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FOSSIL ROOTLESS FUMAROLES IN THE NOBORIBETSU PUMICE FLOW DEPOSITS AND THEIR ALTERATION PRODUCTS IN THE NOBORIBETSU FORMATION, KUTTARA VOLCANO, SOUTHWESTERN HOKKAIDO, JAPAN

by

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(with 6 text-figures, and 2 tables)

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Abstract

Many fossil rootless fumaroles are found in the upper unwelded facies of the Noboribetsu Pumice Flow Deposits, which are distributed around the Kuttara Caldera, SW Hokkaido. Rootless crater pits immediately above the fumaroles are filled by pumice, scoria, ash, and mud of the Noboribetsu Formation overlying the Noboribetsu Pumice Flow Deposits. Alteration due to the fumarolic action clearly extends into the Noboribetsu Formation. The origin of the Noboribetsu Formation is suggested to be a base surge deposit based on its distribution and lithological characteristics.

Introduction

The Kuttara Volcano and adjacent area (Fig. 1) is well known from the Kuttara Caldera, the Noboribetsu Pumice Flow Deposits, and active fumaroles such as Mt. Hiyori, Jigoku-dani ("Hell Valley") and Oyu-numa ("Large Hot Water Pool"). Anorthite megacrysts with diameters up to 5 cm have been studied from this area by Ishikawa (1951) and Akiba et al. (1964). Geology of this area has been reported by Suzuki et al. (1943), Saito et al. (1953), Suzuki et al. (1958) and Minato et al. (1972). Saito et al. (1953), among others, established the stratigraphy of the area (Table 1) for the first time based on a detailed study accompanied with a geologic map. Minato et al. (1972)

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described the Noboribetsu sandstone Formation (the Noboribetsu Formation in this paper) is marine sediment and divided it into five members.

The origin of the Noboribetsu Formation is worthy of attention here in that it is a deposit consisting of "sandy to muddy" materials with well-developed bedding while its distribution extends from the vicinity of the

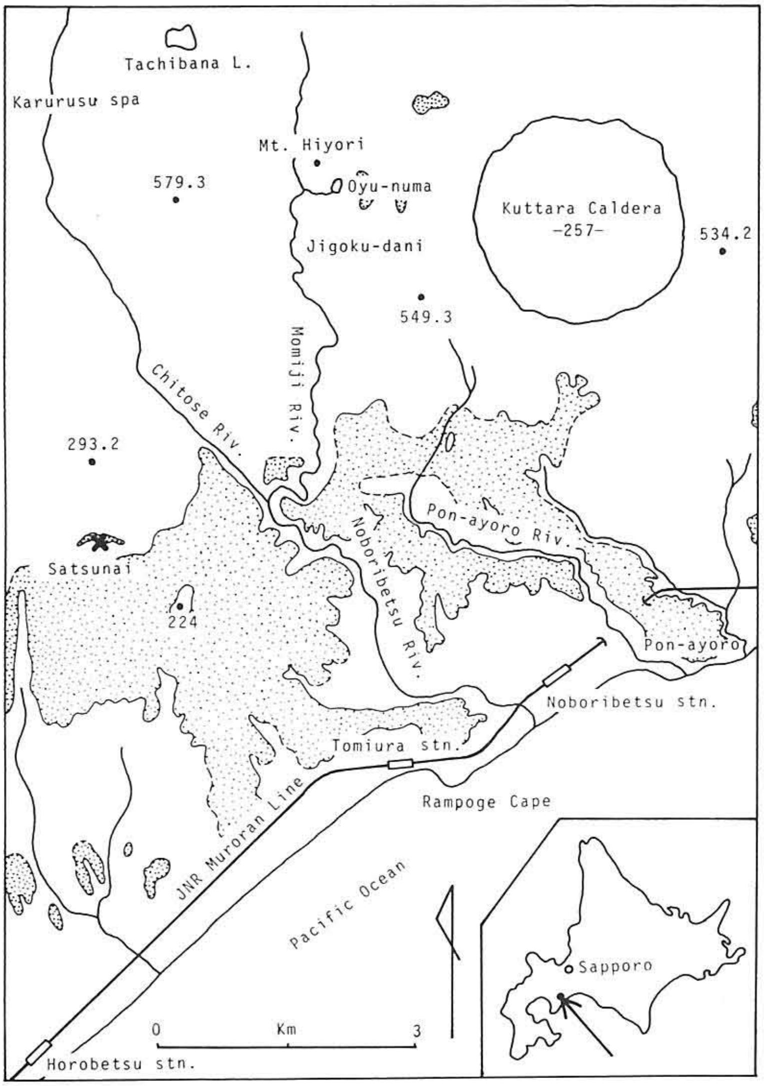

Fig. 1 Location map.
The area of distribution of the Noboribetsu Formation is dotted (Modified from Saito et al., 1953). The location of the fossil rootless fumaroles described in this paper is shown by a cross.

Table 1 Stratigraphic sequence of the Kuttara Volcano area, after Saito et al. (1953). (Noboribetsu Pumice Flow Deposits was originally Noboribetsu Mud Lava in Saito et al.)

Recent		River and shore deposits	
Recent		Talus deposits	
Pleistocene		Lower terrace deposits	Shikotsu Pumice Bed
Pleistocene		Middle terrace deposits	
Pleistocene		Higher terrace deposits	
Pleistocene		Noboribetsu Formation (30m)	
Pleistocene	Kuttara Volcanics	Kojohama Volcanic Detritus Deposits (20m)	
Pleistocene	Kuttara Volcanics	Pon-ayaoro Pumice Deposits (100m)	
Pleistocene	Kuttara Volcanics	Noboribetsu Pumice Flow Deposits (200m)	Tachibana-ike Lava
Pleistocene	Kuttara Volcanics	Rampoge Pumice Deposits (50m)	
Pleistocene		Raiba-yama Lava	Pontoko-yama Lava

caldera, 350m above sea level, down to 40m a.s.l. near the southern seashore (cf, Fig. 1). The distribution and lithofacies of the Noboribetsu Formation suggest that it is not an ordinary sediment as has been implied. While we have long suspected its origin to be a base surge deposit (Moore, 1967), recently we have had a chance to examine its mode of occurrence closely for a survey on the Central Hokkaido Highway construction project. Numerous fossil fumaroles in the unwelded part of the Pumice Flow Deposits and their alteration products in the Noboribetsu Formation were also found in the course of the survey. Fossil fumaroles and their alteration products are reported here. A detailed description of the general geology of the area will be given elsewhere.

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Location of the fossil fumaroles and the geology of the area

Fossil fumaroles are found in a road-cutting (235m a.s.l.) in the Pumice Flow Deposits at Satsunai, 5.8 km to the north of Horobetsu Town, Noboribetsu City (cf. Fig. 1)*. The general topography of the area is a broad, gently southward dipping plateau, 380 to 80m a.s.l., made of the Noboribetsu Pumice Flow Deposits (pyroxene andesitic in composition). The road-cutting has a relative height of 13m and is made across a small hump on the plateau.

* Many fossil fumaroles are also found (not described here) from a road-cutting between this location and 224m-peak, Oyu-numa, and Horobetsu.

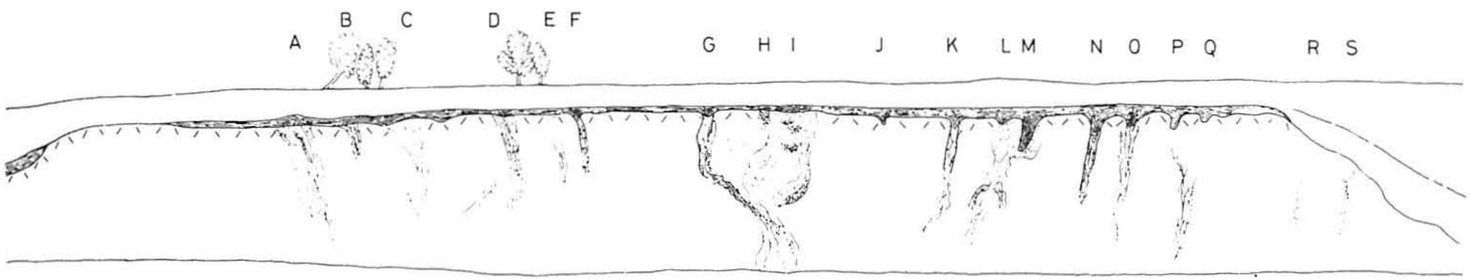

Fig. 2 Sketch of the outcrop shown by a cross in Fig. 1. Showing the mode of occurrence of fossil rootless fumaroles and the overlying Noboribetsu Formation.

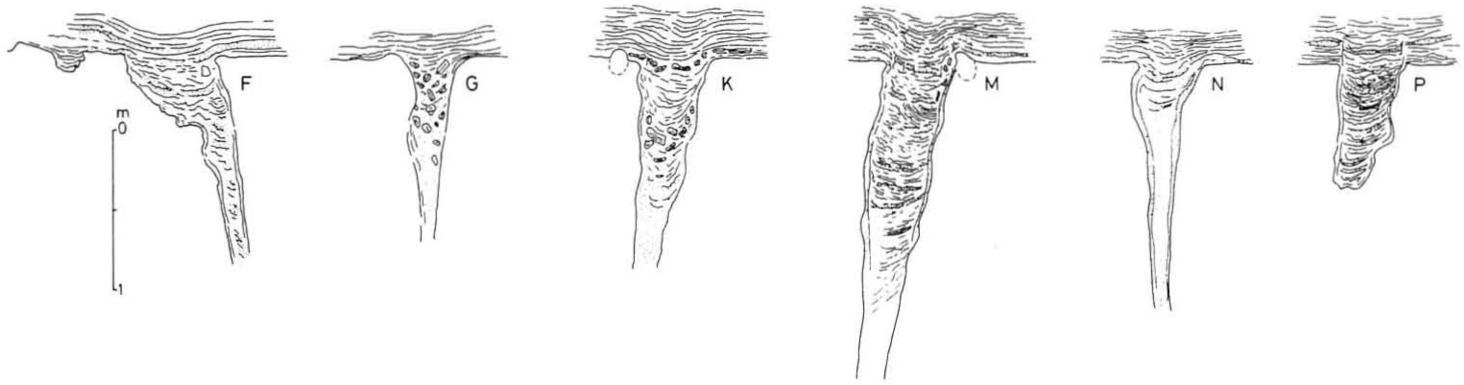

Fig. 3 Detailed sketch of selected crater pits shown in Fig. 2. Note the relation between crater pits and the laminated Noboribetsu Formation.

The thickness of the Noboribetsu Pumice Flow Deposits, which consists here of two cooling units*, as observed on exposures along the Noboribetsu River and Chitose River, is about 80m. Fossil fumaroles occur in the upper unwelded part of the Noboribetsu Pumice Flow Deposits.

A sketch of the road-cutting for a 150m span is shown in Fig. 2. The geology of the exposure in descending order is as follows.

(1) Humus. 10 cm thick.

(2) Brown loam. 15 cm thick.

(3) Usu-b air-fall pumice bed (350 to 500 Y.B.P. according to Oba & Kondo, 1965). Maximum grain-size 3 cm, and thickness 15 cm.

(4) Humus. 30 cm thick.

(5) Brown loam and pumice bed. 1 to 6m thick.

The thickness is generally about 1m but is thicker where the underlying Noboribetsu Formation and the Pumice Flow Deposits are erroded away. An unconformable relation is clearly shown (e.g., both at the left and right edges of the sketch in Fig. 2). Charred wood and pine cones occur in the lower half of the loam. Yellow pumice bed (Maximum thickness 15 cm: Maximum and average grain-sizes 5 cm and 5 mm, respectively) occurs at the base. ((1) to (5) above are not shown in Fig. 2).

(6) Noboribetsu Formation. thickness 0 to 1m.

The lower half is relatively massive while the upper half is well laminated and consists of pale brown, brown, and yellow sand-sized pumice, scoria and ash with a few mud layers intercalating within them. The mode of occurrence of the Noboribetsu Formation is conformable with the delicately undulating upper surface of the underlying pumice flow deposits suggesting no depositional hiatus. As will be described in the later section, materials derived from the Noboribetsu Formation occur in small depressions (rootless crater pits) immediately above the rootless fossil fumaroles which occur in the underlying Noboribetsu Pumice Flow Deposits.

(7) Pumice Flow Deposits

These are unwelded, grey to pale pinkish in color, neither stratified nor sorted. Maximum grain-size of the pumice is about 20 cm. Numerous fossil rootless fumaroles occur. Welded facies occur at an exposure on a river-bed 9m below from the left edge of the road-cutting shown in Fig. 2.

Saito et al. (1953) mapped the unwelded pumice flow deposit and the welded facies of this locality as separate units and correlated them to the Pon-ayoro Pumice Deposits and the Noboribetsu Pumice Flow Deposits,

* No less than three cooling units have been observed in the Noboribetsu Pumice Flow Deposits taking into consideration the observation made elsewhere.

respectively (cf. Table 1). Although a direct relationship between the welded and unwelded facies at this locality is not observable, there remains no doubt according to our observation on many outcrops around this locality that they belong to one and the same pumice flow.

Description of the fossil fumaroles and their relation to the Noboribetsu Formation

Approximately twenty fossil fumaroles are observed in the unwelded pumice flow deposit along the road-cutting. They invariably show reddish brown, white or black colors around fumaroles due to oxidation or solfataric alterations. The degree of alteration varies from place to place. However, around the largest fumaroles observed in this study (Fig. 2, G to I), a sequence of alteration from (deep) reddish brown, to brown, black, yellow, white, and purple in this order is recognized from the center of the fumaroles to the margin (cf. Figs. 4 and 5). Alteration clearly extends into the overlying Noboribetsu Formation, cross-cutting the lamination of the latter.

Immediately above the majority of fossil fumaroles the rootless crater pits have developed, the dimensions of which are up to 50 cm across and 2m deep. Materials derived from the Noboribetsu Formation have filled the pits (Figs. 2 and 3). Lamination of the Noboribetsu Formation immediately above the fumaroles indicate downward warping or faulting and downthrowing at the edge of the pits. Altered blocks derived from the Noboribetsu Formation are also found at the bottom of the pits.

The above observations suggest that 1) the pits were formed by an active fumarolic action, 2) while the fumaroles were active the deposition of the Noboribetsu Formation started, 3) the Noboribetsu Formation above the pits collapsed under its own weight into the pits and 4) the Noboribetsu Formation adjacent to, and in the fumaroles was altered by continuing fumarolic activities.

Fossil fumaroles G to I in Fig. 4 have somewhat higher egresses than adjacent ones. This may be related to the larger sizes of these fumaroles than others.

Alteration products in the vicinity of the rootless fumaroles

Samples of unaltered and altered parts of the Pumice Flow Deposits and the Noboribetsu Formation are examined by the X-ray diffraction (Table 2). For sample localities refer to Fig. 4.

Unaltered parts of the Pumice Flow Deposits (sample 25)

Pumice is weathered and clay fraction smaller than 2μ consists of hydrated halloysite. Matrix also is mostly comprized hydrated halloysite. No kaolinite is identified.

Altered parts of the Pumice Flow Deposits

(Deep) reddish brown colored parts (samples 7 and 7')

The samples were collected from a branching part of the rootless fumarolic vent. A little amount of hydrated halloysite with minor kaolinite and alunite is identified. Formation of clayey materials is not so advanced as in black (samples 1 to 5), white (2, 4, 6, 9 and 13), brown to dark brown (8), and reddish brown (10) colored parts. The latters are described in the following sections. Oxide and hydrooxide of iron which might be responsible for red color are not identified.

Fig. 4 Photograph of the fumaroles G, H, and I shown in Fig. 2.

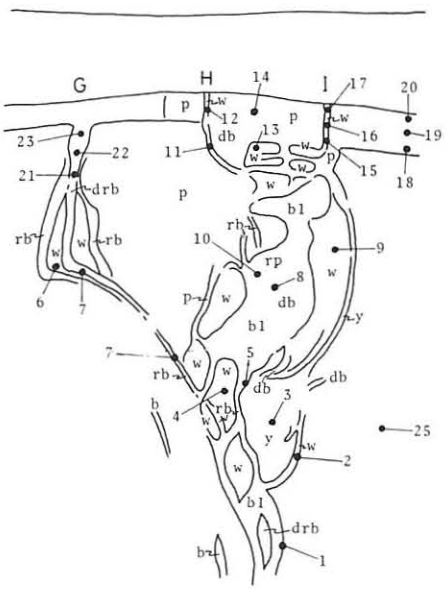

Fig. 5 Color distribution around the fumaroles G, H, and I, as observed in the field. Numbers show sample localities.

b; brown	bl; black
p; purple	w; white
y; yellow	d; deep
r; reddish	

Table 2 List of alteration products

	Samp. No.	Field color of the altered part	color classification* hue	color classification* value	pH	clay minerals: hydrated hall.	clay minerals: kaolinite	clay minerals: 14Å clay min.	clay minerals: montmori.**	alunite	gibbsite
Noboribetsu Pumice Flow Deposits	25	(unaltered)	5 YR	5/4	5.0	+++++***					
	7	(deep) red.brown	7.5 R	4/8	4.5	++	+			+	
	7'		10 R	5/8	5.0	++					
	10	reddish purple	2.5 Y	7/1	5.0	++++	+			+	
	8	brown-dark brown	7.5 YR	5/6	4.5	++++					
	11		7.5 YR	8/1	5.0	++++	+++			++	
	1	black	N	5/0	6.5	+++	++			+	
	5		N	6/0	6.5	+++	+++			+	
	3	yellow	7.5 YR	7/4	4.5	+++++	+			+	
	2	white	2.5 Y	8/2	5.0	+++++	+				
	4		2.5 Y	7/1	6.0	++++	+			+++	
	6		2.5 Y	8/2	4.5	+++++	+			++	
	9		2.5 Y	8/1	5.0	+++++	+			++	
	13		5 YR	8/2	5.0	++	++				++
Noboribetsu Formation	20	(unaltered)	10 YR	4/3	5.0		+	++	+		
	19		2.5 Y	4/2	5.0		+	++	+		
	18		5 YR	3/3	5.0	+		+			
	23	brown	7.5 YR	4/6	4.5	++		+			++
	22		7.5 YR	4/6	4.5	++		+			++
	21		7.5 YR	5/6	4.5	+++				++	
	14	purple	10 R	4/8	4.5	++	+				
	12	white	5 YR	7/2	5.0	++	+++			+++	+
	17		5 YR	8/4	5.0	++	+			++	++++
	16		7.5 YR	7/3	5.0	++	+			++	+++
	15		5 YR	7/3	5.0	++	++			++	++

* Color classification after Oyama & Takehara (1973). ** The occurrence of montmorillonite is shown in this column when positively identified among 14Å clay minerals. *** Relative abundance of alteration minerals is estimated on the averaged X-ray intensities obtained for the three fractions of the same material: i.e., bulk sample, suspended materials, and clay fraction ($<2\mu$). Peaks used include basal reflections (001) of hydrated halloysite, kaolinite, 14Å clay minerals and montmorillonite (shifted peak), (113) of alunite, and (110) of gibbsite.

+++++ peak intensity > 40; ++++ 40> peak intensity > 25; +++ 25> peak intensity > 15; ++ 15> peak intensity > 5; + 5> peak intensity

Reddish purple colored parts (sample 10)

The sample was collected from the middle of the main branch of the fumarolic vent. It contains abundant hydrated halloysite with minor kaolinite clearly showing an advanced stage of clay formation as compared to unaltered sample. Alunite is also found.

Brown to dark brown colored parts (samples 8 and 11)

Sample 8 is from the vicinity of the middle part of the main fumarolic vent whereas sample 11 is from the top of the vent. Sample 8 consists soloy of hydrated halloysite and is similar to the samples from unaltered Pumice Flow Deposits. Sample 11 contains a large amount of kaolinite and alunite in addition to hydrated halloysite.

Black colored parts (samples 1 to 5)

The samples are from the roots of the main fumarolic vent (sample 1) or from a major branch (5). They consist of hydrated halloysite, kaolinite and alunite. Sulphide minerals expected from the color are not found.

Yellow colored parts (sample 3)

This was collected from a branch of the main fumarolic vent and consists of abundant hydrated halloysite, kaolinite and alunite.

White colored parts (samples 2, 4, 6, 9 and 13)

Most of the altered parts show white color. The examined samples contain copious hydrated halloysite with ubiquitous but small amount of kaolinite showing an advanced stage of clay formation. Some samples have an amount of alunite (e.g., samples 4, 6 and 9) or gibbsite (sample 13).

Unaltered parts of the Noboribetsu Formation (samples 18, 19 and 20)

Hydrated halloysite is recognized in a small amount only at the lowest horizon. Minor kaolinite and montmorillonite are identified in samples 19 and 20. 14Å clay minerals are also identified in clay fraction and in bulk samples. Alunite and gibbsite which are widespread in altered parts of the Pumice Flow Deposits are not found.

Altered parts of the Noboribetsu Formation

Fragments of the Noboribetsu Formation occuring in rootless crater pits (samples 21, 22 and 23)

Hydrated halloysite and 14Å clay minerals are found (samples 22 and 23), but they are less abundant as compared with those in the Pumice Flow

Deposits. No kaolinite is found. Gibbsite occurs in samples 22 and 23 collected from the upper parts of the pits while alunite is identified in sample 21 collected from the bottom.

Purple colored parts (sample 14)

The sample is collected from the upper part of the fumarolic vent sandwiched between white veins. Hydrated halloysite and kaolinite are identified while 14Å clay minerals, alunite and gibbsite are not.

White colored parts (samples 12, 15, 16 and 17)

The samples are from veins at the uppermost parts of the fumarolic vents. Hydrated halloysite, kaolinite, alunite and gibbsite are found in all samples, although hydrated halloysite is not abundant. Gibbsite tends to increase towards the upper parts while kaolinite tends to decrease. No 14Å clay minerals are found.

As is clearly shown in the above, hydrated halloysite, alunite, and gibbsite are identified as alteration products of the Noboribetsu Formation due to the fumarolic activities. As the fumarolic activities are originated from the Noboribetsu Pumice Flow Deposits, the Noboribetsu Formation and the Noboribetsu Pumice Flow Deposits can not be separated by a large hiatus as has been interpreted.

Lithofacies and sedimentary structures of the Noboribetsu Formation

A generallized description of the lithofacies of the Noboribetsu Formation is given here.

As far as materials occurring on the plateau are concerned, the Noboribetsu Formation consists mainly of scoria and ash, and occasional pumice intercalated with rare and thin mud, but not of sand or mud as is expected in ordinary water-laid sediments. The thickness as well as the maximum grain-size of the constituent materials tend to decrease from Kuttara Lake (thickness 7m+, grain-size 30 to 5 mm) to places away from the Lake (e.g., at a place shown on the western margin of Fig. 1, 6 km away from Kuttara Lake, the thickness is 1 to 3m and grain-size is 1 mm). Accretionary lapilli (max. grain-size 1 cm) are found near the base of the Noboribetsu Formation in many places. Mud cracks are also found on thin intercalating layers of mud of fine-grained scoria beds in some outcrops.

Occurrence of cross lamination and other dune-like structures are known to characterize base surge deposits. In most cases bedding and lamination of the

Noboribetsu Formation are parallel to each other and are conformable to the delicately undulating surface of the underlying strata. However, cross lamination with a scale of a few meters does exist near Kuttara Lake (observation on a road-cutting between Kuttara Lake and Oyu-numa*) and therefore the origin of the Noboribetsu Formation can not be explained by an air-fall deposit. Sketches of the lamination in the Noboribetsu Formation immediately above the Pumice Flow Deposits at the locality marked by a cross in Fig. 2 is shown

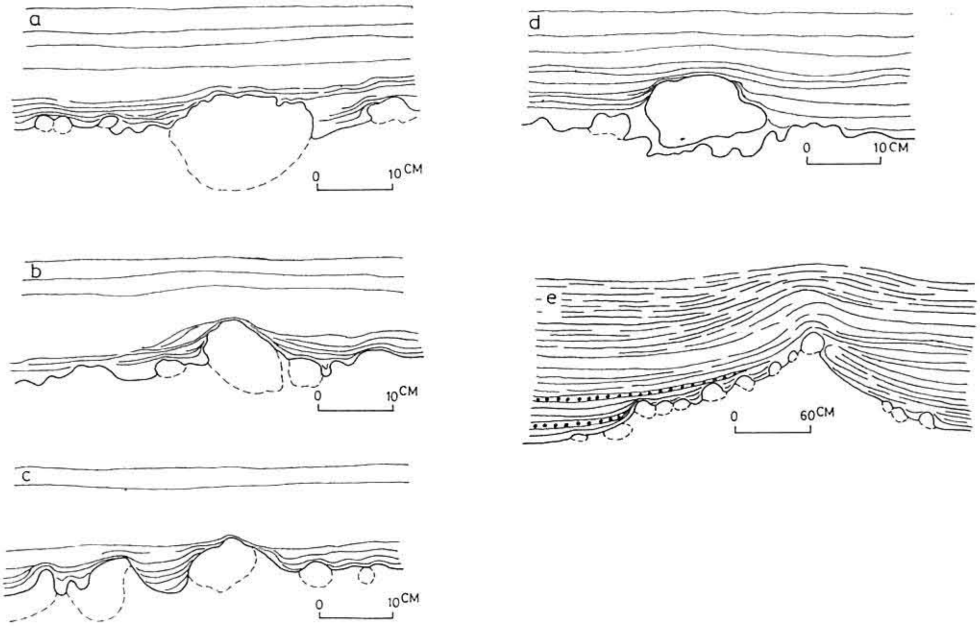

Fig. 6 Lamination at the base of the Noboribetsu Formation.

in Fig. 6. It is clear that the Noboribetsu Formation is not an air-fall deposit under 'windless' conditions. Some pumice particles seem to start to detach from their matrix as if they were windbrown. The shape of the cross lamination seems to suggest the direction from which the base surge deposits were transported. Further studies, however, are necessary.

To conclude, the distribution, lithofacies, development of cross lamination, and the characteristic shape of cross lamination at the base of the Noboribetsu Formation are all indicative of a base surge origin rather than water-laid or air-fall origins.

* "Sandstone dikes" occur at this locality. Similar "dikes" cutting the Noboribetsu Formation are numerous elsewhere.

Discussion

Life span of rootless fumaroles

For the 1912 eruption of the Katmai Volcano, Fenner in 1920 stated that this area is still the site of many fumaroles. For the 1956 eruption of the Bezymianny Volcano, Gorshkov (1959, p.95–96) reports that "by summer, fumarolic activity considerably weakened, however, thousands of steam jets still rose from the flows. . . . the maximum temperature of fumarolic gasses was 200°, predominant was the temperature 100° . . . reserves of heat in the agglomerate mass of the flow is still sufficiently great and there is reason to hope that the fumarolic and explosions phenomena . . . will last for a long time." Macdonald (1972, p.327) in quoting the above, writes "some last only a few hours or days and none last more than a few decades".

If the life span reported in the literature for the rootless fumarolic activities is applicable to the present case, the time between the successive deposition of the Pumice Flow Deposits and the Noboribetsu Formation is geologically nil and both would be interpreted to be conformable.

The stratigraphic position of the Pon-ayoro Pumice Deposits

It has generally been believed that the caldera was formed following the deposition of the Noboribetsu Pumice Flow Deposits. However, as the Noboribetsu Pumice Flow Deposits and the Noboribetsu Formation are conformable without geologic hiatus, as described in the foregoing sections, it is hard to place the formation of the caldera between the deposition of these two.

According to our observation, Kojohama Volcanic Detritus Deposits at least does not exist as a constituent of the main body of the volcano. Therefore, the stratigraphic position of the Pon-ayoro Pumice Deposits becomes a focal point to solve this enigma. The nature and stratigraphic position of the Pon-ayoro Pumice Deposits remain to be solved.

The origin of water in relation to base surge

Base surge is generally believed to be characteristic of magmato-phreatic eruption in which the role of water is essential as is known, for example, in the case of the Taal Volcano (Moore et al. 1966.; Nakamura, 1966.; Moore, 1967). If the Noboribetsu Formation has an origin as a base surge deposit, where does the water necessory to form a base surge come from? Is it water stored in the caldera or an unusual amount of ground water? If it is water stored in the caldera, how was such an amount of water stored in the caldera in so short a span of time corresponding to the active life of rootless fumaroles?

References

Akiba, C., Hariya, Y., Watanabe, J. and Onuma, K., 1964. Form and internal texture of anorthite megacrysts from Kuttara Volcano, Hokkaido. *Jour. Mining and Metallurgical Inst. Japan*, 80(915): 726-727. (in Japanese).

Fenner, C.N., 1920. The Katmai region, Alaska, and the great eruption of 1912. *Jour. Geol.*, 28(7): 569-606.

Gorshkov, G.S., 1959. Gigantic eruption of Volcano Bezymianny. *Bull. Volcan.*, Ser. II, 20: 77-109.

Ishikawa, T., 1951. Petrological significance of large anorthite crystals included in some pyroxene andesites and basalts in Japan. *Jour. Fac. Sci. Hokkaido Univ.*, Ser. IV, 7(4): 339-354.

Macdonald, G.A., 1972. *Volcanoes*. Prentice-Hall, New Jersey, 510pp.

Minato, M., Hashimoto, S., Fujiwara, Y., Kumano, S. and Okada, S., 1972. Stratigraphy of the Quaternary ash and pumiceous products in southwestern Hokkaido, N. Japan. *Jour. Fac. Sci. Hokkaido Univ.*, Ser. IV, 15(3-4): 679-736.

Moore, J.G., Nakamura, K. and Alcaraz, A., 1966. The 1965 eruption of Taal Volcano. *Science*, 151(3713): 955-960.

——, 1967. Base surge in recent volcanic eruptions. *Bull. Volcan.*, Ser. II, 30: 337-363.

Nakamura, K., 1966. The magmatophreatic eruption of Taal Volcano in 1965, Philippines. *Jour. Geogr.*, 75(2): 33-44. (in Japanese with English abstract).

Oba, Y. and Kondo, Y., 1965. Pumice-fall deposits of Usu Volcano, Hokkaido. *Bull. Volcan. Soc. Japan*, Ser. II, 9(2-3): 75-86. (in Japanese with English abstract).

Oyama, M. and Takahara, H., 1973. *Revised standard soil color charts*. Fujihira-Kogyo Co., Tokyo, 13pp. (in Japanese with English abstract).

Saito, M., Osanai, H. and Sako, S., 1953. Noboribetsu Onsen. 1:50,000 Geological map of Japan and explanatory text. *Geological Survey Hokkaido*, 84pp. (in Japanese with English abstract).

Suzuki, J., Ishikawa, T. and Ishibashi, M., 1943. Noboribetsu Onsen and Kuttara Lake. Guide book for excursion. No. 2, *Dept. of Geol. and Min., Hokkaido Imp. Univ.*, 16pp. (in Japanese).

——, ————, Suzuki, Y. and Katsui, Y., 1958. Report of Geological Study Group. Noboribetsu Onsen, *Report of Hot Spring Survey*, No. 15, ed. Environmental Sanitation Section, Public Health Service Department, Hokkaido Provincial Government. 35-50. (in Japanese).

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