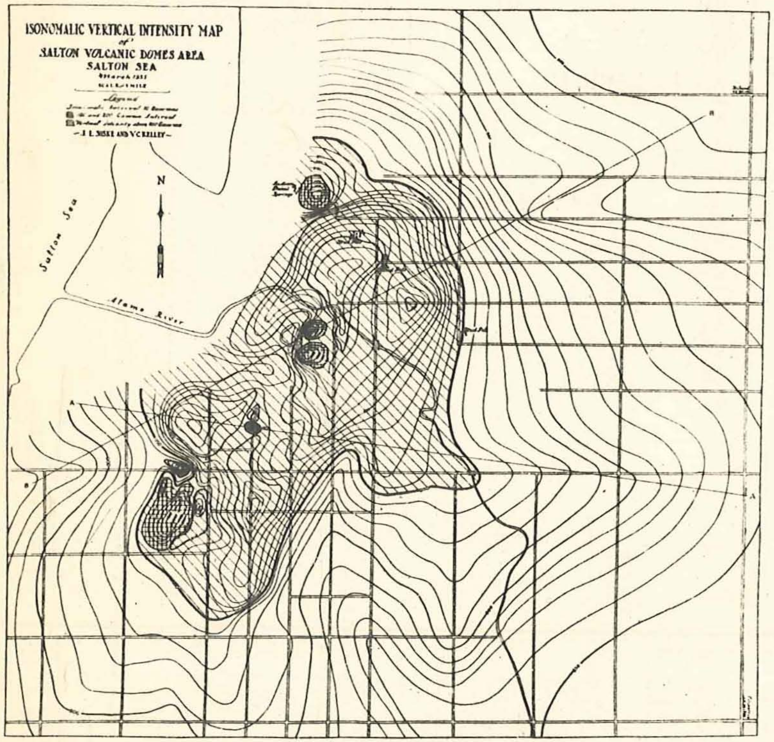

FIG. 8.—Isonomalic vertical intensity map of Salton volcanic domes area

The detailed magnetic survey indicates that the underground igneous mass is not confined to a fissure passing through the hills, nor does it indicate that the mass is confined to the immediate vicinity of the hills. The vertical intensity anomalies indicate that the igneous mass at a considerable depth underlies the whole area occupied by the volcanic cones and other active features such as the mud geysers.

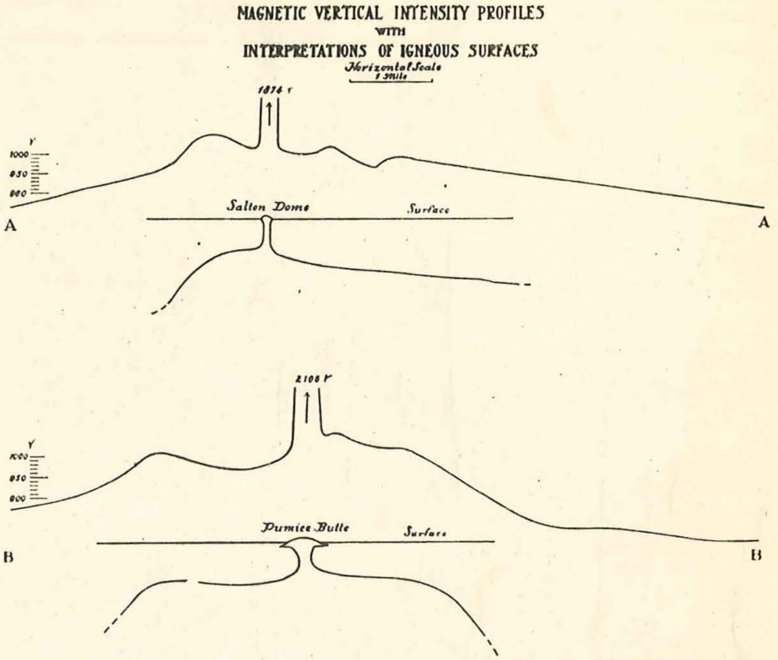

FIG. 9.—Magnetic vertical intensity profiles with interpretations of the subsurface igneous bodies along lines *A–A* and *B–B* of Fig. 8.

Steep magnetic gradients observed over the flats some distance from the curved line of hills indicate that a rapid lateral change occurs in the magnetic susceptibility of the subsurface materials. This conspicuous change in the magnetic gradient may be interpreted as the magnetic periphery of a large, deep, igneous mass which reaches the surface at various points along a fissure or fault in the uppermost layers.

Sections *A–A* and *B–B* of Figure 9 show graphically the changes of intensity along certain directions. The eastern portion of *A–A* indicates that the igneous mass may extend eastward, forming a nose-shaped body. The northeast portion of *B–B* may be interpreted as representing a steep slope of the periphery of the igneous mass.

In conclusion it may be stated that the survey demonstrates that a very marked differential permeability exists between the sediments and the igneous rocks of the area. It is this fact which makes the method useful in detecting the underground extent of the igneous body although buried beneath sedimentary materials. A very much more detailed magnetic survey may show even more minute details, but the general magnetic expression of the area will not be changed.

ACKNOWLEDGMENTS.—The authors wish to express appreciation to Professors J. P. Buwalda and G. H. Anderson for suggestions in preparation of the paper. Also to Professor A. R. Whitman goes recognition for an earlier introduction to some of the problems of the area.