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Geological Study of Matsukawa Geothermal Area, Northeast Japan

By

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Introduction

Along the Backbone Ranges of Northeast Japan, there are some volcanic regions consisting of Quaternary volcanoes. Among them, Hachimantai National Park is one of the famous volcani cregions in Japan and it occupies the area extending over 1000km^2 along the boundary of Iwate and Akita prefectures. In this region, twelve fumarolic and hotspring areas are distributed.

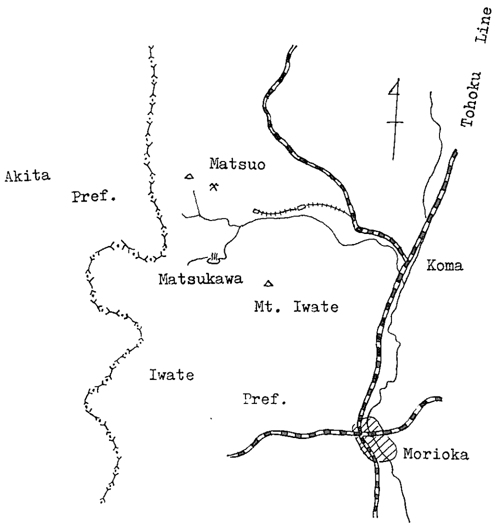

Fig. 1 Index map showing the location of Matsukawa area

The Matsukawa geothermal area is located in the southeastern corner of Hachimantai volcanic region and on the northeastern foot of Mt. Iwate, an active volcano. It is about 50km far from Morioka and it takes one and a half hour by car. (Fig. 1)

Formerly, Matsukawa was a small resort area, but fifteen years ago, drilling was made by village office to get thermal water for bathing. It is interesting to say that geothermal steam was emitted from the bore holes of 150–300m, in depth though geothermal manifestation is so poor that there are no fumaroles exclusive of a few hotsprings with temperature of 40–80°C. This is the beginning of geothermal exploration in this area

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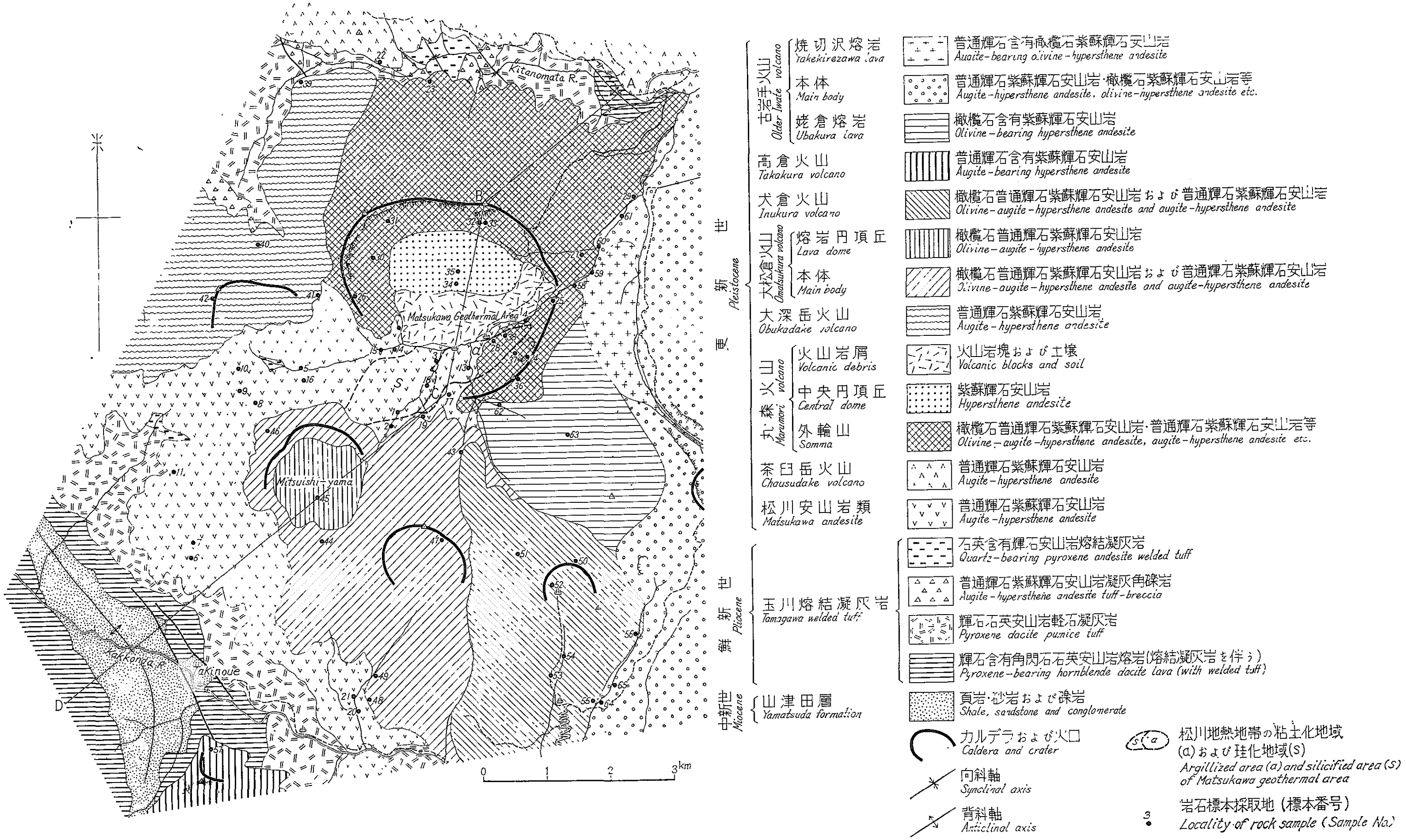

Fig. 2 Geological map of Matsukawa and its surrounding area

and since 1958, the regular exploration has been made under the cooperation of Geological Survey of Japan and Azuma Kako Co., Ltd. After geological survey, geophysical prospecting and test drilling were carried out, four productive wells have been drilled by the Company under the aid of the Research Development of Corporation of Japan, since 1963. The depths of No.1–No.4 wells are 945, 1080, 1200 and 1500m respectively. Among them, No. 1, No. 2 and No. 3 wells have succeeded to get geothermal steam of 150 tons per hour in total discharge. Japan's first geothermal power plant was put in operation on October 8th, 1966. Its capacity, limited to 9500 kilowatts at the outset, is to be increased to 15,000 kilowatts by next April.

The writers have carried out geological survey and core investigations in this area since 1957. In this paper, the results of studies on subsurface structure, rock alteration and geothermal condition of this area are described briefly on the basis of the data mainly obtained by drilling.

1. Geology

The geological map of southeastern part of the Hachimantai volcanic region including Matsukawa area is shown in Fig. 2.

The most part of this region is covered by Quaternary volcanic rocks. In the Matsukawa area, Matsukawa andesite, Marumori somma lava and its debris are exposed (Nakamura and Sumi, 1961). As topographical feature, caldera and central cone can be seen, but it is not sure that the caldera was formed by which way, depression or explosion.

Thr ough this area, Matsukawa river runs away from south–west to north–east and it has two tributaries, Akagawa and Sumikawa rivers. The north side of the Matsukawa river is relatively gentle in topographic relief, while upper streams of these rivers make steep gorges in Matsukawa andesite.

The basement rocks of this area are composed of Tertiary welded tuff and marine sediments distributed on Takinoue geothermal area, about 8 km far from Matsukawa to southwestern direction, and along the Kitanomata river located on the north side of Matsukawa area. Welded tuff overlain by Matsukawa andesite was found at the depth of 160m when drilling was made by the village office in the Matsukawa area.

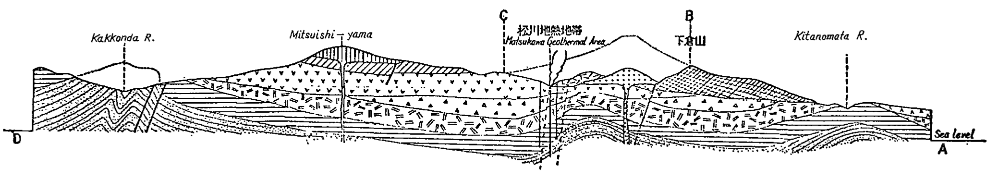

Fig. 3 Geological section of the Matsukawa geothermal area

Fig. 3 shows the profile through Takinoue, Matsukawa and the upper stream of Kitanomata rivers. Geological structure of Takinoue area has a complicated anticlinal structure with steep faults. As to geothermal manifestation, fumaroles and hotsprings issue along anticlinal axes developed in Tertiary sediments. In the Matsukawa area, the structure of the basement rocks shows also anticlinal or dome structure as explained later.

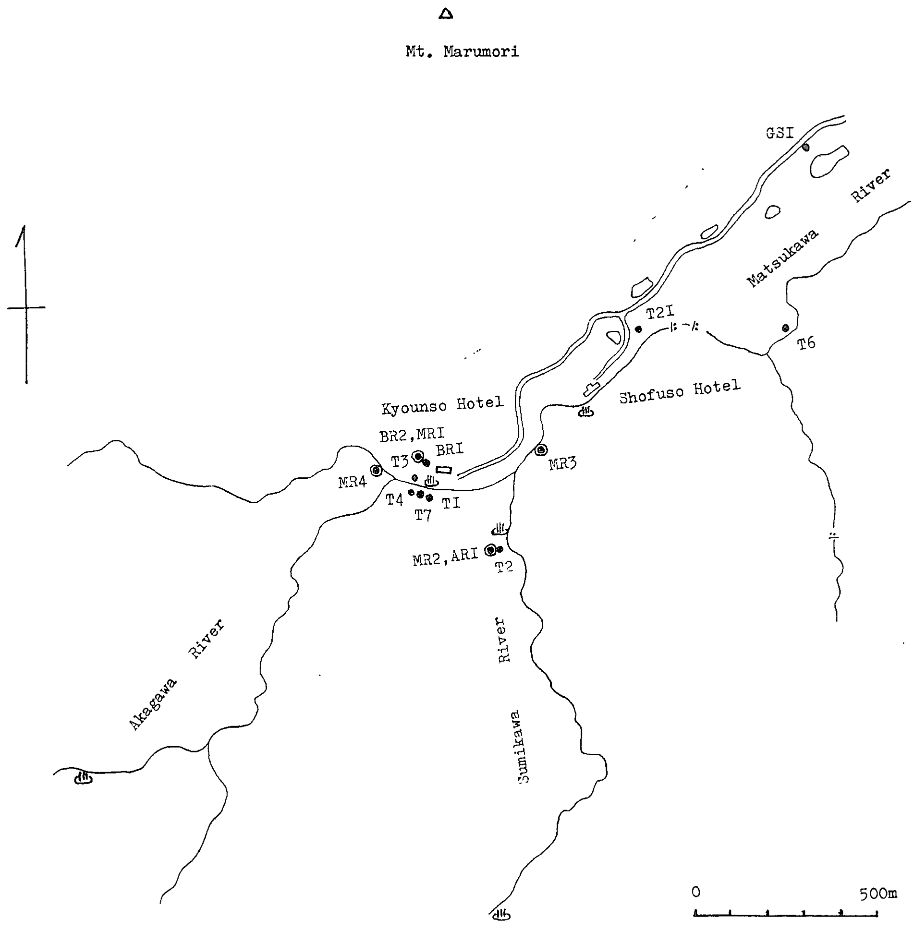

Fig. 4 Index map showing the locations of test bore holes and productive wells

Fig. 4 is the index map showing locations of test bore holes and productive wells. MR-1, MR-2, MR-3 and MR-4 are productive wells and other symbols and numbers show the positions of test bore holes. The distances of each productive well are 150-300m.

According to the core investigation of each productive well, the stratigraphic profile of the Matsukawa area is shown in Fig. 5, in which the boundary between Tertiary marine sediments and welded tuff is

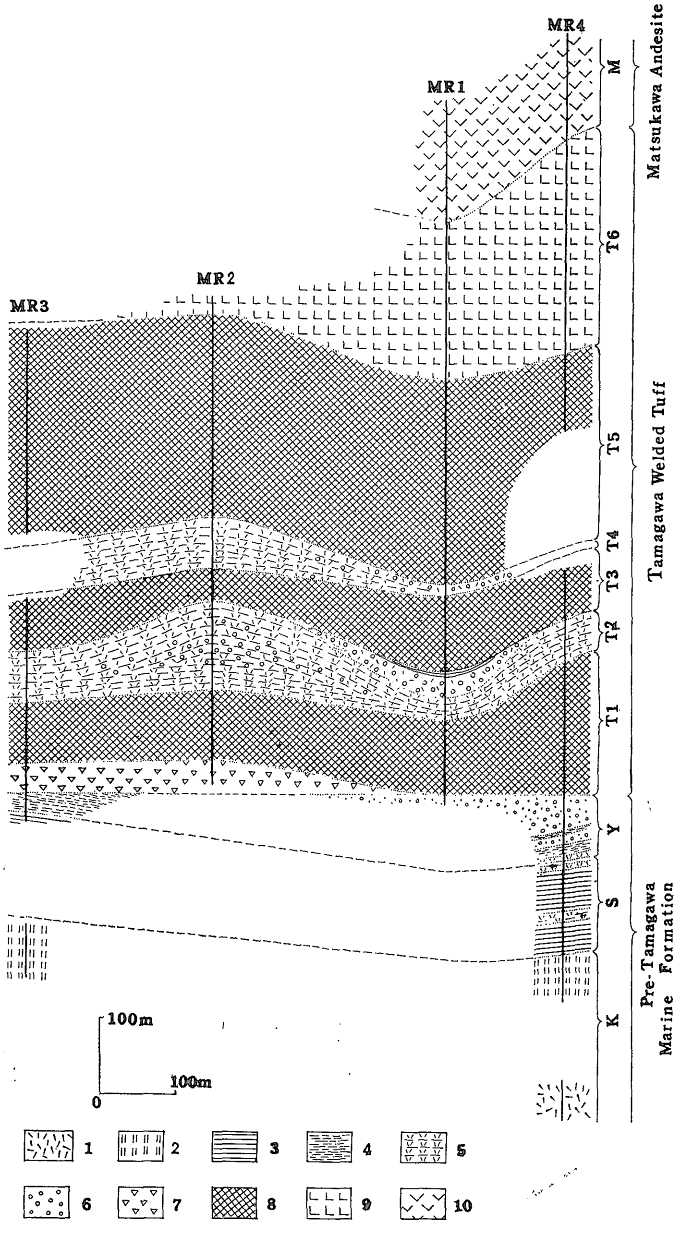

Fig. 5 Stratigraphic section of the Matsukawa geothermal area
1 : Mafic tuff breccia 2 : Rhyolite volcanic breccia
3 : Siliceous shale 4 : Black shale
5 : Sedimentary tuff 6 : Conglomerate
7 : Accidental tuff breccia 8 : Dacite welded tuff
9 : Andesite welded tuff and lava 10 : Andesite lava
Y : Yamatsuda formation

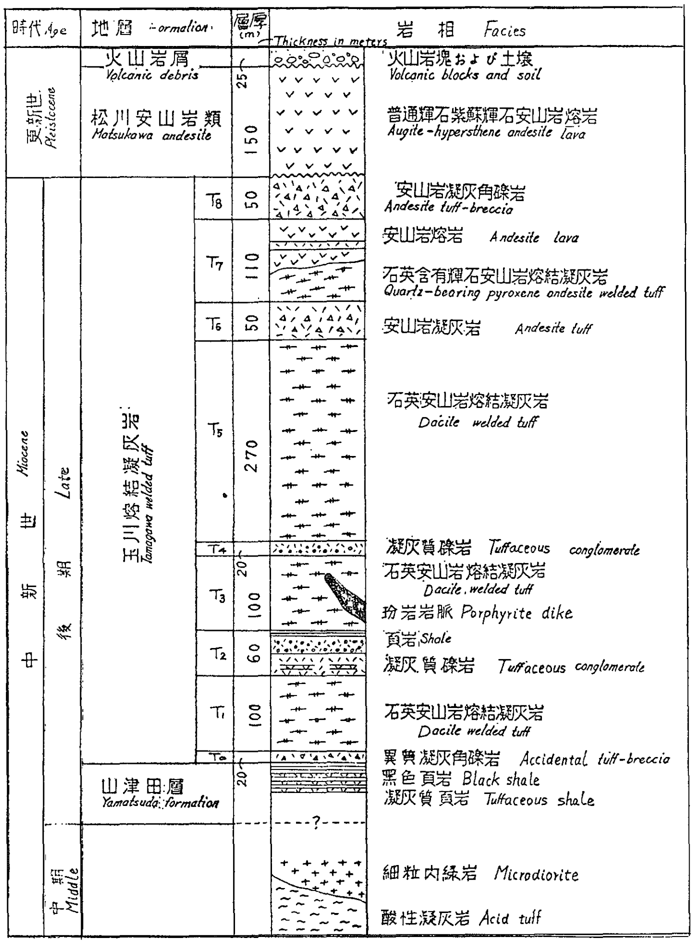

Fig. 6 Stratigraphic sequence at the Matsukawa geothermal area

arranged on the same level. From this data, stratigraphic sequence can be made (Fig. 6).

In this sequence, Matsukawa andesite of 150m thick is regarded as a cap rock because of low alteration and low temperature as known by drilling (Ando and Watanabe, 1957). The welded tuff formation is divided into nine members by lithological differences and most of them have horizontal welding planes which can be seen in core samples. Compared with the Takinoue area, the thickness of marine sediments named Yamatsuda formation is extremely thin in this area and below this formation, so-called green tuff formation is found.

2. Subsurface Structure

It is difficult to know the subsurface structure of Matsukawa area by geological survey on the surface, because this area is almost covered by Quaternary volcanic rocks. However, some informations of the

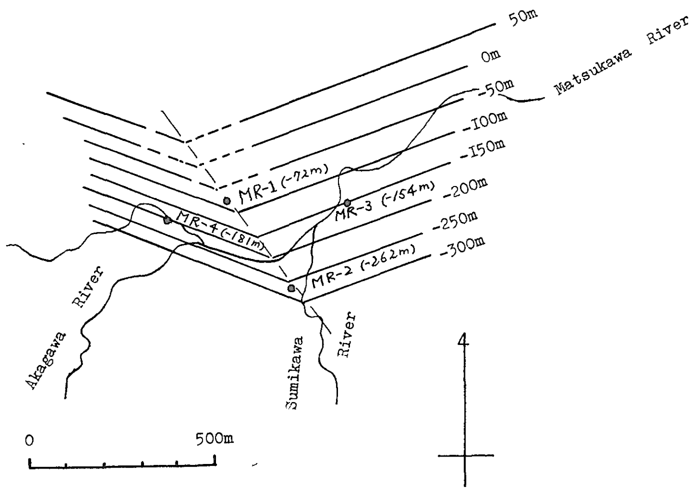

Fig. 7 Structural contour map of the Matsukawa geothermal area Numbers show the height of the base of welded tuff formation with the unit above sea level.

subsurface structure have been gotten by drilling as follows :

According to stratigraphic profile in each well, the depth to the top of Tertiary marine sediments is different between the north side and south side of Matsukawa river. From this data, the structural contour map can be made as shown in Figs. 7 and 8. In these figures, numbers show the height of the base of welded tuff formation with the unit above sea level. If the bedding planes of the basement rocks are nearly horizontal as seen in core samples of welded tnff formation, this means that there may be a fault zone parallel to the structural contour lines, namely along the Matsukawa river. Besides this fault zone, there must be another break line formed by the compound of two different stresses and drawn by connecting each cross point of contour lines. Since the present developed area is not only limited to small extent but deep bore holes are a few, it is not sure what kind of fault is predominant in this area. But, it may be assumed that the structural movement of this area would be related to the activity of Marumori volcano from the viewpoint of geological situation of subsurface structure presented in Fig. 8.

III. Rock Alteration

In spite of weak geothermal manifestation of this area, a large altered rock area is distributed along the Matsukawa river with the direction from north-east to south-west as shown in Fig. 9.

Formerly, the writers tried to classify the altered rocks into four subzones by macroscopic features (Nakamura and Sumi, 1961), but, in this paper, they are classified into six subzones by the characteristics of mineral assemblage (Sumi, 1966). As seen in Table 1, the altered rocks

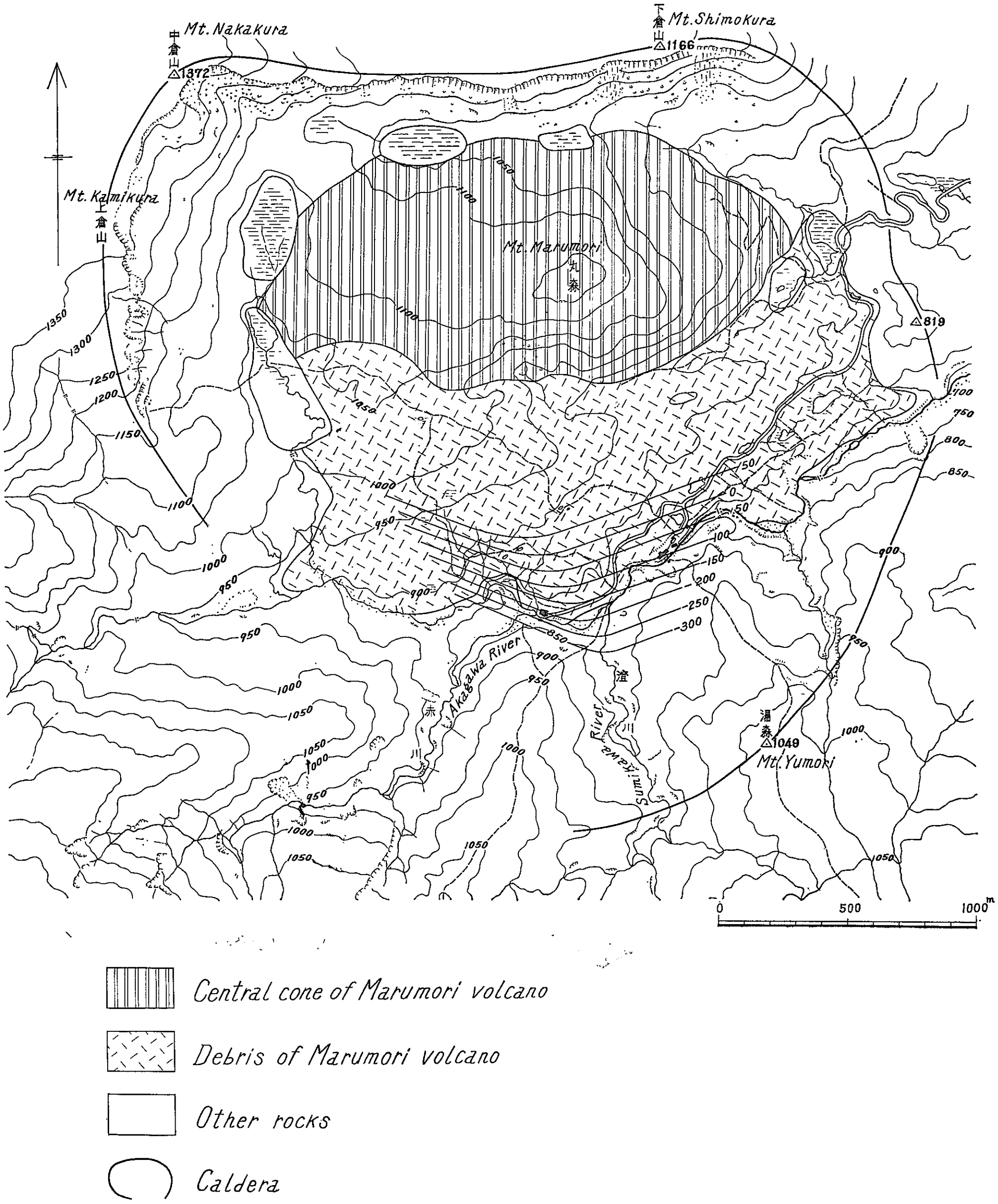

Fig. 8 Subsurface structure in the Matsukawa geothermal area

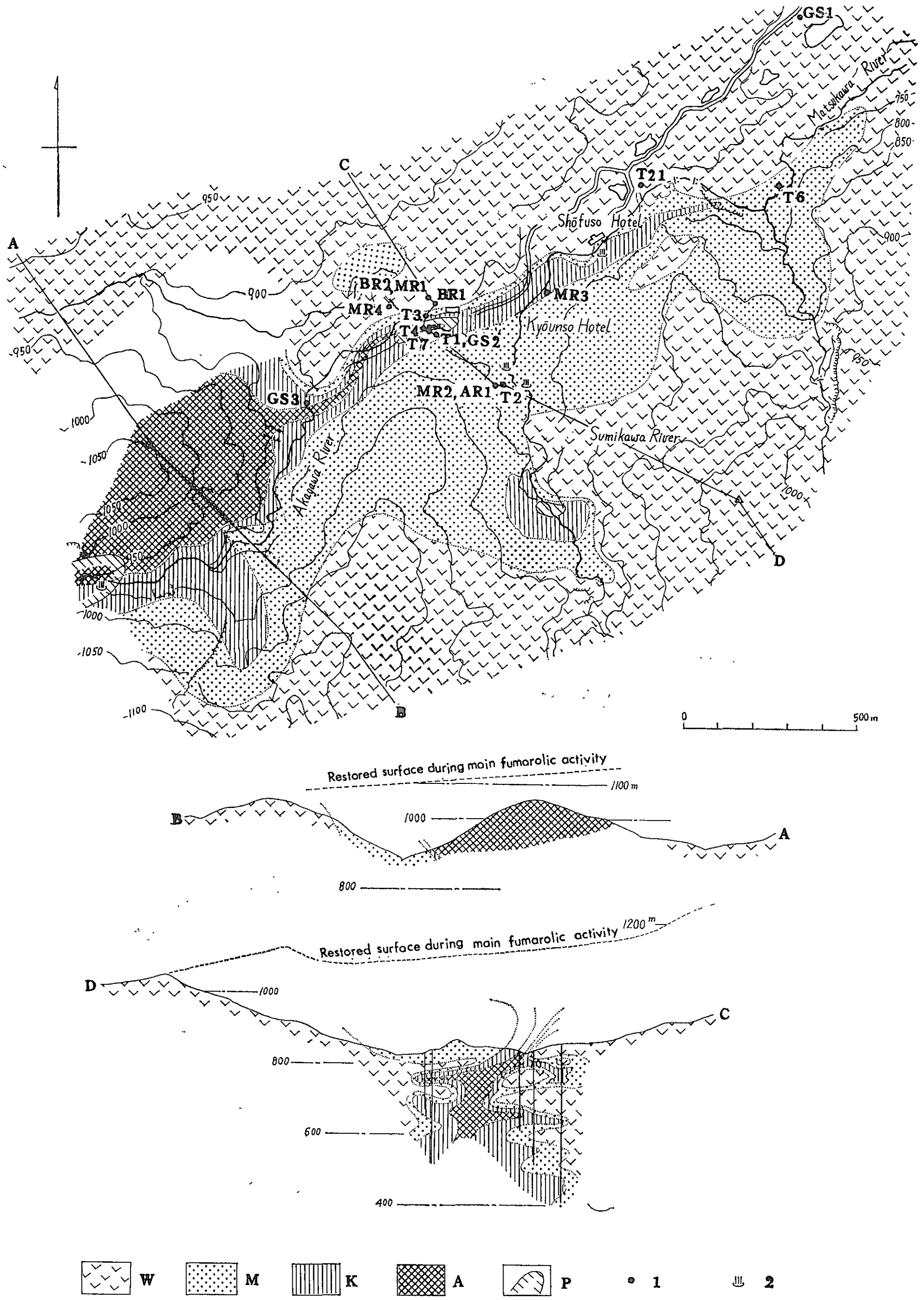

Fig. 9 Distribution map of altered rocks in the Matsukawa geothermal area

W : weakly altered zone　M : Montmorillonite zone

K : Kaoline zone　A : Alunite zone

P : Pyrophyllite zone

1 : Bore hole　2 : Hotspr ing

Table 1 Mineral assemblages in each altered zone

Zone I	Weakly altered zone	Montmorillonite zone	Kaolin zone	Alunite zone	Pyrophyllite zone
Zone II	Dark green colored zone	Argillized zone / Silicified zone		Silicified zone / Silica-stone zone	
Saponite	——				
Montmorillonite		——			——
Sericite		- - -			
Kaolin		- - -	——		——
Alunite			- - -	——	
Pyrophyllite					——
Andalusite					——
Diaspore					——
Zunyite					——
Chlorite		- - -			
Quartz	——	——	——	——	——
α-Cristobalite		- - -	- - -		
"Leucoxene"	——	——	- - -		
Rutile		- - -	——	——	——
Pyrite	——	——	——	——	——
Calcite	——	- - -	- - -		
Sulfur			- - -	- - -	

I : K. Sumi (1966), II : H. Nakamura & K. Sumi (1961)

of this area are composed of weakly altered zone, montmorillonite zone, kaoline zone, alunite zone and pyrophyllite zone. The new subdivision was made by using some kinds of clay minerals as index ; by setting the boundary between montmorillonite and kaoline with disappearance of montmorillonite, and that between kaoline and alunite with disappearance of kaoline. Pyrophyllite zone is characterized by containing diaspore, anhydrite and zunyite in addition to pyrophyllite, and this zone overlaps one above another and therefore, the boundary between this zone and others is not clear. According to the data of temperature measurement in bore holes, the temperature near surface of this area is not so high as pyrophyllite can be formed. Accordingly, it is assumed that pyrophyllite zone would not be the same product as other subzone, but that of early stage of geothermal activity.

Figs. 9 and 10 show the cross section of altered zone made by core investigations of test bore holes and productive wells. In the limit to the depth of 600m, zonal arrangement of alunite, kaoline and montmorillonite zone is also found from inner to outer in vertical plane.

In Fig. 9, the alunite zone exposed along the upper stream of Akagawa river is regarded as the shallowest product formed by fumarolic action when geothermal activity was stronger. If the surface of the present developed area kept the same altitude as the above-mentioned area at

Table 2 Chemical composition of hotsprings Fe^{2+} acidity

Name	Temp. (°C)	pH	Cl^-	SO_4^{2-}	acidity (meg/l)	HS^-	HCO_3^-	Na^+	K^+	Al^{3+}	Fe^{2+}	Ca^{2+}	Mg^{2+}	NH_4^+	HBO_2	H_2SiO_3	T. S. M.
1. Upper stream of Akagawa river	31.6	3.9	1.0	229.6	3.64	14.9	0.0	20.8	10.0	5.3	0.7	48.2	8.7	1.5	2.2	36.4	413
2. Upper stream of Sumikawa river	44.4	5.8	1.5	306.2	9.52	62.7	198.3	70.3	17.6	2.1	1.4	76.9	24.2	2.0	19.9	49.4	734
3. Kyounso Hotel	44.6	3.2	3.0	94.6	5.06	44.6	0.0	14.0	7.3	5.3	0.7	8.2	2.1	2.'	11.1	29.9	250
4. Shofuso Hotel	78.5	3.1	3.0	315.2	3.95	5.0	0.0	40.0	9.6	11.5	8.6	31.8	8.2	2.5	13.3	88.4	670

unit : mg/l Analyst : K. MAEDA

Table 3 Chemical composition of steam, its condensed water and drainage water from productive wells

Name	Date	vapour : gas (vol. %)		Component of gases (vol. %)				
				H_2	CO_2	SO_2	O_2	R.
Steam from MR-1	Aug. 15, 1964	99.80	0.20	13.7	82.1	tr.	0.0	4.2
Steam from MR-2	Aug. 15, 1964	99.78	0.22	14.1	81.8	tr.	0.0	4.1

Analyst : K. MAEDA

Name	Date	PH	RPH	Cl^-	SO_4^{2-}	HCO_3^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Al^{3+}	CO_2	H_2S	HBO_2	H_2SiO_3	T.S.M.	Free S
1. Condensed water of MR-1	Jan. 25, 1964	4.6	4.7	3.9	3.3	1.5	0.8	0.3	0.1	0.1	0.45	0.38	15.4	11.9	0.1	2.3	21.5	14.6
2. 〃	Aug. 15, 1964	4.5	4.6	6.7	13.2	6.1	2.2	1.2	0.6	2.2	4.30	0.35	73.7	49.8	0.1	6.5	44.0	6.2
3. Drainage water of MR-1	Aug. 15, 1964	4.9	4.9	12.4	1779.9	36.6	263.5	143.5	22.9	8.7	507.7	28.6	—	tr.	248.2	825.5	3843	—
4. Condensed water of MR-2	Aug. 15, 1964	5.3	5.3	1.7	2.8	9.1	0.7	0.2	0.4	0.4	0.004	0.18	81.4	60.7	1.2	1.7	15.0	3.9
5. Drainage water of MR-2	Aug. 15, 1964	6.9	6.9	5.3	114.8	45.8	57.0	4.0	5.6	1.3	0.11	4.2	—	tr.	43.4	594.1	853	—
6. Condensed water of MR-2	Feb. 2, 1965	5.9	5.9	0.5	2.1	—	5.6	3.0	0.40	0.24	0.04	0.1	50.1	101.0	2.0	2.6	21.9	
7. Condensed water of MR-3	Feb. 2, 1965	4.0	4.2	0.5	72.0	0.0	40.4	16.2	3.42	0.44	18.61	0.1	83.0	14.9	4.8	34.7	173	
8. Drainage water of MR-3	Feb. 2, 1965	5.0	5.0	8.8	1343.3	18.3	204.8	84.2	28.79	2.62	389.5	12.8	—	tr.	65.3	773.5	3015	

unit : mg/l

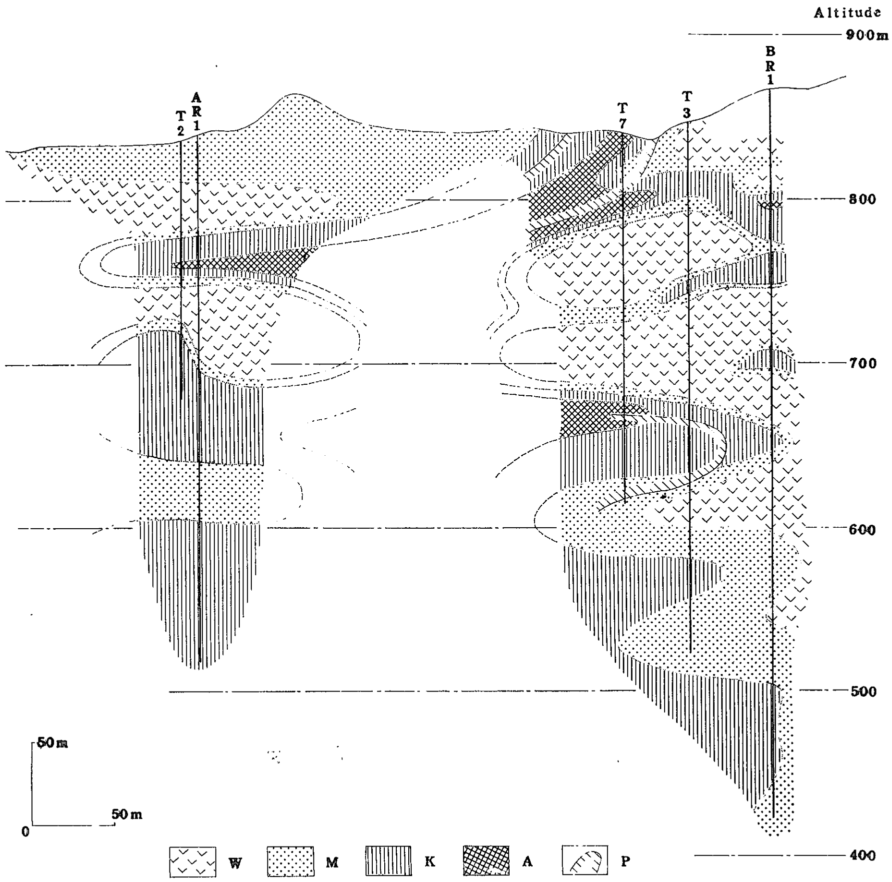

Fig. 10 Geologic section through C-D lines
W, M, K, A & P→see Fig. 9

that time, the eroded surface of older topography can be restored as shown in Fig. 9. Based on such an idea, the altered rocks exposed around the developed area would not be the shallowest products, but the inner part 300m below from the older surface. It is another reason why pyrophyllite is found at the present surface and is considered as the product of early stage of geothermal activity in this area.

In Fig. 10, the shape of altered rocks along vertical plane shows symmetrical appearance in the extent of 300m in depth. This means that selective alteration was made in the upper part of welded tuff formation consisting of alternation of tuff and lava flow. On the contrary, the selective alteration is not seen in Matsukawa andesite. This is due to the lithological character of compact Matsukawa andesite. It remains unsolvable that, in the deeper part, what sort of shape of zonal arrangement would be seen, but, there may be a possibility to consider that kaoline zone would spread in welded tuff formation below 300m because it has numerous cracks as seen in core samples.

From these facts, it can be said that the occurrences of pyrophyllite zone, and alunite from the depth of 600m have an important role to know the unique condition of hydrothermal system in this area and that Matsukawa is another type of geothermal fields which have not seen in other fields such as Wairakei (STEINER, 1953), Salton Sea (WHITE and MUFFLER, 1964) and Steamboat Hotspring (SIGVALDASON and WHITE, 1961, 1962).

4. Chemical Composition of Hotsprings and Drainage Water from Bore Holes

To consider the formation of altered rocks in this area, it is important to know the chemical composition of hotsprings and drainage water from bore holes.

Table 2 shows the chemical composition of hotsprings in this area. They are all acidic and characterized by a little high content of sulphates.

Table 3 shows the chemical composition of steam, its condensed water and drainage water from productive wells. These samples were obtained in a period of six months after emission, but, at present, the steam of productive wells has become super-heated and has no drainage water. It is not clear why such a change has occurred, however, it can be assumed that the chemical composition of drainage water would present the original property of hot water reserved in basement rocks of this area.

As seen in Table 3, the chemical compositions of MR-1 and MR-3 are different from that of MR-2; the former is acidic and characterized by high content of sulphates, while the latter is intermediate and sulphates content is rather low. This fact suggests that hydrothermal water reserved in the Matsukawa area is originally acidic one, and altered rocks with alunite and kaoline zones have been formed under the acidic condition with temperature of about 300°C in the depth of 1000m as known by temperature measurement in bore holes.

5. Geothermal Condition of Matsukawa Area

As mentioned at the beginning of this report, there are twelve fumarolic and hotspring areas in the Hachimantai volcanic region. It is one of important and interesting problems that as heat source which volcano or volcanism has a relation to geothermal manifestations in this region. On this question, there are few evidences to clarify the relation between volcanism and geothermal activity in each area. As to Matsukawa area, however, the only clue is the distribution of altered rocks after extrusion of Matsukawa andesite. Judging from the distribution of volcanoes formed after the extrusion of Matsukawa andesite, it is assumed that the volcanic activity of Mitsuishi and Marumori volcanoes might be associated with geothermal activities in the Takinoue and Matsukawa areas. At the same time, the altered zone along Matsukawa river is included in a zone connecting two volcanoes mentioned above, which is considered as structural zone developed in basement rocks.

At the beginning of geothermal activity in Matsukawa, the activity would be so strong that pyrophyllite was formed under more acidic condition with higher temperature than those at present. During this time, hydrothermal water might be characterized by containing free hydrochloric acid from the fact that zunyite is found accompanied with pyrophyllite zone.

There is no information about when caldera and central cone of Marumori volcano were formed, but it may be considered that the subsurface structure around Marumori volcano was formed by the effect of extrusion of magma as shown in figs. 7 and 8.

Summarizing the historical review of geothermal activity, it is concluded that hydrothermal water in the Matsukawa area is characterized by sulphuric acid at present, though it might contain free hydrochloric acid in early stage, and that it is reserved in fissures developed along structural zone, especially in those formed by crustal movement relating to the extrusion of Marumori volcano, and in horizontal cracks developed in welded tuff formation. It goes without saying that the fissures cutting through the basement rocks have more important role than horizontal cracks to produce geothermal steam and, accordingly, that it is necessary to detect the fault zone around Marumori volcano for the purpose of geothermal development of the Matsukawa area in future.

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松川地熱地域における地質学的研究

中村 久由　角 清愛

要　旨

日本で初めて地熱開発に成功した岩手県松川地域において筆者らがこれまで行なってきた地質調査，調査井・生産井のコア調査の結果を取り纏め，地下構造，岩石の変質，地熱のあり方についてその要点を説明した。すなわち，松川地域の地下構造は，背斜状またはドーム状の構造を示すがこれは丸森火山の活動に関係があるらしい。地熱は松川沿いに走る断層帯に伴うが，2次的に第三紀熔結凝灰岩の横の割目にも貯えられる。岩石の変質はアルナイト・カオリン・モンモリロナイト帯で特徴づけられ一部パイロフィライトを含むところがある。これらの変質作用は酸性の熱水によってもたらされたものであり，現在生産井から噴出する熱水の性質もこれを裏書きしている。