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Geophysical Studies on Sikotu Caldera, Hokkaido, Japan

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Abstract

Sikotu Caldera and the surrounding area have been fairly well studied from the standpoint of geology. In this paper, the writers report the results of gravimetric and geomagnetic surveys carried out respectively around and on the caldera lake and analyze the data quantitatively. The subterranean structure of the caldera is deduced to be very similar to other calderas in Japan, *i.e.* Kuttyaro, Aso and Aira. The causes of caldera formation are discussed with quotations from the results of geological studies on this caldera, and a theory on this problem proposed by one of the present authors (I.Y.) proves to be compatible with geological observations.

1. Introduction

Lake Sikotu is situated to the south of Sapporo, Hokkaido, the distance between them being about 30 km, and is a caldera lake: the formation of this volcanic depression was accompanied by ejection of a huge amount of pyroclastics, at present some parts of which form welded tuffs around the caldera. The depth contours of the lake are shown in Fig. 2 where the altitude of the lake surface is about 250 meters above sea level and its maximum depth is 368 meters. The bottom profile is of typical caldron shape. The form of the lake is an approximate circle of about 15 km in diameter, narrowed by the post-caldera volcanoes Eniwa, Huppusi and Tarumai. Eniwa and Tarumai are active and the latter is famous for the lava dome on its top which was formed in two weeks by the 1909 eruption.

As for the geology of this district, the first study was commenced by J. Suzuki and T. Shimotomai (Ishikawa)[1]. A geological map was compiled by S. Doi[2] in 1957 and detailed discussions on the welded tuff from the caldera were made by M. Minato, J. Ishii and S. Kumano[3], and on the pumice fall deposits by Y. Katsui[4]. According to their results, the caldera was formed by two major eruptions in the Pleistocene: the age of carbonized wooden pieces found in the Sikotu welded tuff was determined by the radioactive method as about 20,000 years before present. The distribution of ejecta from the caldera after Doi is shown in Fig. 3 where ejecta are classified into two groups

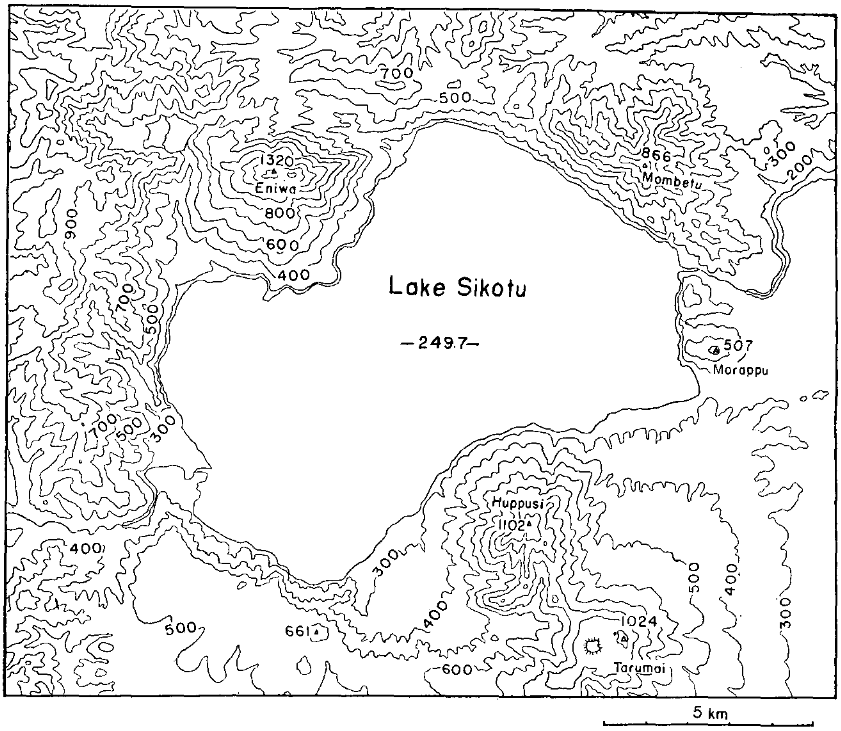

Fig. 1. Topography around Sikotu caldera lake. (Contours in *meters*)

by their periods of ejection. Minato *et al.* determined, by precise observations in the field, the topography of this district both before and after the ejection of the welded tuff and obtained a thickness distribution of the welded tuff around the caldera as shown in Fig. 4. They note that the pumice was ejected from several fissures to certain directions, not to all ones.

Since the environs of the caldera are, as in the cases of many calderas, widely covered by thick volcanic ejecta originating from the caldera itself and its main part is under deep water, geophysical methods should be very useful to obtain the present subterranean structure of the caldera and, further, combined discussion of geological and geophysical observations will afford some clue to the causes of caldera formation.

2. Gravimetric surveys around the caldera lake.

The gravimetric surveyes were carried out by means of land gravimeters: in 1962 a North-American gravimeter was used at 21 points by courtesy of

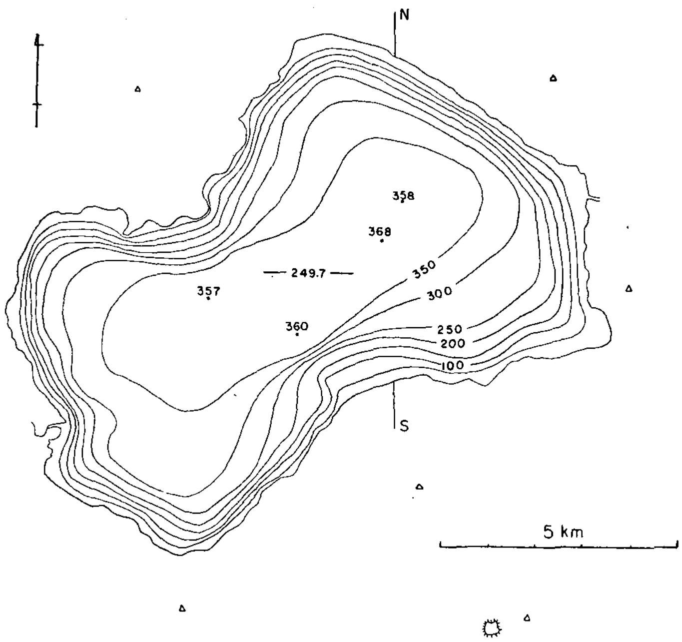

Fig. 2. Depth contours of Lake Sikotu. in *meters*.

the Geographical Survey Institute and in 1963 a LaCoste & Romberg gravimeter was used to supplement the previous survey at another 45 points. As for the observation points, many spot heights along the road running from Chitose to the lake were occupied and also many observation points were set along the shoreline of the lake. Heights of the remaining stations were determined by means of a precise microbarometer of the American Paulin System within an accuracy of about 3 meters at worst.

To obtain the Bouguer anomaly, the authors take the density of the earth-crust as 2.67 gr./cc and the vertical gradient of gravity as 0.3086 mgal/meter and neglect the topographic corrections because the topography is not very steep here. The Bouguer anomalies thus obtained are accurate within 1 mgal. The result of the gravimetric surveys is listed in Table I and the distribution of observation points and the profile of the Bouguer anomaly from Chitose to the lake are shown in Fig. 5. Toward the caldera, the Bouguer anomaly shows a steep increase at about the 100 meter elevation contour and its augment reaches about 50 mgal at the caldera rim. This is a conspicuous characteristic around Sikotu Caldera in marked contrast to other calderas ever

Table I. Gravity values observed around Sikotu caldera lake.

Station No.		φ 42°N	λ 141°E	Height (m)	Normal value (mgal) 980,	Observed value (mgal) 980,	Free-Air anomaly (mgal)	Bouguer anomaly (mgal)
1	緑町独標	49.′1	38.′3	18.2	432.67	443.39	16.3	14.3
2	独標	48.9	36.9	20.6	432.37	441.76	15.8	13.4
3	苗別橋独標	48.7	35.8	27.6	432.07	438.47	14.9	11.8
4	烏柵舞独標	48.4	35.5	33.0	431.62	436.93	15.5	11.8
5	独標	47.7	34.2	74.6	430.57	425.69	18.1	10.8
6	独標	47.4	33.4	71.2	430.13	425.62	17.5	9.5
7	〃	47.3	32.2	85.3	429.98	424.64	21.0	11.5
8	第三発電所独標	47.5	30.6	120.2	430.27	421.45	28.3	14.9
9	独標	47.2	29.4	159.5	429.83	417.71	37.1	19.3
10	〃	47.1	28.0	210.3	429.68	416.55	51.8	28.3
11	水明郷入口独標	47.0	26.7	232.7	429.53	419.65	61.9	35.9
12	独標	46.3	26.6	244.8	428.48	418.82	65.9	38.5
13	国立公園入口独標	45.5	25.7	257.2	427.28	421.55	73.6	44.9
14	滝の上独標	45.9	25.2	250.1	427.88	426.97	76.3	48.3
15	支笏湖畔	46.1	24.4	252.7	428.18	430.32	80.1	51.9
16	樽前登山口独標	44.8	25.1	285.6	426.23	416.87	78.8	46.9
17	モーラップ	44.4	24.5	251.5	425.63	424.09	76.1	48.0
18	米軍キャンプ場	44.0	22.7	251.5	425.03	424.21	76.8	48.7
19	伐採事務所	42.7	19.1	251.7	423.08	421.18	75.8	51.5
20	美笛桟橋	43.3	16.1	251.6	423.98	427.21	80.9	52.8
21	多峰古峰山下	42.1	17.8	254.5	422.18	428.52	84.9	56.4
22	丸駒	46.7	18.9	249.0	429.08	419.41	67.2	39.4
23	湖岸	47.2	19.0	249.0	429.83	418.07	65.1	37.3
24	〃	47.6	19.6	249.0	430.42	422.23	68.6	40.8
25	ポロピナイ桟橋	47.8	19.7	249.0	430.72	425.90	72.0	44.2
26	丸駒付近	46.9	19.0	320.3	429.38	406.43	75.9	40.1
27	湖岸	46.5	18.6	249.0	428.78	418.14	66.2	38.4
28	三角点下	46.0	18.4	273.7	428.03	414.67	71.1	40.5
29	山道	46.0	17.8	317.6	428.03	404.47	74.4	39.0
30	ホテル	46.1	17.0	249.0	428.18	421.69	70.4	42.5
31	湖岸温泉	46.1	16.1	249.0	428.18	428.45	77.1	49.3
32	湖岸	45.5	15.5	275.1	427.28	426.69	84.3	53.6
33	〃	45.1	15.4	292.8	426.68	422.13	85.8	53.1
34	になる橋	44.2	15.4	279.3	425.33	427.19	88.0	56.8
35	美笛営林署	43.4	15.9	252.5	424.13	426.28	80.1	51.9
36	湖岸	42.9	16.3	249.0	423.38	431.21	84.7	56.9
37	〃	42.6	17.2	274.4	422.93	424.33	86.1	55.4
38	〃	42.2	17.8	249.0	422.33	429.85	84.4	56.6
39	〃	42.4	18.8	249.0	422.63	426.32	80.5	52.7
40	〃	43.0	19.7	249.0	423.53	422.96	76.3	48.5
41	〃	43.7	20.4	263.5	424.58	418.17	74.9	45.5
42	大崎湖岸	44.1	21.4	297.9	425.18	410.38	77.1	43.9
43	湖岸	44.3	23.6	249.0	425.48	422.29	73.6	45.8
44	北大支笏寮	46.5	24.3	282.5	428.78	426.60	85.0	53.4
45	湖岸	46.6	23.8	249.0	428.93	433.00	80.9	54.1
46	ポロピナイ湖岸	48.0	19.9	248.2	431.02	428.64	74.2	46.5
47	湖岸	48.1	20.3	〃	431.17	429.86	75.3	47.6
48	〃	48.0	20.9	〃	431.02	435.50	81.1	53.4
49	〃	47.8	21.6	〃	430.72	435.81	81.7	54.0
50	〃	47.5	22.1	〃	430.27	436.30	82.6	54.9
51	〃	47.3	23.2	〃	429.98	434.60	81.2	53.5
52	〃	47.1	22.9	〃	429.68	433.31	80.2	52.5
53	〃	46.9	23.3	〃	429.38	433.77	81.0	53.3
54	モーラップ湖岸	45.6	24.4	〃	427.43	428.77	77.9	50.2
55	〃	44.5	24.7	〃	425.78	425.72	76.5	48.8

Table I. Continued.

56	モーラップ湖岸	44.7	24.7	248.2	426.08	426.80	77.3	49.6
57	〃	44.9	24.5	〃	426.38	426.20	76.4	48.7
58	〃	45.3	24.4	〃	426.98	429.27	78.9	51.2
59	千才鉱山桟橋	45.9	24.4	〃	427.88	430.04	78.8	51.0
60	湖畔 (No. 15)	46.1	24.4	〃	428.18	431.08	79.5	51.8
61	ふ化場湖岸	46.3	24.3	〃	428.48	431.71	79.8	52.1
62	滝の上～モーラップ	45.7	25.4	254.0	427.58	424.06	74.9	46.5
63	モーラップ山の間	45.4	25.1	268.5	427.13	424.37	80.1	50.1
64	丸山	45.1	26.7	237.0	426.68	415.44	61.9	35.4
65	三叉路	45.1	25.9	261.0	426.68	418.39	72.2	43.1
66	千才・苫小牧分岐点	45.7	26.3	248.2	427.58	419.26	68.3	40.6

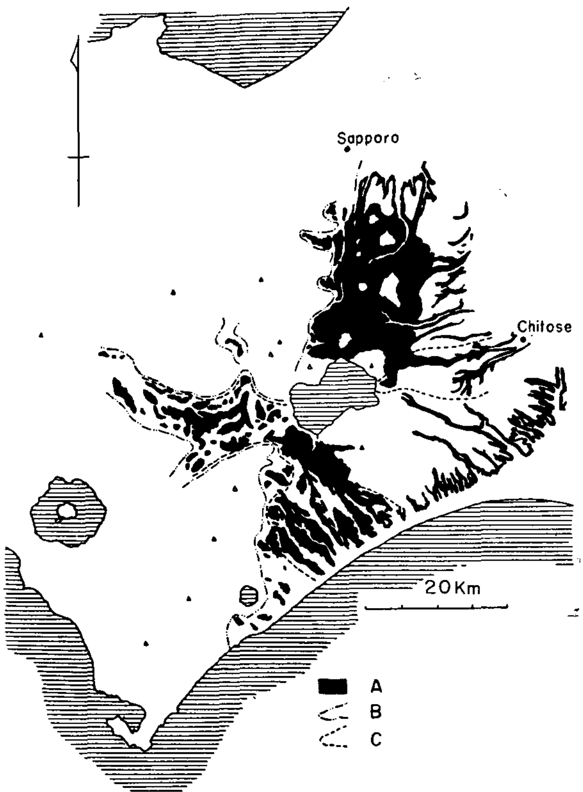

Fig. 3. Distribution of pyroclastics from Sikotu Caldera after S. Doi.
A: Pyroclastics from Sikotu Caldera
B: Region covered by welded tuff of later period
C: Region covered by welded tuff of earlier period

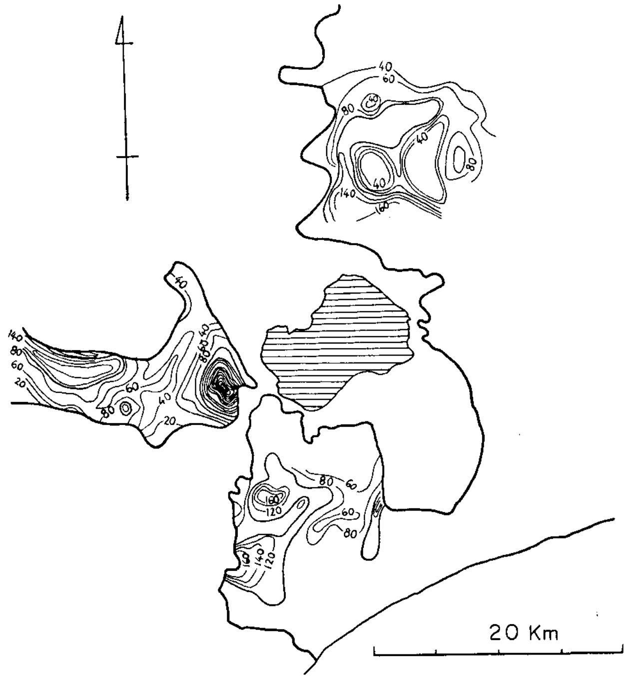

Fig. 4. Thickness contours of Sikotu welded tuff in *meters* after M. Minato *et al.*

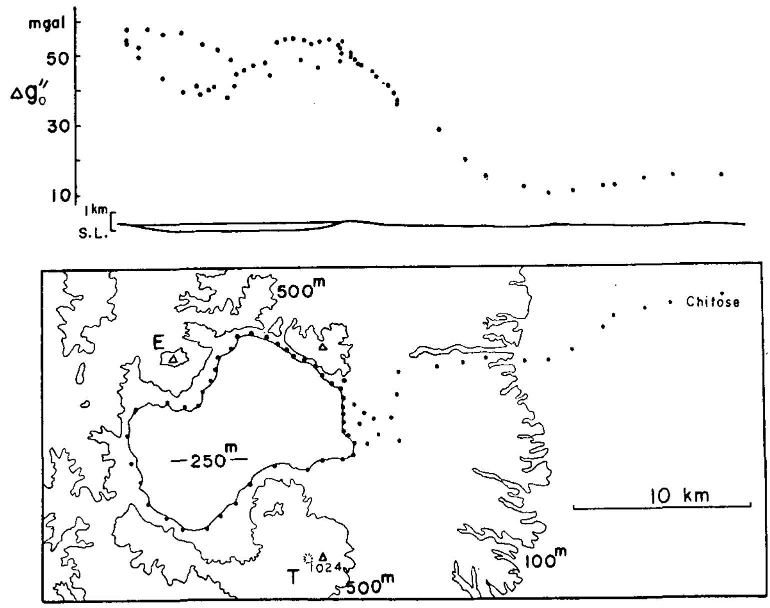

Fig. 5. Gravity anomaly profile along a line from Chitose to Lake Sikotu.

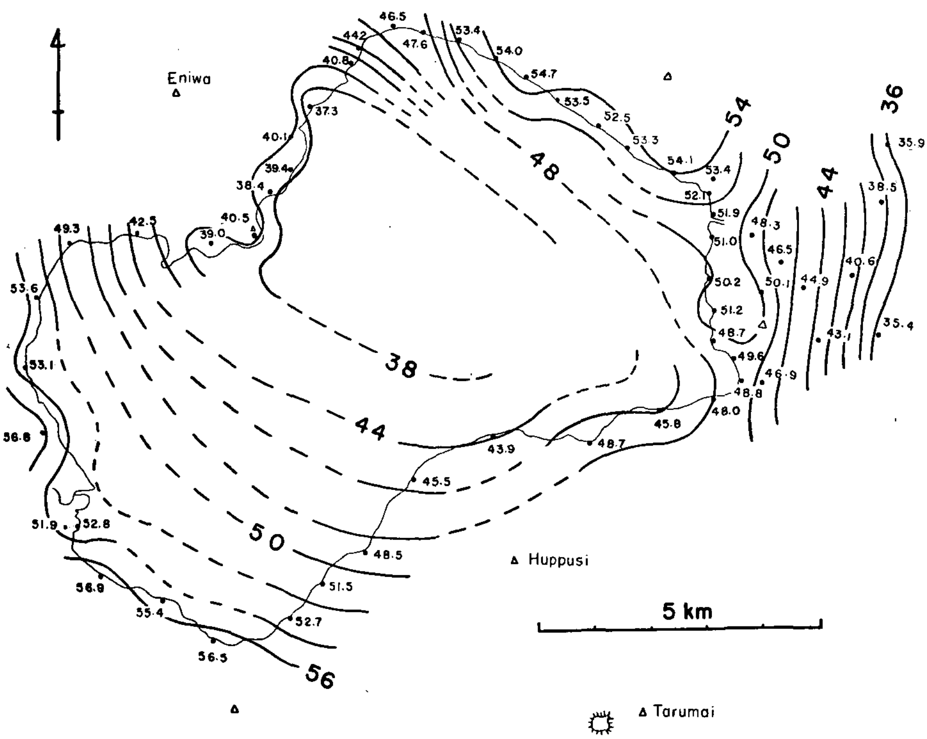

Fig. 6. Bouguer gravity anomaly in *milligal* (not corrected for topography).

surveyed and may be a reflection of the subterranean structure. The distribution of the Bouguer anomaly around the lake is shown in Fig. 6, where the authors have fortunately succeeded in figuring the general aspect of the gravity field around and also on the caldera, although the measurements were made only on land: we can easily presume a centre of low gravity anomaly at the eastern half of the lake. The corrections for the water are approximately negligible because the distribution of the Bouguer anomaly over the water is obtained by extrapolation of the measurements on land. The distribution is not concentric with the shape of the lake as a whole but with the eastern half and the decrement in comparison with the caldera rim amounts about 20 mgal. This low gravity anomaly is of common magnitude to other calderas surveyed. In Fig. 6, the contour lines of high gravity anomalies, *i.e.* 50～54 mgal on the eastern shore and 54～56 magl on the western shore, just correspond to the existence of Tertiary rocks which are expressed as hatched regions in Fig. 10.

Prior to the present gravimetric survey, the authors calculated expectancy of the mean gravity anomaly over the caldera by Gauss' theorem

$$\iint \Delta g\, dx\, dy = 2\pi G \cdot \Delta M .$$

Hence,

$$\overline{\Delta g} = \frac{2\pi G \cdot \Delta M}{\text{Area}} \tag{1}$$

where ΔM and G denote mass deficiency and gravitational constant respectively. Mass deficiency ΔM is caused by a kind of replacement of the pre-caldera volcano (its mean density is 2.5 gr./cc) with the present caldera deposits (their mean density is 2.2 gr./cc). According to the discussion by one of the authors (I.Y.)[5], ΔM is expressed by the following formula:

$$\Delta M = 0.3\, V_e\, \rho_e / \rho_m \tag{2}$$

where V_e, ρ_e and ρ_m denote volume and density of the original ejecta (density of welded tuff is 2.0 gr./cc) and density of the pre-caldera volcano (2.5 gr./cc) respectively.

As for the volume of welded tuff from Sikotu Caldera, Minato *et al.* estimated the volume of ejecta shown in Fig. 4 as 60 km^3, and of ejecta concealed by alluvium in the eastern region and flowed into the southern region now occupied by the sea, as approximately 40 km^3. In addition to the above welded tuff, the volume of pumice fall deposits is estimated as approximately 20 km^3 by Y. Katsui. The total V_e is thus about 120 km^3, and by equation (2), the mass deficiency at Sikotu Caldera is 2.8×10^{10} tons. Then, substituting all observed values into equation (1), we get expectancy of the mean gravity anomaly as about 6.9 mgal. In fact, on the lake, we get the relatively low gravity anomaly of about 20 mgal at the maximum as before-mentioned. This observed value is just compatible with the above estimates.

Strictly speaking, an estimation of the volume of pyroclastics by geological observations contains ambiguity. Applying Gauss' theorem reciprocally, we can estimate mass deficiency by graphical integration of the gravity anomaly over the caldera in Fig. 6 as 3.2×10^{10} tons. This value verifies, the writers think, both the accuracy of geologists' estimation at Sikotu Caldera and the validity of equation (2). The above result is plotted in Fig. 7 which appeared in the writer's (I.Y.)[5] previous paper. The fact that a common relationship exists between mass deficiency and diameter for both volcanic calderas and meteorite craters means that both might be formed by the same physical processes.

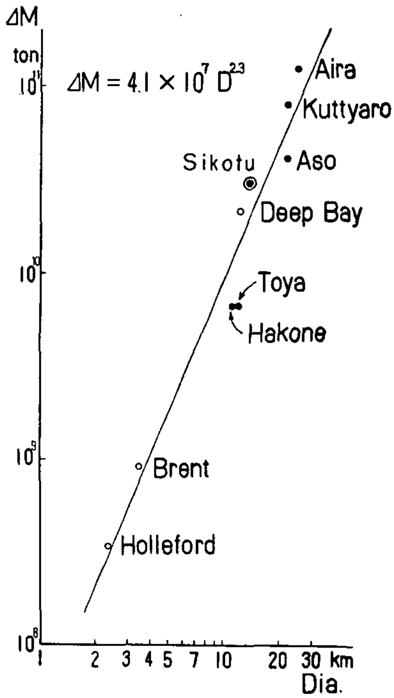

Fig. 7. Relationship between mass deficiency and diameter for calderas in Japan (solid circles) and meteorite craters in Canada (hollow circles).

3. Geomagnetic surveys on the caldera lake

A magnetic survey by means of a proton precession magnetometer on the lake surface was carried out to supplement the results of gravimetric surveys which were carried out only around the lake although they are suggestive by themselves. Magnetic surveys on the water are very useful because the disturbances due to magnetic material at or near the earth-surface will diminish at some distance. On the lake a detector coil in a small watertight vessel was towed by a small motor boat at a distance of 50~100 meters from it. The courses of the magnetic measurements on the water are shown in Fig. 8 where the hollow circles denote the land measurements. On the courses, a towing boat ran at a mean speed of about 8 km/hour and a measurement was made every one or two minutes. The magnetometer measures the total intensity of geomagnetic field with an accuracy of 1γ. Distribution of the total intensity

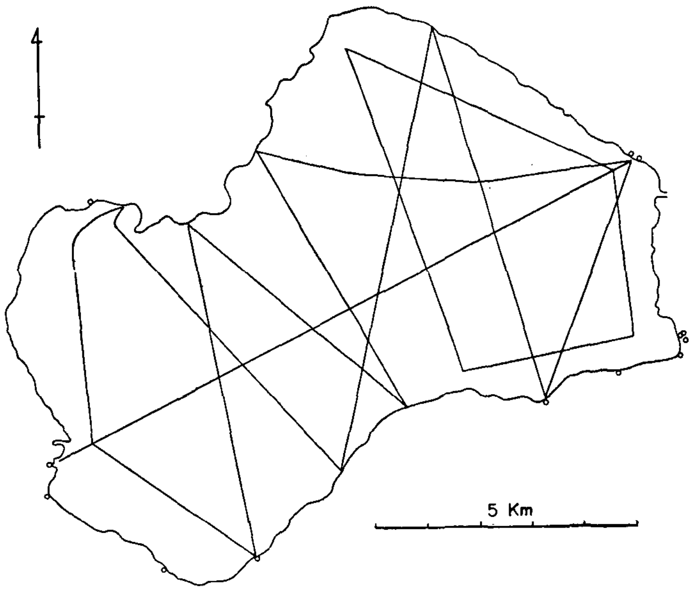

Fig. 8. Courses of proton magnetometer surveys on Lake Sikotu. Hollow circles denote land surveys.

is shown in Fig. 9, with contours drawn every 100γ.

In this region, the normal lines of equal total intensity are rather parallel in the direction of east and west and the mean normal value is about 49,600γ: the field intensities observed on the lake are locally anomalous and generally smaller than the above normal value.

The complicated anomalies observed to the south of Volcano Eniwa and in the north-eastern corner of the lake, *i.e.* at the foot of Volcano Mombetu, may be attributable to the effects of lava flows or rocks under the water which were ejected from the respective volcanoes. Such anomalies are very conspicuous near the shore; however, it is outside the authors' scope to deal in any detail with these anomalies of short wave length. In the middle of the lake, the anomalies are rather simple and their wave lengths are larger: there are two locally high anomalies situated in the eastern and western parts of the lake respectively. The eastern one just coincides with the centre of the low Bouguer gravity anomaly while the western one does not correspond to any gravity anomaly. This difference is very suggestive: the former is attributable to structure of larger scale and the latter to shallower structure of minor scale.

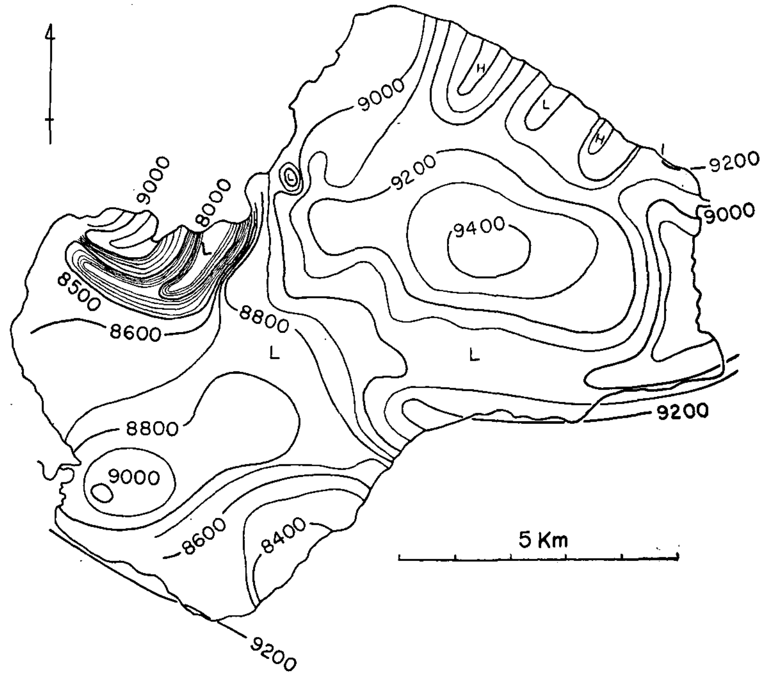

Fig. 9. Distribution of the total magnetic force on Lake Sikotu. Each numeral should be added to 40,000 *gamma*.

In order to study the geomagnetic anomalies of the lake, rock specimens were collected at the shore referring to a geological map of this region completed by S. Doi. Some parts of it, just around the lake, are shown in Fig. 10. The caldera was formed in the Pleistocene as previously mentioned: along the shore line of the lake, Quaternary volcanics are found among Neogene Tertiary ones which are hatched in the figure. All rocks are andesitic. About 50 rock specimens representative of the pre- and post-caldera volcanoes were collected at the sites shown by the small solid circles in Fig. 10. The directions of natural remanent magnetization (N.R.M.) of several specimens are plotted on a Schmidt projection as shown in Fig. 11: they are distributed rather easterly from the direction of the present geomagnetic field. Frequency distribution of intensity of N.R.M. is shown in Fig. 12, from which an average intensity may be presumed as 10^{-3}e.m.u./cc. Susceptibilities of several specimens (andesite) were measured as 1.0×10^{-3}e.m.u./cc on an average.

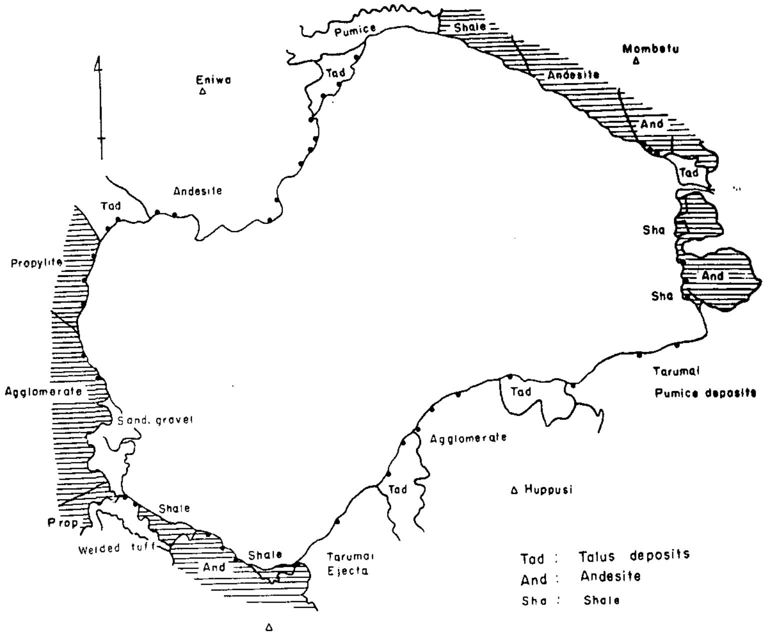

Fig. 10. Geological sketch map along the shore of Lake Sikotu after S. Doi. Hatched areas denote Neogene Tertiary and solid circles denote the sampling sites of the rock specimens for magnetic measurements.

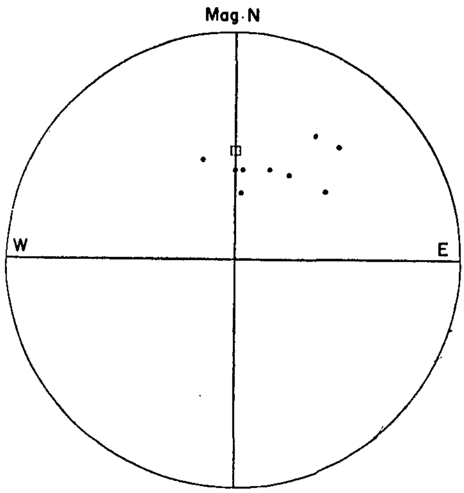

Fig. 11. Schmidt projection of natural remanent magnetism of volcanic rocks around Lake Sikotu. A square denotes the present geomagnetic field.

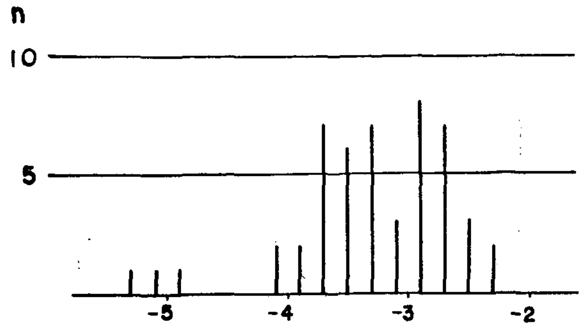

Fig. 12. Frequency distribution of intensity of natural remanent magnetism of the rocks from the shore of the caldera lake. Abscissa is logarithm of N.R.M. measured in *e.m.u./gr.*

P.S. H.R. Blank Jr. *et al.* of the U.S. Geological Survey carried out an aeromagnetic survey over Sikotu Caldera in 1964. Their discussion will appear in the near future.

4. Subterranean structure of the caldera and the causes of its formation.

In the previous sections, the authors described the results of gravimetric and geomagnetic surveys carried out around and on the caldera lake respectively. Though there are other geophysical methods for investigation of subterranean structure, for example, seismic, geothermal and resistivity methods, it is not easy, in fact, to practise these methods on and around Lake Sikotu.

In this respect, to get some direct information on the material of caldera deposits from boring cores is very desirable whether that boring well is dug at the caldera concerned or not. Fortunately we have a boring 1,000 meters in depth dug in 1963 at the middle of Kuttyaro Caldera in the eastern part of Hokkaido. A detailed discussion on these cores will be published elsewhere: To a depth of 1,000 meters, many parts of the cores consist of coarse material, *i.e.* agglomerate-tuff, pumice and ash, including a very small quantity of andesitic gravels and lava fragments. Fig. 13 shows two physical properties of these core samples. Circles marked with crosses in the figure denote the gravels or lava fragments. Density of agglomerate-tuff saturated with water increases from about 1.4 gr./cc at the surface as the depth increases and approaches asymptotically to about 2.2 gr./cc. Intensity of N.R.M. of the core samples measured at room temperature is shown also in Fig. 13. Their mean value is

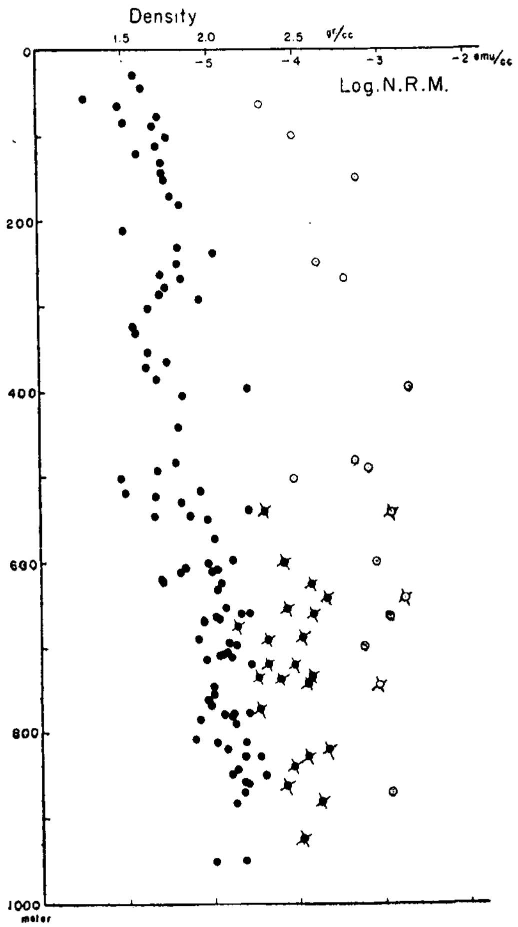

Fig. 13. Core specimens of the boring dug at the middle of Kuttyaro Caldera.
Solid circle: density saturated with water
Hollow circle: intensity of N.R.M. at room temperature.
Crosses denote gravel or lava fragment.

10^{-3} e.m.u./gr. in order of magnitude.

Gravity anomaly and magnetic anomaly are generally related by Poisson's theorem, which states that the magnetic potential is proportional to the gravity component in the direction of magnetization. On Lake Sikotu, we observed low gravity anomalies accompanied by positive magnetic anomalies as shown in Figs. 6 and 9. It is ambiguous whether both the anomalies are caused by the same origin or not. However, the two kinds of anomalies contradict each other in their patterns; the gravity anomaly has a unicentred pattern while the magnetic anomaly two maximums. These anomalies can not be interpreted combinedly by Poisson's theorem which assumes uniform magnetization of causative material. Therefore, it may be concluded that the origins of the two anomalies are different. In the following, the two anomalies are discussed separately and the subterranean structure along the profile of line NS in Fig. 2 is surmised.

In analyses of the gravity anomalies, the results obtained on Kuttyaro Caldera[6] serve as an important reference. We assume the densities of the caldera deposits and pre-caldera volcano (or basement rocks) as 2.2 and 2.5 gr./cc respectively, referring to Fig. 13. When the density contrast 0.3 gr./cc is adopted, the bottom depth of the circular conical caldera deposits is estimated as about 2 km at the maximum by the same method as at Kuttyaro Caldera: we would observe a relatively low Bouguer gravity anomaly of about 20 mgal at the middle of the lake and if an infinite plane is assumed as a model of the caldera deposits, its depth amounts to 1.6 km. At the caldera rim, the gravity anomaly begins to decrease inwardly and the same holds true of the other calderas. This means that the discontinuous boundaries at the caldera rims do not stand vertically but are inclined towards the centre of the calderas.

The magnetic anomaly observed along line NS is not attributable to caldera deposits but to intrusive rocks among the caldera deposits or at the bottom of the caldera deposits. Magnetization of these intrusive rocks is much higher than those of basement rocks and caldera deposits. The magnetic anomaly profile is analyzed by the fall-off curves of the vertical intensity with horizontal distance after L.L. Nettleton and by the slope method after L.J. Peters, both of these methods being independent of magnetization, on the assumption that the configuration of magnetic material may be approximated by a vertical semi-infinite cylinder. The average values of the depth to the magnetic cylinder and of its diameter are about 2 km and 1.5 km respectively. The gravitational effect of the above cylinder to the lake surface is calculated at only 0.6 mgal at its maximum if the density contrast between the intrusive rocks and basement rocks is assumed as 0.1 gr./cc. If we could observe gravity on the lake in future, this effect should be too small to be identified.

To check the above result, a single pole model whose pole strength is proportional to the intensity of magnetization and cross-sectional area of the cylinder is adopted and the maximum vertical anomaly to be observed is

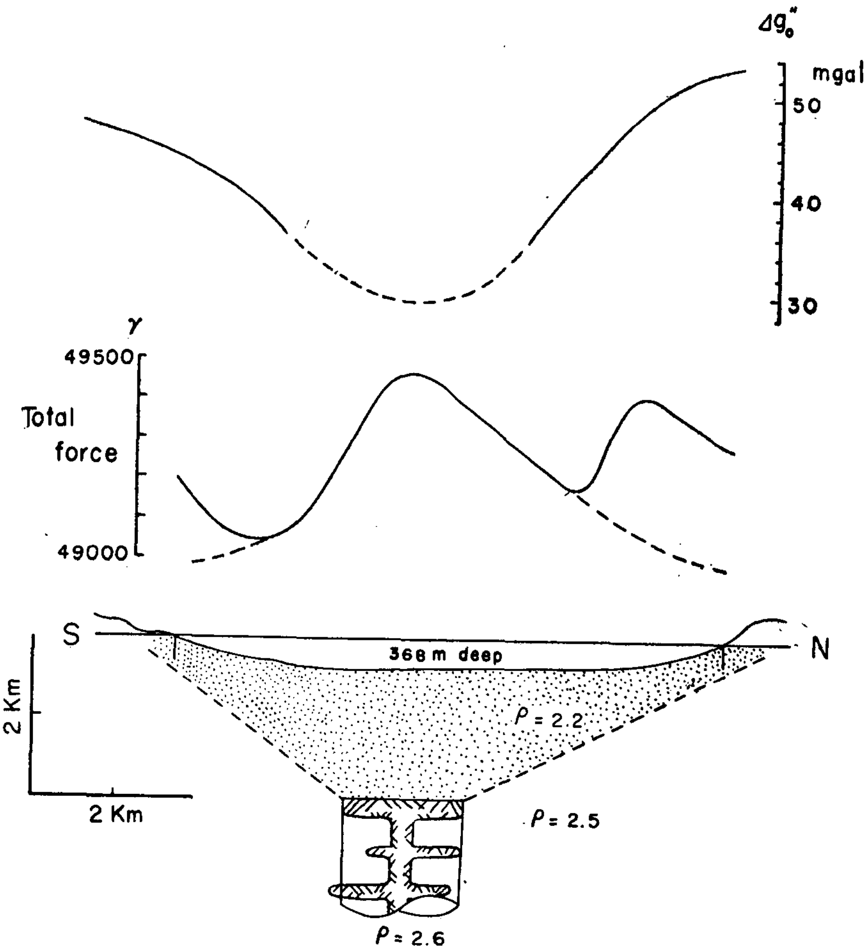

Fig. 14. Profiles of observed anomalies and deduced subterranean structure along line NS shown in Fig. 2.

obtained as about 500γ. This is just the same order of magnitude as the observed value.

The subterranean structure thus deduced is shown in Fig. 14, where a vertical semi-infinite cylindrical model is used to represent some intrusive rocks in the form of lava sheets and lava columns. As for the subterranean structure of the region between Chitose and the lake, we may refer to the results of seismic prospecting carried out by the Japan Petroleum Exploration Company Ltd. (JAPEX). The results are schematically shown in Fig. 15:

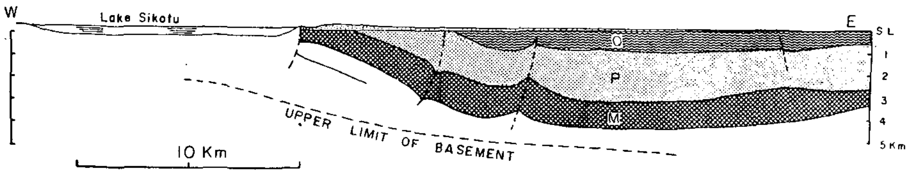

Fig. 15. Subterranean structure along a line from Chitose to Lake Sikotu compiled from the results of seismic prospecting (by courtesy of the Japan Petroleum Exploration Company Ltd.).
Q: Quaternary P: Pliocene M: Miocene

beneath the caldera, the basement rises to a depth of about 2 km, which is just the same as one obtained from our gravimetric and geomagnetic surveys on the caldera and is thus compatible with our model.

As for gravimetric studies on calderas, one of the authors (I.Y.)[6),7),8)] has already analyzed the gravity data on Kuttyaro, Aira and Aso calderas with good success. The prominent features of these calderas are as follows:

1. Low gravity anomalies amounting to a few score of milligals are almost concentric with the centres of calderas and indicate existence of coarse material to a depth of a few kilometers beneath the calderas.

2. The faults or discontinuous boundaries at the caldera rim do not stand vertically but are inclined towards the centre of the calderas.

3. Mass deficiencies observed at the calderas are just compatible with the total mass of pyroclastics found around the calderas.

4. In order to interpret the transportations of pyroclastics as far as 50 km distant from the craters, one must suppose extraordinary and laterally explosive energy whether the material was carried in the air or it was flowed over the earth surface.

These hold good also on Sikotu Caldera as before-mentioned and support, *in the writers' opinion, a theory concerning the origin of caldera formation* of low anomaly type that calderas were formed by both violent ejection of pyroclastic material and the simultaneous subsidence in fragments of the pre-caldera volcanoes. In addition, a geomagnetic survey carried out on the lake affords another information on the subterranean structure of Sikotu Caldera.

Concerning the causes of the formation of Sikotu Caldera, M. Minato *et al.*[3)] already published a theory deduced from precise studies of the various geological data. It must be very useful, the writers suppose, to refer to it with consideration for the before-mentioned geophysical results. Minato *et al.* cite the notable facts as follows: in the culminating eruptions the pyroclastics

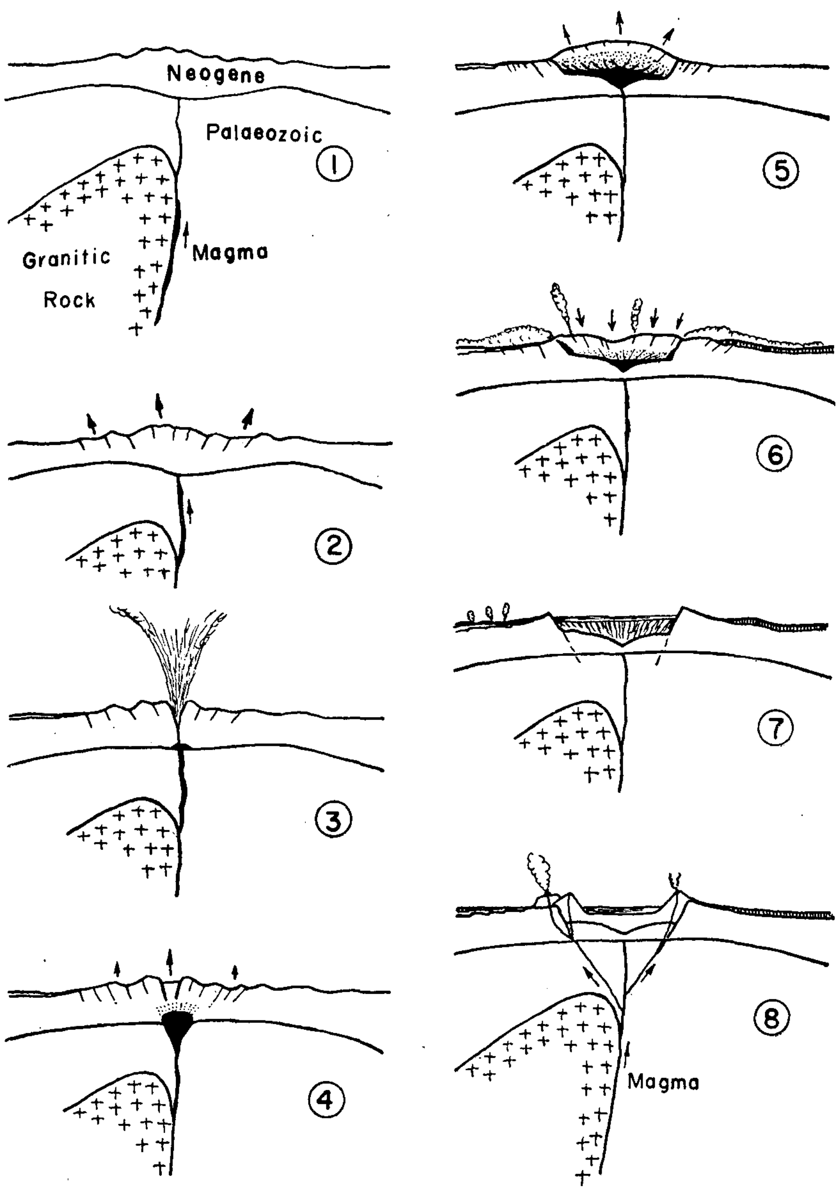

Fig. 16. Sequence of ejections of pyroclastics and of caldera formation at Sikotu Caldera. The figure is reproduced from the paper of M. Minato *et al*[3]. Captions for each figure are given in text.

were not ejected from a single crater or a few fissures in all directions uniformly but from several fissures with lateral velocity in certain directions. In advance of the caldera formation, some upheaving and faulting had occurred on the pre-caldera volcanoes.

Fig. 16 shows the sequence of activities of Sikotu Caldera, originally drawn by Minato *et al.*[3] and schematically reproduced by the present writers. According to the geophysical results, the thickness of Neogene beneath the caldera is about 2 km and the remains of the magma which caused the violent explosions are responsible for the observed positive magnetic anomalies. The section of the caldera bottom needs a minor modification as shown in Fig. 14, in the writers' opinion, *i.e.* the boundary near the rim should be more monotonous.

Captions for Fig. 16 are as follows (the responsibility for the working rests with the present authors):

① and ②: Magma may have came up along the boundary between granitic rocks and palaeozoics. Much water is now expected to have been contained in the overlieing Neogene.

③: Explosions resulting in pumice falls on a large scale occurred when magma reached the aqueous layers of the Neogene.

④: After first explosion, magma was still extending into the Neogene.

⑤: As a result, upheaving of earth surface was accelerated.

⑥: Finally, magma was extruded out from certain fissures caused by unceasingly expansion of magma. The roof of magma chamber was broken into pieces by this violent eruption, which fell back to the bottom.

⑦: The explosion product extruded out by this eruption became partly welded. Secondary fumaroles may have existed on the ejecta around the caldera for a while.

⑧: Volcanoes Eniwa, Huppusi and Tarumai were newly born along the caldera walls.

The above geological explanation for the causes of the formation of Sikotu Caldera proves to be almost supported by the geophysical observations and further, will be quantified also by them.

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References

1) SUZUKI, J. and SHIMOTOMAI, T.: On Volcano Tarumai (in Japanese), Jour. Volcanol. Soc. Japan, I, **1** (1933), 17–43.

2) DOI, S.: Explanatory text of the geological map of Japan, Tarumaizan, 1957, Geological Survey of Hokkaido.

3) MINATO, M., ISHII, J. and KUMANO, S.: A study of the welded tuffs in Japan-On the Shikotsu welded tuff, 2nd Report—(in Japanese), Jour. Geol. Soc. Japan, **65** (1959), 209–221.

4) KATSUI, Y.: On the fossil forest embedded in the Shikotsu pumice fall deposit, Hokkaido (in Japanese), Jour. Geol. Soc. Japan, **65** (1958), 379–385.

5) YOKOYAMA, I.: Volcanic calderas and meteorite craters with the special relation to their gravity anomalies, Jour. Sci. Hokkaido Univ., ser. VII, **2** (1963), 37–47.

6) YOKOYAMA, I.: Gravity survey on Kuttyaro caldera lake, Jour. Phys. Earth, **6** (1958), 75–79.

7) YOKOYAMA, I.: Gravity survey on the Aira caldera, Kyusyu, Japan, Nature, **191** (1961), 966–967.

8) YOKOYAMA, I.: Gravity anomaly on the Aso caldera, Geophysical papers dedicated to Prof. K. Sassa (1963), 687–692.