PUMICE FLOW DEPOSITS OF THE TOWADA CALDERA AT THE VICINITY OF KOSAKA TOWN, AKITA PREFECTURE, JAPAN*

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INTRODUCTION

Geological surveys around some Krakatoan calderas in Japan have recently been carried out, and it was clarified that gigantic Krakatoan calderas issued several to decade pyroclastic flows among which pyroclastic falls, lake deposits and fossil soils are intercalated (KUNO, 1962; KATSUI and SATOH, 1963). Calderas in Japan have already been classified into the Krakatoan and the Glencoe types by KUNO (1953) who accounted for the fact that in the calderas of the Krakatoan type the post caldera lavas comprise a rock series formed through contamination of the same magma. Apart from KUNO's view of "evolution of lavas", KATSUI (1963) studied the calderas of the Krakatoan type aiming at the evolution and magmatic history of pyroclastic materials. In the present paper, magmatic evolution and its time range of the Towada caldera, one of the representative Krakatoan calderas in Japan, are considered.

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BRIEF HISTORY OF THE TOWADA VOLCANO

The geology of the Towada volcano near the northeastern extremity of Honshu, Japan, has already been studied by TOMITA (1930), KINOSHITA (1931), KAWANO (1939), KUNO (1953), YAGI (1962) and KUNO et al. (1964). The last authors investigated the eruptive and emplacement mechanism by sorting of the pumices

and lithic fragments of pyroclastic flows and falls of the Towada caldera. According to above studies, history of the Towada volcano is summarized as follows.

The activity of the Towada volcano which started in younger Pleistocene in a Miocene volcanic rock area is divided into following three stages.

The first stage of the activity was an eruption of lava and pyroclastic materials of pyroxene andesites and then the older stratovolcano was built up. At the end of this stage, a tremendous amount of pumice, in the form of pumice flows, estimated at about 45 km^3 in volume by ISHIKAWA et al. (1957), was repeatedly erupted from the center of the cone and covered an extensive area, making a wide and gently sloping plateau around the volcano. Consequently, the central part of the stratovolcano collapsed and the outer first stage caldera which is now under consideration in the present paper was formed. The diameter of the caldera is found to be about 10 km.

The second stage of the activity started with building of a pyroxene andesitic strato-volcano in the southeastern part of the outer caldera. At the end of this stage, pyroxene andesitic pumice was ejected in the form of pumice falls from the central crater of the new cone, resulting in the formation of the inner second stage caldera, 2.5 km across.

The third stage of the activity was the formation of two domes of pyroxene dacite lava at the central portion of the outer first stage caldera.

GEOLOGY AT THE VICINITY OF KOSAKA TOWN

At the vicinity of Kosaka town, situated at 20 km southwest of the center of the Towada caldera, the pumice flow deposits related to the first stage caldera formation are extensively distributed. Geological sequence and map of this area are shown in Table 1 and Fig. 1.

The basement rocks of this area are Miocene rhyolites including Kuroko-type ore deposits.

Kosaka welded tuffs, extending to Hanawa city, about 25 km south of this area, are composed at least of two cooling units. The lower unit is hornblende-biotite-bearing augite-hypersthene dacitic tuff and the upper is augite-hypersthene dacitic tuff. The lower

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Table 1. Geological sequence at Kosaka Town

Formation		Note
Holocene	Pumice fall deposit a	Hakkoda-a (MATSUNO, 1961) 2,000 yrs B.P.
	Pumice fall deposit b	Hakkoda-b (MATSUNO, 1961) 7,500 yrs B.P.
Pleistocene	Upper Kosaka pumice flow deposit	10,400±200 yrs B.P., (Gak-460)
	Middle Kosaka pumice flow deposit	12,000±250 yrs B.P., (Gak-385)
	Lower Kosaka pumice flow deposit	33,000+ yrs B.P., (Gak-384)
	Kosaka welded tuffs	
Miocene	Rhyolites

Fig. 1. Geological map at the vicinity of Kosaka Town

1. Upper Kosaka pumice flow deposit
2. Middle Kosaka pumice flow deposit
3. Gravel
4. Lower Kosaka pumice flow deposit
5. Kosaka welded tuffs
6. Sample localities. L and M are Loc. 12 and U is Loc. 17 in Fig. 2.

unit is 20 m in thickness and the upper is 15 m.

Kosaka pumice flow deposits, related to the outer first stage caldera formation, rest on the above mentioned

welded tuffs. In the type locality, a cliff of the left bank of the Kosaka river, the deposits consist of the lower, the middle and the upper pumice flows. The lower pumice flow deposit shows light pinkish colour and includes pumice lumps, the maximum diameter of which is 2—3 cm. Pumice lumps of the middle pumice flow deposit are white in colour and are 5—10 cm in diameter. Pumice lumps of the upper pumice flow deposit are grey in colour and very large in size and so great in proportion that they contact with one another. Mafic minerals included in every pumice are hypersthene, augite and iron ore. Each of the three pumice flow deposits is underlain by a gravel bed. On the top of each gravel bed there are peat layers.

Pumice fall deposits such as Hakkoda-b and -a, dates of which are inferred to be about 7,500 and 2,000 years B. P. respectively, are those defined by MATSUNO (1961).

CHARACTERISTICS OF THE KOSAKA PUMICE FLOW DEPOSITS

Regarding the three pumice flow deposits above mentioned, chemical analyses of pumices, ^{14}C datings on charcoal and peats and pollen analyses on peats were carried out. The samples were taken from the localities shown in Fig. 2, where the succession of the pumice flows was quite distinct.

Chemical analyses of the pumices are shown in Table 2 with previous three analyses of similar pumices also related to the Towada first stage caldera formation.

The results of ^{14}C datings are as follows.

33,000+years B. P. (GaK-384) Peat, underlying the lower pumice flow deposit

12,000±250 years B. P. (GaK-385) Wood, in peat underlying the middle pumice flow deposit

10,400±200 years B. P. (GaK-460) Charcoal, included in the upper pumice flow deposit

Fig. 2. Columnar sections showing relations among samples.
Symbols same as in Fig. 1.

Fig. 3. Diagram showing change in chemical composition and dates of eruption
L, M and U correspond to 1, 2 and 3 in Table 2.
Other numbers are shown in the same table.

Fig. 4. Change in chemical composition of the Matsuyama welded tuff (after MATSUMOTO et al., 1964)
1. 5 m above the base
2. 7 m above the base
3 and 4. higher than 7 m above the base

Table 2 Chemical composition of pumices of the Towada caldera

	1	2	3	4	5	6
SiO ₂	73.76	69.21	68.20	69.73	70.40	68.47
TiO ₂	0.07	0.53	0.42	0.39	0.58	0.69
Al ₂ O ₃	13.89	15.13	15.75	13.59	13.93	15.14
Fe ₂ O ₃	1.08	1.95	1.65	1.14	0.91	1.26
FeO	0.34	1.61	1.85	1.36	1.67	1.68
MnO	0.12	0.11	0.11	0.08	0.12	0.10
MgO	0.14	0.96	1.07	0.64	0.62	0.73
CaO	0.37	3.80	4.14	2.81	3.15	3.89
Na ₂ O	3.11	2.68	2.53	4.13	4.35	4.28
K ₂ O	1.78	0.44	0.37	1.20	0.97	0.92
P ₂ O ₅	0.02	0.10	0.13	0.21	0.20	0.12
H ₂ O ⁺	4.35	2.74	2.78	4.16	2.63	2.31
H ₂ O ⁻	0.56	0.29	0.30	0.97	0.19	0.05
Total	99.59	99.55	99.30	100.41	99.72	99.64

1. The lower Kosaka pumice flow deposit. Anal. ABE.
2. The middle Kosaka pumice flow deposit. Anal. ABE.
3. The upper Kosaka pumice flow deposit. Anal. ABE.
4. The pumice flow deposit at a road cut near Aobuna-tôge. Anal. KAWANO (KAWANO, 1939).
5. The pumice flow deposit S to Ezohune. Anal. YAGI (YAGI, 1962).
6. The pumice flow deposit at Sawaguti Anal. YAGI (YAGI, 1962).

Previously, two ¹⁴C datings of charcoal in the pumice flow deposit related to the Towada first stage caldera formation were reported. One performed in connection with chemical analyses 5 and 6 in Table 2 shows about 18,000 years B. P. (YAGI, 1962), and the other, of the Hachinohe pumice bed, 40 km east of the Towada caldera, shows 12,700±270 years B. P. (OIKE, 1964).

Chemical compositions in Table 2, though they are

various for pumices related to the same caldera, show the characteristics of the Nasu volcanic zone; a higher *qz* and (*al-alk*) in relation to *si*, and also a higher *mg* to *k* in Niggli's value (ISHIKAWA and KATSUI, 1959). As shown in Fig. 3, it is clear that there is a regular relationship between the chemical compositions of the pumices and the dates of eruption.

Similarly, the successive change in chemical composition in a reverse order to that of the normal differentiation of magma was already shown in the case of the Mashû and the Shikotsu calderas where the change in chemical composition is thought to have a connection with the change of the eruptive type from pumice fall to flow (KATSUI, 1963). Furthermore, in the Crater Lake caldera, the chemical composition changes from dacitic to basic (WILLIAMS, 1942). It is considered that similar successive change in chemical composition is usually observed in some pyroclastic flow deposits. Bandelier ash flows record a change from early high-silica rhyolites to quartz latites at the end of the last ash flow cycle (SMITH, 1960). Recently, MATSUMOTO et al. (1964) reported four chemical analyses of samples from Matsuyama welded tuff of Miocene age, which were taken from the levels of 5 m and 7 m above the base, and the other two higher levels. As shown in Fig. 4, the similar succession to Fig. 3, though they are close to Na₂O+K₂O corner, is distinct. That is, in the continuous rock body of Matsuyama welded tuff, successive change in chemical composition is shown in a reverse order of normal differentiation of magma. It is probable that Matsuyama welded tuff would be composed of *multiple-flow cooling unit* (SMITH, 1960) consisting of several flow units of different chemical compositions.

Although date of the lower Kosaka pumice flow deposit is known only as 33,000+ years B. P., the present writer wishes to give a more detailed consideration of

Fig. 5. Presumption of date of the lower Kosaka pumice flow by extrapolation of colour index and S. I. value

Fig. 6. Pollenanalytical results of peats underlying the lower (Column 1), the middle (Column 2) and the upper (Column 3) Kosaka pumice flow deposits

his own on this problem. In Fig. 5, the abscissa shows absolute date and the ordinate colour index and S. I. value, $100 \times \text{MgO}/\text{MgO} + \text{FeO} + \text{Fe}_2\text{O}_3 + \text{Na}_2\text{O} + \text{K}_2\text{O}$, as defined by KUNO et al. (1957). From Fig. 5, the date of eruption of the lower Kosaka pumice flow deposit is presumed to be about 40,000 years B. P. which corresponds to the Götweigerian subinterglacial of the Würmian stage. Pollen analyses of peats are shown in Fig. 6. In columns 2 and 3, main constituents are needle-leaved trees indicating the glacial age, but in column 1, needle-leaved trees mingle with broad-leaved trees. The above fact means that the temperature indicated by column 1 must be warmer than those by columns 2 and 3; it is consistent with the presumption that the date of eruption of the lower Kosaka pumice flow deposit may be about 40,000 years B. P. According to these facts, the start of the eruption of the first stage pumice flow of the Towada volcano is thought to date back to at least 40,000 years B. P.

FORMATION OF KRAKATOAN CALDERA AND PYROCLASTIC FLOWS

Generally, many a gigantic Krakatoan caldera erupts

numerous pyroclastic flows for a long time. The second stage caldera of the Hakone volcano issued eleven successive flow units (KUNO, 1962) and the Kutcharo caldera half score pyroclastic flows (KATSUI and SATOH, 1963). As gravel and fossil soils are intercalated among them, reasonable time gap is considered. In the Kutcharo caldera, pumice fall deposits are so numerous that eruptive type is considered to be more complicated. The Towada volcano formed the first stage caldera after issuing at least three pumice flows for about 30,000 years following the formation of the strato-volcano. It is of interest to consider the mechanism on the formation of Krakatoan caldera especially as to whether the formerly existed cone collapsed in every pumice flow eruption time little by little or all at once after the eruption of the last pumice flow.

In the case of the Towada volcano the change in chemical composition of pumices was achieved without any change of eruptive type, unlike the Mashû and the Shikotsu calderas where change in chemical composition of pumices also in eruptive type were observed at the same time. The both cases above mentioned contrast with the activity of the Asama volcano in 1783 (ARAMAKI, 1956 and 1957) where there was no change in chemical composition of volcanic products though there was a

noticeable change of eruptive type.

Although no pumice fall deposit is intercalated among three pumice flow deposits at the vicinity of Kosaka town, deposits of pumice falls like ash falls in Alluvium in Japan are presumed to be distributed in some area east of the Towada caldera. The Towada caldera is an adequate field for research on Krakatoan caldera and from this reason, the study of this caldera needs to be promoted in future.

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秋田県小坂付近における十和田カルデラの軽石流堆積物

佐藤 博之

(要 旨)

秋田県小坂付近には、十和田カルデラ第1期の活動に由来する軽石流堆積物が広く分布する。これらの軽石流堆積物は礫層によつてへだてられる3層からなり、礫層の最上部すなわち軽石流堆積物の直下には泥炭が存在する。 ^{14}C 年代決定・軽石の化学分析・泥炭の花粉分析が行なわれ、軽石流の噴出年代と化学組成との間に規則的な関連があることが明らかになった。 ^{14}C 年代決定の結果は、下位から 33,000 ± 年 B. P., 12,000 ± 250 年

B. P., 10,400 ± 200 年 B. P. である。

一般に巨大なクラカトア型カルデラは、数回の火山碎屑流の噴出を長期にわたつておこなうものが多い。十和田火山は成層火山の形成後に、約 30,000 年にわたつて少なくとも3回の軽石流を噴出して陥没したものと考えられる。陥没がそのつど行なわれたか、最後に一時に行なわれたかは興味ある問題である。

地	名
Asama.....	浅 間
Hachinohe.....	八 戸
Hakkoda.....	八甲田
Hakone.....	箱 根
Hanawa.....	花 輪
Kosaka.....	小 坂
Kutcharo.....	屈斜路
Mashu.....	摩 周
Matsuyama.....	松 山
Nasu.....	那 須
Shikotsu.....	支 笏
Towada.....	十和田

Appendix

Since this manuscript was submitted, two papers as follows were published.

KIGOSHI, K. and KOBAYASHI, H. (1965), Gakushuin natural radiocarbon measurements IV. *Radiocarbon*, vol. 7, p. 10—23.

OKAZAKI, Y. and SATOH, H. (1965), Pollen analysis and dates of the upper Pleistocene deposits near Towada caldera, Akita prefecture. *The Quaternary Research*, vol. 4, p. 162—171 (in Japanese)

^{14}C datings considered in the present paper are originally described in the former, and in the latter paleoclimate shown by Fig. 6 of this paper is discussed in detail.