

Exo- and Endo-Magmatic Hydrothermal Differentiations
Observed among the Chemical Components Exhaled
by Noboribetsu Volcanic Activity

by

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Abstract

The Noboribetsu volcano, surrounded by many volcanoes such as Showashinzan, Tarumaé and so on, is one of the large hydrothermal activities in Japan, and its activity has been repeating the intensity variation for the last one hundred years. In the present paper, a quantitative elucidation is presented on the relation between the variation of activity and the chemical composition of materials exhaled through craters.

Introduction

Japan occupies the western portion of the Circum Pacific Volcanic Zone, and has many volcanoes and hot springs¹⁾. Therefore, it is expected that there may be some opportunities which are favourable to the analysis of the relation between the variation of the strength of the volcanic activity and the change of the chemical components exhaled by the former²⁾. The quantitative elucidation of this problem is desirable to many geochemical subjects, especially to that of the endo-magmatic hydrothermal differentiation. In this paper, this problem is dealt with regard to Noboribetsu volcanic activity which is favoured with such qualifications. (cf. Table 1).

The Noboribetsu volcano is situated at the southern part of Hokkaido, surrounded by many volcanoes such as Showashinzan, Tarumae and Usu, and corresponds to the remnant activity of a series of Kuttara volcanism in Nasu volcanic zone³⁾.

The Noboribetsu volcano has two explosion craters, Death valley and Oyunuma. The diameters of both craters are about 500 m respectively and the latter is filled with boiling water. The remnant energy of the volcanism has been consumed by the activity of many minor craters and fumaroles in both craters, issuing steam, boiling water and molten sulfur.

The activity has been repeating the changes for the last one hundred years. And there exists the distinct endo-magmatic hydrothermal differentiation among the chemical components exhaled

Table 1 Strength of Noboribetsu Volcanic Activity

	Issuing Amount of Water (t/day)	Issuing Amount of Salt (t/day)	Heat Energy Expelled (cal/day)
Noboribetsu	8×10^3	28	8×10^{11}
Total Activity in Japan	1.5×10^5	10^3	7.5×10^{12}
Hot River, Yellow Stone Natl. Park, U.S.A.	5.5×10^4	92	2.5×10^{12}
Total Activity in Yellow Stone Natl. Park, U.S.A.	2.8×10^5	—	—

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through craters.

It is impossible at present to elucidate clearly whether the observed variations of the activity have a direct relation to the new birth of Showashinzan or not and also to the earthquake of Tokachioki on the 4th of March, 1952. But, some interesting facts have been found among the observed values, which may give important clues for the analysis of the paragenesis of those natural phenomena.

Scale of Noboribetsu Hydrothermal Activity:

The total weight of the mineral water issuing from all Japanese hot springs amounts to 1.5×10^5 tons a day⁴⁾. If this value is multiplied by 3.86 g/l, the average salt content of Japanese mineral water⁵⁾, it is estimated that 10^8 tons of saline substances are brought out to the ground surface by mineral water daily. Heat energy exhaled by it also amounts to 7.5×10^9 kcal a day.

The thermal activity of Noboribetsu has been recognized as the largest one in Japan, as presented in Table 1. The total weight of the mineral water transported by this activity amounts to 8×10^3 tons daily, which corresponds with one twentieth of the total weight of the mineral water in the whole Japan. Heat energy exhaled by this activity is equal to a mechanical work of 2×10^{22} erg/year, corresponding with one tenth of the sum of all Japanese springs'. This mechanical work done by Noboribetsu's activity annually is of order of magnitude of only $10^{-2} \sim 10^{-3}$ of that of the total work done by a single volcanic eruption such as Sakurajima's in 1914, but it is equal to the mechanical work done by volcanic emanations. If the value is multiplied by the duration of its activity, an enormous value will be obtained and the importance of the hydrothermal activity in the course of volcanism will be recognized.

As regards to the geological structure of Noboribetsu volcanic activity, it should be noticed especially that at Noboribetsu there exists evidently the distinct exo-and endo-magmatic hydrothermal differentiations which have never been so clearly observed in other places. This means that the Noboribetsu volcano is favoured with the following two peculiarities: great scale and special geological structure. It may, therefore, be concluded that the Noboribetsu volcano offers the most favorable field to the geochemical investigation of the hydrothermal activity in Japan.

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Exo-magmatic Hydrothermal Differentiation of the Original Hydrothermal Solution

Adiabatic Expansion of the Original Hydrothermal Solution

The geochemical structure of Noboribetsu volcanic activity can be considered as follows. The original hydrothermal solution is believed to be liquid water at high temperature and pressure (200°C and 30 atms)⁽⁶⁾⁽¹⁵⁾.

As the original solution rises to the ground surface from unknown magma reservoir, the hydrostatic pressure decreases gradually and vaporization takes place. Consequently, the temperature of the solution falls little by little. This process consuming energy through the explosion fissure is repeated until the violent vaporization phenomenon breaks out suddenly in a large cavity of the fissure as a result of an adiabatic expansion. Thus the original solution violently separates steam from itself and its temperature falls to about 100°C, leaving the secondary solution in the cavity. The separated steam is pushed up higher through the fissure and is given off into the air out of many fumaroles at the upper parts in this area. The activity of Death valley depends on this steam. On the other hand, the secondary solution left in the cavity issues out in the lower zone through many small branches of the fissure at an issuing rate of 30 liters per second. These are hot springs found at Noboribetsu town.

In Oyunuma area, the hydrothermal activity is accompanied by issuing of molten sulfur⁷⁾. This is also one phase of Noboribetsu volcanic activity, but the separation of this phase from the main stem is considered to precede the separation of Death valley phase. The time of the explosion of Oyunuma precedes that of Death valley⁸⁾ and the present activity of the former is only a half of the magnitude of the latter's activity. But, the recent change in the activity has always synchronized in these three areas. It is concluded therefore that the three phases originate in the same activity.

Exo-magmatic Hydrothermal Differentiation of the Chemical Components

When the separation of steam from the original solution takes place adiabatically, chemical components are differentiated into the gaseous and liquid phases according to their own solubility. The water-soluble components such as Na, K, Ca, Mg and Cl ions remain in the liquid, but on the other hand volatile substances like H₂S and CO₂ are vaporized together with steam. This is the exo-magmatic hydrothermal differentiation of the chemical components, a phenomenon which has never been observed so clearly in any other volcanoes.

As a result of this separation, the secondary solution issuing at the town contains much saline components, but no volatile ones. Its content of sulfur compounds is only minute. It is neutral solution, without oxidation of sulfur compounds to sulfuric acid.

Volatile sulfur compounds are transported to the upper regions by steam and released there from fumaroles as H₂S and SO₂ gases, and oxidized to sulfuric acid by air at the bottom of Death valley. Therefore, the mineral solutions found there are strongly acid, but contain no saline substance at all.

The solutions boiling in the contact zones of the two groups retain both Chloride and Sulfate ions and are weakly acid. This group is considered to be mixture of both groups.

Analytical results are presented for each group in Table 2. The exo-magmatic separation of sulfur compounds from the saline substances and the strict retention of Chloride ions in the mother liquid are obviously recognized in this table.

Table 2 Exo-Magmatic Hydrothermal Differentiation of Chemical Components Contained in the Original Solution

Three Types of Noboribetsu Activity	pH	Cl ⁻ (g/l)	SO ₄ ²⁻ (g/l)
Secondary Hydrothermal Solution (cf. Table 3a)	7.0	3.83	0.033
	6.8	2.04	0.031
	7.0	4.66	0.052
Residual (Mixed Type) Solution (cf. Table 3b)	2.3	2.13	0.46
	2.4	2.70	0.66
	2.9	1.96	0.23
Sulfur Water (cf. Table 3c)	1.4	0	2.90
	1.4	0.003	2.39
	1.2	0	2.77

Characteristics of Each Group

Secondary Hydrothermal Solution (cf. Table 3a)

- 1) This has neutral property and contains much saline substances. Their contents are not at all affected by the seasonal and climatic conditions. The effect of the surface water to this solution is considered to be very minute, if there is any.
- 2) Total volume of water discharged amounts to 30 l/sec. This value corresponds to three times of the total water volume from Death valley.
- 3) Na, Ca and Cl ions are contained in this solution as the major components, and K and Mg ions as the minor. Moreover, Li ion is also found as a trace element together with Sr, Ba, Ti, Cu, Ag, Zn, Pb, Mn, Fe, Al, and V ions and compounds.
- 4) The concentration and composition of the major components change in accordance with

Table 3a Chemical Composition of Secondary Hydrothermal Solutions (g/l)

Name	T (°C)	pH	Total Salt	HCO ₃ ⁻	CO ₂	Cl ⁻	SO ₄ ²⁻	Na ⁺	Ca ²⁺	Al	H ₂ S	Silicic Acid
An	74	6.8	4.07	0.25	0.20	2.04	0.031	0.895	0.310	0.022	0.002	0.202
Bn	54	7.0	2.12	0.37	0.16	0.90	0.031	0.795	0.302	0.000	0.0006	0.161
Cn	53.5	6.3	2.82	0.08	0.20	1.41	0.029	0.588	0.226	0.004	0.001	0.198
Dn	96	7.5	8.90	n.d.	n.d.	4.60	0.056	1.82	0.768	n.d.	n.d.	n.d.
En	95.2	7.0	7.35	0.14	0.02	3.83	0.033	1.66	0.539	0.043	0.004	0.255
Fn	—	6.7	7.70	0.14	0.05	3.99	0.022	1.62	0.587	0.011	0.005	0.294
Gn	83.5	6.2	4.82	0.08	0.06	2.53	0.052	1.20	0.391	0.004	0.007	0.264
Hn	80.5	6.1	5.80	0.06	0.06	2.64	0.067	1.24	0.572	0.040	0.005	0.252
In	74	7.0	8.32	0.14	0.03	4.01	0.030	1.70	0.591	0.025	0.003	0.263
Jn	73	6.9	8.40	0.14	0.03	4.53	0.037	1.86	0.652	0.045	0.003	0.265
Kn	62	7.3	n.d.	0.03	0.01	4.02	0.028	1.72	0.592	0.013	0.002	0.249

All contains ferrous ion less than 0.001 g/l

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Table 3b Chemical Composition of Mixed Type Solutions (g/l)

Name	T (°C)	pH	Cl ⁻	SO ₄ ²⁻	Al ³⁺	Fe ²⁺
Am	93	n.d.	1.54	0.73	n.d.	n.d.
Bm	89	2.5	2.06	0.51	n.d.	0.020
Cm	95	2.4	2.13	0.46	0.030	0.002
Dm	82	2.4	1.94	0.67	0.029	0.035
Em	92	2.4	0.47	0.96	0.067	0.043
Fm	97.5	n.d.	2.57	0.28	0.007	0.017
Gm	97	4.6	0.99	0.37	0.006	0.007
Hm	96	2.5	1.13	0.37	0.017	0.015
Im	86	1.5	0.52	0.44	0.023	0.015
Jm	91	1.7	0.14	2.21	0.012	0.014
Km	85	2.3	0.41	0.68	0.040	0.015
Lm	93.5	1.7	0.10	0.66	n.d.	0.024
Mm	74	1.8	0.15	0.55	0.064	0.035
Nm	94	2.5	0.12	0.41	0.018	0.016
Om	93	2.6	0.12	0.45	0.015	0.033

Table 3c Chemical Composition of Sulfur Waters (g/l)

Name	T (°C)	pH	Cl ⁻	SO ₄ ²⁻	Al ³⁺	Fe ²⁺
A	94.5	1.2	0.000	2.77	0.150	0.048
B	96	1.2	0.000	4.30	0.132	0.046
C	96	1.2	0.003	1.90	0.116	0.036
D	96	1.4	0.003	1.33	0.180	0.100
E	93	1.4	0.000	4.53	0.414	0.153
F	96	1.6	0.029	1.33	0.099	0.036
G	93	2.4	0.003	0.33	0.008	0.003
H	92	1.6	0.005	1.03	0.032	0.027
I	93	1.7	0.005	n.d.	n.d.	0.267
J	92	2.4	0.005	n.d.	n.d.	0.171
K	91	1.6	0.034	2.08	0.628	0.137
L	90	1.6	0.003	1.12	0.291	0.077
M	96	1.6	0.003	0.62	n.d.	0.051
N	93	1.4	0.000	2.68	0.022	0.006
O	85	1.7	0.003	1.00	0.042	0.015
P	91	1.4	0.000	2.90	0.162	0.109
Q	88	1.7	0.000	2.40	0.137	0.063
R	94	2.4	0.010	1.30	0.077	0.041
S	41	1.7	0.034	3.09	0.323	0.320

the variation of the strength of the hydrothermal activity, directly affected by the endo-magmatic differentiation. That is, at a certain strength of the apparent volcanic activity, concentration of each major component has a constant value respectively to that of chloride ion, which is controlled strictly by the strength of the activity. Thus, the kind of components contained in the secondary hydrothermal solutions is determined by the exo-magmatic differentiation and

their composition is decided by the endo-magmatic condition. This will be elucidated more clearly in a later section by examining observed values.

Specific Properties of Sulfur Water in Death Valley (cf. Table 3c)

In Death valley, there are many "Hells" which are filled with boiling water. The character common to the "Hells" is the fact that they contain much sulfuric acid and no hydrochloric acid, with some exception. These so called "Hells" owe their sulfur source to a jetted steam which has been separated from the original hydrothermal solution and have oxidized it into sulfuric acid by air in their kettles. Some of these "Hells" appear only in the period of the increasing activity and disappear during the decreasing activity.

A river flows into Death valley from its eastern wall at a rate of 23 l/sec⁹⁾. Heated by steam jetted out from fumaroles, and mixed with acid solutions from kettles, the river water is gradually converted into a very strong acid solution. Thus, the formation of the acid solution with a flow of 32 l/sec⁹⁾ is accomplished during its flow down across Death valley towards the western egress of the valley. "Hells" character is presented in Table 3c. And the process of formation of the hot river is shown in Table 4. Chloride ion is considered to have been introduced by the secondary hydrothermal solutions which could find their ways up to Death valley. (cf. Table 3b)

Naturally, the apparent activity in Death valley depends on the strength of the steam. In other words, the temperature, pressure and volume of the steam expelled at the adiabatic expansion control the apparent activity of Death valley.

Table 4 Variation of Chemical Components in the Hot River Water as It Runs (g/l)

Flowing Amount of Water	pH	T (°C)	H ₂ S	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Fe ²⁺	Al ₃ ⁺	Silicic Acid
Ground Water 1	6	6	n.d.	0.006	0.052	0.017	0	0	0.059
" 2	2.9	n.d.	0.008	0.008	0.113	0.018	0.006	0.008	n.d.
Upper Reaches of Hot River 1	2.7	27	0.002	0.076	0.238	0.023	0.007	0.011	0.170
" 2	2.7	28	0.004	0.097	0.295	0.024	0.008	0.019	0.195
" 3	2.4	49	n.d.	0.091	0.439	0.028	0.011	0.033	0.161
" 4	2.4	62	0.028	0.140	0.478	0.035	0.011	0.020	0.179
" 5	2.4	80	0.016	0.151	0.506	0.037	0.017	0.014	0.199
Lower Reaches of Hot River 6	2.4	75	n.d.	0.164	0.391	0.038	0.007	0.029	0.199

But, the amount of chemical substances such as sulfuric acid, and Fe and Al ions, is affected decidedly by the climatic conditions, because chemical substances are exposed to the weather. On fine days, the formed sulfuric acid is stored in Hells' kettles, but on rainy days it is transported by the surface run off into the hot river. Under the latter condition, the acid leaving the Valley amounts up to hundred times as much as the amount of the sulfuric acid under the former condition. Consequently, the geochemical measure can not be applied to the determination of the strength of the activity of this valley, unlike the case of secondary solutions in the town. Mixed Type Solutions (cf. Table 3b)

Minor explosion craters are distributed here and there at the bottom of this valley, where mixed type solutions usually issue violently at the centre. The general trend of their distribution accords with geological structural trends in this area. That is, they occur on a line along the main fissure and are concentrated especially at the contact zone in the western area, where the

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activity of the secondary solutions is in contact with that of the acid solution. Variation of the activity corresponds with that of the valley but this will be discussed later.

Chemical Composition of the Original Hydrothermal Solution

It is necessary to obtain the chemical composition, temperature and pressure of the original hydrothermal solution in order to elucidate Noboribetsu volcanic activity. When these are obtained, it will be an easy task to get the change of the chemical composition connected with the variation of the volcanic activity, if one is given a lucky opportunity or keeps working on until he hits such an opportunity.

The chemical composition of the original hydrothermal solution, C , can be calculated by solving the next equation.

$$C = Wt/Vt \dots \dots \dots (1)$$

here

C : the content of the chemical substance contained in the original solution.

Wt : the amount of every saline substance transported daily up to the ground surface by the three activities already mentioned.

Vt : the amount of the thermal water issuing out daily, including the steam.

Wt and Vt are calculated by the following equations, (2) and (3)

$$Vt = \sum v \dots \dots \dots (2)$$

$$Wt = \sum v.c \dots \dots \dots (3)$$

here,

v : the amount of issuing water from each spring per day, including the steam.

c : the content of chemical components contained in each spring water.

v and c are observable, so C can be calculated. W_2 thus obtained in each area is presented in Table 5. It is shown in this table that every activity in Noboribetsu is of the same order of magnitude. The chemical composition of the original solution is now calculated by dividing Wt by Vt which amounts to 8×10^8 tons/day.

In Death valley, however, the ground water contributes so greatly to the formation of the thermal solution that its effect cannot be ignored. The volume of the water flowing into the

Table 5 Daily Amount of Issuing Chemical Component, Value of W_2 (ton/day)

	Water Total salt	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	Na ⁺	Ca ²⁺	Fe ²⁺	Al ³⁺	Silicic Acid
Death Valley	3×10 ³ 3.0	0.6	0.9	0	0.3	0.1	0.02	0.3	0.8
Oyunuma	1.7×10 ³ 0.3	0.06	0.07	0	0.03	0.006	0.03	0.03	0.02
Noboribetsu Town	3×10 ³ 25	12	0.07	0.5	5.0	2.0	10 ⁻³	10 ⁻⁴	1.0
Total	8×10 ³ 28	12.7	1.1	0.5	5.3	2.1	0.05	0.3	1.8

Table 6 Contribution of Ground Water to the Hot River (kg/day)

	Amount of Flowing Water	H ₂ S	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Fe ²⁺	Al ³⁺	Silicic Acid
Ground Water 1	1200×10 ³	0	0.72	6.25	2.04	0	0	9.45
" 2	890×10 ³	0.71	0.71	11.7	1.56	0.62	0.71	n.d.
Total	2090×10 ³	0.71	1.43	17.9	3.6	0.62	0.71	n.d.

valley is 23 l/sec⁹⁾. This amounts to two thirds of the thermal solution flowing out of the valley. But, in regard to chemical substances, the amount brought into the valley by the ground water is only minute and can not bear comparison with the value transported from the underground. Contribution of the ground water is presented in Table 6.

Now, the chemical composition of the original hydrothermal solution can be estimated, after the effect of the ground water are excluded. Its value is presented in Table 7 as the chemical composition I. The chemical composition II is obtained in Death valley-Town system only, if Oyunuma's activity is set aside.

Table 7 Chemical Composition of the Original Hydrothermal Solution (g/l)

	Total Salt Content	Cl ⁻	SO ₄ ²⁻	Na ⁺	Ca ²⁺	Fe ²⁺	Al	H ₂ S	Silicic Acid
Composition 1 (Calculated)	4.73	2.15	0.186	0.90	0.36	0.008	0.068	0.034	0.30
" 2 "	7.18	3.25	0.28	1.36	0.54	0.013	0.10	0.051	0.46
Secondary Solution (Observed)	7.35	3.83	0.033	1.66	0.54	0.0002	0.011	0.004	0.29

Table 8 Resemblance between Both Hydrothermal Solutions

	Na ⁺ /Cl ⁻	Ca ²⁺ /Cl ⁻
Original Solution	0.65	0.29
Secondary Solution	0.67	0.25

(mil. Val. Ratio)

It should be noticed that there is a close resemblance between the chemical composition of the original solution and that of the secondary solution, as shown in Table 8. This resemblance is kept especially well among the soluble saline components such as Na, Ca and Cl ions. Some differences found among non-volatile substances like Fe, Al ion and silicic acid denote that these elements result from chemical attack on wall rocks by sulfuric acid in Death valley.

We are now able to observe the chemical composition of the original solution easily and accurately by the simple chemical analysis of the secondary solution without the troublesome work of calculating equation (1).

First of all, it is necessary in this study to connect the chemical composition of water with the strength and variation of the volcanic activity. For this purpose, it is required to continue the daily observation of c-value until we encounter the variation of the activity. And as a result of the continuous observation, the general regularities have been made clear between the change of c-value and the variation of the activity as follows.

"The Concentration of the Soluble Elements (Na, K, Ca, Mg and Cl ions) and the Value of Mil-Val Ratios among Them (Na/Cl, K/Cl, Ca/Cl and Mg/Cl) Change with a Close Relation to the Variation of the Activity". Ultimately, it has been concluded that the variation results from the change of the endo-magmatic condition and more over, the future variation can be predicted 6 to 20 months previously to its occurrence. Changes of the chemical composition may give important clues to the elucidation of the endo-magmatic process. Further description will be presented in later sections.

Temperature and Pressure of the Original Hydrothermal Solution

Fukutomi and Fujiki¹⁰⁾ reported the temperature and pressure of the hydrothermal solution, on which they considered Death valley's activity depended by measuring the volume and heat energy of the thermal solution (Table 9). According to geochemical consideration, their calculation depends only on the steam and "partial portion" of the secondary solution, and they miss a large portion of the latter. Therefore, strictly speaking, physical values of the original solution should be calculated by introducing into their estimation those of the secondary solution issues at the town.

Table 9 Physical Property of the Thermal Water (after T. Fukutomi & T. Fujiki)

	Nov. 10, 1951		Feb. 5, 1952		Mar. 19, 1952	
	Temp. (°C)	Press. Atm.	Temp. (°C)	Press. Atm.	Temp. (°C)	Press. Atm.
Total Activity of Death Valley	239	32	201	16.0	267	52
Largest Hell in Death Valley			167	7.3	171	8.6
New Hell			148	4.5	182	10.4

If the original hydrothermal solution is not contaminated with the ground water in its progress of the elevation up to the surface, the deeper the solution descends in the fissure, the higher the temperature and the pressure become. And we can extrapolate the temperature and pressure at a certain depth where the volume of steam becomes zero ultimately and only the water of high temperature exists therein. Then, the next equation can be acquired at that state.

$$VacT=H \dots \dots \dots (4)$$

here,

V: the total volume of thermal solution observed in Noboribetsu area.

H: the total heat energy observable, expelled through fumaroles and hot springs.

a, *c*: the density and the specific heat of the solution, conventionally assigned as *ac*=1.0

T: the temperature of the particular solution in question.

As *V* and *H* are observable, *T* can be calculated by Equation 4. Here, the mechanical work done by solution is entirely ignored, or set as zero at the first approximation.

The pressure of the solution corresponding to *T* is obtained by Kaley's table, if *T* is known.

Table 10, thus obtained, denotes that the thermal activity of Noboribetsu depends on the magmatic hydrothermal stage.

Table 10 Physical Property of the Original Hydrothermal Solution

Nov. 10, 1951		Feb. 5, 1952		Mar. 19, 1952	
Temp. (°C)	Press. Atm.	Temp. (°C)	Press. Atm.	Temp. (°C)	Press. Atm.
220	23	200	15	238	32

Variation of the Hydrothermal Activity in the Volcanism

It has been recognized that Noboribetsu volcanic activity repeated the variations of its

strength. This phenomenon is not restricted to any certain minor crater only, but is considered to be controlled by the fundamental activity of this volcanism.

For the last hundred years, it has been the general tendency that the active centres characterized by repeated small explosions move to a lower zone from a higher one. This movement approached the town, the centre of the active area of the secondary solutions. From height difference of this movement it is calculated that the activity has lost a pressure of 10 atms during the above period. In other words, this phenomenon indicates that the origin of this volcanism has lost its energy rapidly. These variations are presented in Table 16.

The original hydrothermal solution may denote the differentiation of the chemical components in the course of such an energy reduction process of the igneous origin and may further show some chemical change in case of accidents such as earthquakes with centre in a neighbouring province.

Endo-magmatic Hydrothermal Differentiation

Changes of the Chemical Composition of the Original Hydrothermal Solution in Accordance with Variation of the Activity

It has been recognized that the chemical composition of the original hydrothermal solution changes in accordance with the variations of the activity as presented in Tables 11, 12 and 13. More over, in Table 14 are shown also the daily changes of chloride ion concentration of one of the secondary solutions. Each table shows that the concentration of chloride ion has gradually changed in the secondary solution during last 15 years.

According to geochemical considerations, this tendency of increase of chloride ion should indicate the fact that after the adiabatic expansion of solution in the fissure there remained in a cavity more concentrated mineral waters of much higher temperature than what there was 15 years ago. This means that the activity gradually comes to expell much more saline substances, (than before). Moreover the increase of salinity is accompanied with an increase in amount of issuing water and steam, so this must result from the increasing activity of the origin.

Table 11 Variation of the Noboribetsu Volcanic Activity shown by Change of the Chemical Composition in the Hot River Water (g/l)

Date of Observation	Cl ⁻	SO ₄ ²⁻	Fe ²⁺	Date of Observation	Cl ⁻	SO ₄ ²⁻	Fe ²⁺
1898	0.226	0.591	0.028	Apl. 15. 1952	0.133	0.305	0.044
1925	0.007	0.22	0.068	" 29. 1952	0.126	0.405	0.028
1938*	0.039	0.560	0.016	Jun. 3. 1952	0.110	0.425	0.040
Sep. 1949	0.194	0.307	0.008	Aug. 1952	0.088	—	—
Nov. 1949	0.164	0.391	0.007	Oct. 1952	0.079	—	—
May 1951	0.625	0.305	0.009	Mar. 1953	0.081	—	—
Jul. 1951	0.580	0.306	0.037	May 1953	0.080	—	—
Nov. 1951	0.226	0.458	0.028	Aug. 1953	0.256	—	—
Feb. 5. 1952	0.187	0.446	0.028	Sep. 1953	0.099	—	—
Mar. 11. 1952	0.193	0.334	0.028	Dec. 1953	0.085	—	—
" 24. 1952	0.176	0.406	0.032	Jul. 1954	0.072	—	—
Apl. 1. 1952	0.166	0.360	0.037	Sep. 1954	0.074	—	—
" 11. 1952	0.147	0.297	0.028				

* after H. Okuno

Exo- and Endo-Magmatic Hydrothermal Differentiations Observed among the Chemical Components Exhaled by Noboribetsu Volcanic Activity (Masayo Murozumi)

Table 12 Variation of the Activity of a Mixed Type Hell*

Date of Observation	T (°C)	pH	Cl ⁻	SO ₄ ²⁻	Na ⁺	Ca ²⁺	Fe ²⁺	Al ³⁺	Silicic Acid
1925	n.d.		0.70	0.723	0.443	0.128	0.034	0.029	0.360
Feb. 1938**	n.d.		0.954	0.722	0.499	0.148	0.042	0.064	0.381
Sep. 1938**	92	2.17	0.873	0.498	0.499	0.142	0.024	0.025	0.427
Feb. 1939**	94	2.07	0.883	1.08	0.496	0.144	0.035	0.036	0.438
Jul. 1949	94	2.3	2.79	0.543	1.30	0.409	0.017	0.065	0.434
Nov. 1949	93	2.4	2.70	0.659		0.396	0.019	0.030	
May 1951	86	2.5	2.06	0.506			0.020	0.020	
Jul. 1951	89		2.07	0.443			0.044		

* This hell was destroyed by its own explosion in Nov. 1951.

** after H. Okuno

Table 13 Variation of the Activity of a Mixed Type Hell

Date of Observation	T (°C)	Cl ⁻	SO ₄ ²⁻	Fe ²⁺	Al ³⁺	Silicic Acid
Sep. 1937*	98	1.02	0.298	0.015	0.046	0.597
Feb. 1938*	91	1.06	0.274	0.037	0.013	0.624
Oct. 1938*	95	1.12	0.315	0.007	0.016	0.477
Feb. 1939*	96	1.16	0.317	0.008	0.009	0.488
Jun. 1941*	91	1.25	0.355	0.018	—	
Nov. 1949	94	—	—	—	—	
May 1951	98	2.57	0.282	0.017	0.007	
Nov. 1951	99	2.94	0.301			
Feb. 1952	99	2.86	0.251			
Mar. 1952	99	3.00	—			
Jun. 1952	99	2.90	0.290			
Aug. 1952		3.15	—			
Sep. 1952		2.98	0.332			
Mar. 1953		2.62				
May 1953		2.38				
Aug. 1953		2.34				
Oct. 1953		2.37				
Sep. 1953		2.28				
Dec. 1953		2.31				
Apl. 1954		2.07				
Oct. 1954		1.90				
" 1955		1.35				
Nov. 1955		1.28				
Dec. 1955		1.29				
Jan. 1956		1.24				
May 1956		1.15				
Sep. 1956		1.12				

* after H. Okuno

In May, 1951, as the sudden increase of chloride ion concentration was observed throughout Death valley, it was planned to study succeeding changes in the activity by means of continuous geochemical observation of the element.

During increasing activity, chloride ion is gradually concentrated, but conversely it is diluted

Table 14 Variation of Chloride Ion Concentration of a Secondary Hydrothermal Solution, Picked up from the Data of the Daily Observation

Date of Observation	Cl ⁻ (g/l)	Date of Observation	Cl ⁻ (g/l)	Date of Observation	Cl ⁻ (g/l)
Sep. 1949	4.53	Jan. 9. 1952	4.42	Jun. 1. 1953	3.35
May 1951	4.64	" 10. 1952	4.43	Jul. 2. 1953	3.37
Jul. 1951	4.82	Feb. 5. 1952	4.50	Aug. 3. 1953	3.39
Nov. 27. 1951	4.17	Mar. 11. 1952	4.42	Sep. 1. 1953	3.34
" 28. 1951	4.18	Apl. 1. 1952	4.31	Oct. 1. 1953	3.28
Dec. 2. 1951	4.58	May 6. 1952	4.12	Nov. 2. 1953	3.24
" 3. 1951	4.53	Jan. 1. 1952	4.02	Dec. 1. 1953	3.13
" 4. 1951	4.56	Jul. 1. 1952	3.83	Jan. 20. 1954	3.07
" 5. 1951	4.62	Aug. 1. 1952	3.87	Feb. 13. 1954	2.96
" 6. 1951	4.67	Sep. 1. 1952	3.86	Mar. 2. 1954	2.87
" 7. 1951	4.63	Oct. 1. 1952	3.81	Jan. 23. 1954	1.72
" 8. 1951	4.53	Nov. 20. 1952	3.77	Aug. 23. 1954	1.76
Jan. 2. 1952	4.54	Dec. 2. 1952	3.74	Sep. 23. 1954	1.83
" 4. 1952	4.49	Jan. 8. 1953	3.55	Oct. 23. 1954	1.89
" 5. 1952	4.49	Mar. 11. 1953	3.45	Nov. 23. 1954	1.94
" 6. 1952	4.48	Apl. 1. 1953	3.38	Dec. 4. 1954	1.96
" 8. 1952	4.48	May 2. 1953	3.38	Aug. 1. 1955	2.32

Table 15a Variation of the Chemical Composition of a Secondary Solution Hot Spring, No. 5

Date	HCO ₃ ⁻ mil.		Na ⁺ mil.		Ca ²⁺ mil.		Cl ⁻ mil.		Na ⁺ /Cl ⁻ mil.	Ca ²⁺ /Cl ⁻ mil.	(Na ⁺ +Ca ²⁺)/Cl ⁻	SO ₄ ²⁻ (mg/l)
	(g/l)	Val.	(g/l)	Val.	(g/l)	Val.	(g/l)	Val.				
1949 7.	0.741	2.3	1.66	72.2	0.539	26.9	3.83	108	66.8 × 10 ⁻²	24.9 × 10 ⁻²	91.7 × 10 ⁻²	33
1951 7.	0.137	2.2	1.709	74.3	0.532	26.6	3.86	109	68.2	24.4	92.6	33
1951 11. 26	—	—	1.568	68.1	0.476	23.8	3.22	90.7	75.0	26.2	101.2	—
1952 2. 5	0.181	3.0	1.481	64.3	0.450	22.5	3.31	93.5	68.1	24	92	30
1952 3. 11	0.185	3.0	1.377	59.8	0.416	20.8	3.05	85.8	69.7	24.2	93.9	—
1952 6. 1	0.232	3.8	1.162	50.5	0.319	16.0	2.51	70.7	71.5	22.6	94.1	—
1952 7. 30	—	—	1.085	47.2	—	—	2.23	62.7	75.2	—	—	—
1952 10. 8	0.215	3.5	0.971	42.2	0.239	12.0	1.91	53.7	78.6	22.4	101.0	—
1953 3. 11	0.239	3.9	0.706	30.7	0.129	6.5	1.28	36.0	85.3	18.0	103.3	—
1953 5. 25	0.239	3.9	0.629	27.4	0.133	6.7	1.12	31.5	87.0	21.3	108.3	45
1953 8. 6	0.210	3.4	0.598	26.1	0.102	5.1	1.05	29.6	88.2	17.2	105.4	54
1953 9. 11	0.211	3.5	0.604	26.3	0.101	5.1	1.12	31.5	83.4	16.2	99.6	—
1953 10. 12	—	—	0.637	27.7	0.120	6.0	1.18	33.1	83.7	18.1	101.8	—
1953 12. 2	—	—	0.641	27.9	0.129	6.5	1.19	33.5	83.3	19.4	102.7	—
1954 3. 8	—	—	0.700	30.5	0.161	8.1	1.33	37.7	81.0	21.5	102.5	—
1954 5. 22	—	—	0.799	34.7	0.198	9.9	1.54	43.4	80.0	22.8	102.8	—
1954 7. 22	—	—	0.851	37.0	0.212	10.6	1.69	47.6	77.8	22.3	100.1	—
1954 9. 2	—	—	0.875	38.2	0.226	11.3	1.78	50.2	76.2	22.5	98.7	—
1955 9. 10*	—	—	1.05	45.7	—	—	2.45	69.0	66.3	—	—	—
1955 11. 30*	—	—	1.12	48.7	—	—	2.52	71.0	68.5	—	—	—
1956 1. 18*	—	—	1.11	48.3	—	—	2.51	70.7	68.3	—	—	—
1956 3. 27*	—	—	1.09	47.4	—	—	2.46	69.3	68.3	—	—	—
1956 5. 9*	—	—	1.09	47.4	—	—	2.41	67.8	66.8	—	—	—
1956 8. 4*	—	—	1.10	47.8	—	—	2.44	68.7	69.6	—	—	—
1956 9. 21*	—	—	1.14	49.6	—	—	2.51	70.7	70.1	—	—	—

* after H. Akaiwa

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during decreasing activity, as shown in those tables. As for major cations, their concentrations change parallel with chloride content at the first approximation. But, with regard to the mutual relation among chemical constituents, the values of Na/Cl, Ca/Cl and (Na/Cl+Ca/Cl) show the specific change taking place one after another as presented in Tables 15a and 15b. Another fact that has been found among chemical constituents is that Na/Cl decreases while Ca/Cl

Table 15b Variation of the Chemical Composition of a Secondary Solution
Hot Spring, No. 29

Date	Ca ²⁺ (g/l)	mil. Val.	Na ⁺ (g/l)	mil. Val.	Cl ⁻ (g/l)	mil. Val.	Na ⁺ /Cl ⁻ mil. Val.	Ca ²⁺ /Cl ⁻ mil. Val.	Na ⁺ +Ca ²⁺ /Cl ⁻ mil. Val.
1949 7.	0.652	32.6	1.86	80.8	4.53	127.7	63.3 × 10 ⁻²	26.5 × 10 ⁻²	89.8 × 10 ⁻²
1951 7.	0.695	34.8	2.148	93.3	4.89	137.8	67.8	25.3	93.1
" 11. 27	0.613	30.7	2.026	88.1	4.18	117.8	74.8	26.1	100.9
" 12. 3	0.630	31.5	2.263	98.5	4.53	127.7	77.3	24.6	101.9
" 12. 8	0.623	31.2	2.234	96.7	4.53	127.7	75.8	24.4	100.2
" 12. 19	0.637	31.9	2.283	99.3	4.51	127.1	77.8	25.0	102.8
" 12. 22	0.638	31.4	2.230	96.7	4.52	127.4	75.9	24.7	100.6
1952 1. 5	0.629	31.5	2.128	92.5	4.49	126.6	73.2	24.9	98.1
" 1. 18	0.667	33.4	2.339	101.8	4.47	126.0	80.7	26.5	107.2
" 1. 25	0.662	33.1	2.259	98.3	4.43	124.8	78.8	26.5	115.3
" 2. 5	0.606	30.3	2.015	87.7	4.50	126.7	69.2	23.9	93.1
" 3. 25	0.573	28.7	1.973	85.9	4.32	121.8	70.6	23.5	94.1
" 4. 24	0.544	27.2	1.936	84.2	4.22	118.9	70.8	22.9	93.7
" 5. 16	0.516	25.8	1.922	83.6	4.07	114.6	72.9	22.5	95.4
" 6. 1	0.514	25.7	1.921	83.5	4.02	113.3	73.8	22.7	96.5
" 6. 2	0.507	25.4	1.872	81.4	4.03	113.7	71.7	22.3	94.0
" 6. 9	—	—	1.949	84.8	3.97	111.9	75.8	—	—
" 7. 8	0.497	24.9	1.873	81.4	3.91	110.4	73.8	22.6	96.4
" 7. 10	—	—	1.961	85.2	3.98	112.2	75.8	—	—
" 9. 2	0.471	23.6	1.807	78.6	3.86	108.8	72.3	21.7	94.0
" 10. 13	0.474	23.7	1.828	79.5	3.81	107.4	74.1	22.1	96.2
" 10. 24	—	—	1.795	78.1	3.78	106.5	73.3	—	—
" 11. 25	0.443	22.2	1.765	76.8	3.71	104.7	73.4	21.2	94.6
" 12. 19	0.427	21.4	1.739	75.7	3.61	101.7	74.4	21.0	95.4
1953 1. 8	0.427	21.4	1.734	75.4	3.55	100.0	75.4	21.4	96.8
" 3. 30	0.400	20.0	1.658	72.2	3.45	97.1	74.3	20.6	94.9
" 4. 14	0.403	20.2	1.665	72.4	3.41	96.0	75.4	21.1	96.5
" 5. 25	0.395	19.8	1.646	71.6	3.39	95.4	75.1	20.8	95.9
" 6. 6	0.406	20.3	1.658	72.2	3.45	97.1	74.3	—	—
" 7. 7	0.413	20.6	1.681	73.1	3.49	98.4	74.3	—	—
" 8. 6	0.406	20.3	1.662	72.3	3.39	95.4	75.8	21.3	97.1
" 9. 9	0.395	19.8	1.612	70.2	3.29	92.7	75.8	21.4	97.2
" 12. 12	0.384	19.2	1.585	68.9	3.25	91.6	75.3	21.0	96.3
" 12. 2	0.356	17.8	1.547	67.2	3.12	87.8	76.6	20.3	76.9
1954 3. 8	0.327	16.4	1.432	61.8	2.83	79.7	77.7	20.6	98.3
" 5. 22	0.329	16.5	1.442	62.8	2.84	80.0	78.5	20.7	99.2
" 7. 22	0.350	17.5	1.468	63.8	3.03	85.4	74.8	20.5	95.3
" 9. 2	0.427	21.3	1.49	64.8	3.11	89.0	72.8	20.9	96.7

increases conversely in the increasing period of the activity, but on the other hand, Na/Cl increases and Ca/Cl decreases in the decreasing activity. This phenomenon shows that although Cl, Na and Ca ions are expelled into the solution much more than K and Mg ions from so called magma at the hydrothermal stage, some differentiations exist even among former elements when the activity is affected by minor changes.

Chloride ion is more sensitive than sodium and calcium ions to these minor changes of the activity. And Ca ion is replaced by Na ion in the expelled solution during the period of the intense activity. That is, during this period Na ion is much more retained in so called magma than Ca ion is.

This is the endo-magmatic hydrothermal differentiation of major elements. To be more precise, apparent changes of the activity were recognized several times as shown in Table 16. When the changes in activity are trending in one direction i.e. increasing or decreasing activity, the Na/Cl value progresses to the limited direction. When the process of the variation is turned to the opposite direction, a very obvious and discontinuous change is introduced into the characteristic figure of the change of this chemical value. That is, the specific value of Na/Cl increases gradually during the decreasing period of the activity, despite of the decrease of both Na and Cl ions' contents. On the other hand, Na/Cl decreases during the increasing activity when all elements become concentrated.

Table 16 Variation of the Strength of Noboribetsu Volcanic Activity

Date of Observation	Activity
July —Nov. 1951	Temporary decreasing activity before violence
Nov. 26 —Dec. 2. 1951	Sudden changes towards increasing activity
Dec. 1951 —Jan. 1952	The most violent activity
Jan. 25 —Feb. 5. 1952	Explosion, accompanied by weak earthquake Chemical composition was changed decidedly. Decreasing tendency started, but the apparent activity remained very violent.
—Aug. 1953	Decreasing activity
Aug. 6 —Sep. 11. 1953	Decreasing activity changed to increasing activity, chloride ion concentration started to increase.
—present (1957)	Chloride ion has been concentrated.

Ca/Cl exhibits the opposite property to Na/Cl, as already mentioned.

Sum of values (Na/Cl+Ca/Cl) also changes specifically in accordance with changes in the activity. This value is smaller than 1.0 during the increasing activity but becomes larger than 1.0 in the decreasing time. When the value is larger than 1.0, in other words when the activity is kept at the consumed stage, more CO₂ is introduced to form HCO₃ ion in the secondary solution. Carbonate compounds, calcite and aragonite thus show variation of volcanic activity.

K ion shows the same character as Na ion, and K/Cl changes inversely with Cl ion concentration as presented in Table 17. Mg ion, however, makes an obscure change.

In regard to halogen ions, some differentiation is also observed among Cl, Br and I ions. I ion is more concentrated in this volcanic hydrothermal solution than in other mineral ones.

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These three halogen ions show the same increasing and decreasing properties with changes in volcanic activity at the first approximation. But, speaking correctly, as presented in Table 18, a small differentiation takes place among these three ions also. The most sensitive ion to the

Table 17 Endo-magmatic Hydrothermal Differentiation of Potassium

Date of Observation	K ⁺ (g/l)	mil. Val.	Cl ⁻ (g/l)	mil. Val.	K ⁺ /Cl ⁻ in mil. Val. Ratio
Jul. 5. 1951	0.199	5.09	3.80	109	4.7
Feb. 5. 1952	0.159	3.99	3.31	98.8	4.0
May 25. 1953	0.075	1.92	1.12	31.5	6.1
Aug. 6. 1953	0.072	1.84	1.05	29.6	6.2
Sep. 11. 1953	0.068	1.74	1.12	31.5	5.5
Oct. 12. 1953	0.072	1.94	1.18	33.1	5.9

Table 18 Endo-magmatic Hydrothermal Differentiation Observed among Halogen Ions

Date of Observation	Cl ⁻ (g/l)	I ⁻ (mg/l)	Br ⁻ (mg/l)	Br ⁻ /I ⁻
Nov. 27. 1951	4.18	2 ~2.5		
Dec. 2. 1951	4.58	3 ~3.5		
" 5. 1951	4.62	3.5~4.0		
" 8.~Dec. 20. 1951	4.53~4.74	3 ~3.5		
" 24. 1951	4.55	2.5~3.0		
" 29. 1951	4.52	2.0~2.5		
" 31. 1951	4.52	3.0~3.5		
Jan. 2.~Jan. 16. 1952	4.58~4.46	2.0~2.5		
" 18. 1952	4.47	3.0~3.5		
" 21. 1952	4.42	2.0~2.5		
" 29.~Mar. 22. 1952	4.38~4.27	3.0~3.5		
Apl. 1. 1952	4.31	2.0~2.5		
" 8. 1952	4.29	2.7	6.9	2.6
" 16. 1952	4.25	2.6	6.2	2.4
" 22. 1952	4.17	2.8	6.3	2.3
May 17. 1952	4.12	2.6	6.2	2.4
Jun. 24. 1952	3.95	2.4	6.0	2.5
Jul. 13. 1952	3.91	2.0		
Aug. 10. 1952	3.90	2.0		
" 20. 1952	3.68	1.6		
" 23. 1952	3.89	2.0		
Sep. 16. 1952	3.86	2.3	5.2	2.3
Oct. 18. 1952	3.84	2.2	5.9	2.7
" 27. 1952	3.77	2.1	5.6	2.7
Dec. 16. 1952	3.63	2.0	5.5	2.8
Mar. 17. 1953	3.42	2.0	5.5	2.8
Jun. 1. 1953	3.35	1.9	5.3	2.8
Oct. 1. 1953	3.28	1.8	5.2	2.9
Nov. 17. 1953	3.15	1.8	5.2	2.9
Feb. 8. 1954	2.99	1.7	4.8	2.8
Jun. 28. 1954	2.98	1.7	4.8	2.8
Dec. 1. 1954	3.38	1.9	5.3	2.8

variation is I ion, for the degree of the concentration of I ion at active time is larger than that of Cl and Br ions.

Isotopic Fractionation of Hydrogen in Hydrothermal Water

Isotopic fractionation of hydrogen composing a secondary hydrothermal water is determined in the special relation to recent variations of the post-volcanic activity. Protium content of the hydrothermal water seems to be enriched over that of fresh water during the increasing activity. On the contrary it becomes smaller than that of fresh water during period of decreasing activity as shown in Table 19. This means that isotopic fractionation of hydrogen exists and becomes apparent during changes in the post-volcanic activity.

Table 19 Isotopic Composition of Hydrogen in a Secondary Solution

Date	Mean Deviation from Tokyo Tap Water	Chloride Ion Concentration (g/l)	Post-Volcanic Activity
Feb. 5. 1952	-1.33	4.50	Increased
Oct. 11. 1952	-1.22	3.89	
Mar. 11. 1953	+1.73	3.45	
May 25. 1953	-0.52	3.37	
Aug. 6. 1953	-0.25	3.39	
Oct. 12. 1953	+0.70	3.24	
Dec. 2. 1953	+1.29	3.12	
Mar. 8. 1954	+1.40	2.83	
May 22. 1954	+1.29	2.84	Decreased
Jul. 13. 1954	+0.91	2.06	
Sep. 13. 1954	+0.54	3.12	

Analyzed by Dr. Y. Horibe and Miss. M. Kobayaka of Tokyo Metropolitan University

The cause of the isotopic fractionation has not been made clear but the following explanation is considered most probable.

At the adiabatic expansion of the original hydrothermal solution, the isotopic exchange equilibrium is established between the steam and the residual solution. The more the amount of steam separated from a unit volume of the original hydrothermal solution, the more enriched in deuterium the residual secondary solution. Through the exo-magmatic processes, the temperature and the volume of the original hydrothermal solution undergoing the adiabatic expansion are considered to be the most important factors in the fractionation of the hydrogen isotopic composition. Isotopic analysis is in progress.

Hypothetical Relation of the Variation to Some Other Geological and Geophysical Phenomena

As presented in Table 16, the sudden changes of the thermal water took place twice in November 1951 and in February 1952 just before the Tokachioki earthquake, when the activity was at the maximum strength. The earthquake occurred on April 4, 1952. With the change of February, 1952, the activity started to decrease rapidly until August, 1953 (cf. Table 15 a, b).

It should be noticed that these two changes occurred just before the earthquake.

Papers¹¹⁾ have reported that disturbances in chemical composition of ground and mineral

waters have taken place before and after many earthquakes. Compared with such cases discussed in these papers, the distance between Noboribetsu and Tokachioki is much farther. In fact, the distance may be too long to consider these two natural phenomena in connection, although both took place synchronously. Still, it seems impossible at present to deny completely the hypothetical existence of some relations between them. Elucidation of this problem shall be made through future investigations.

Moreover, the recent variations of Noboribetsu volcanic activity are also synchronous with the new birth of Showashinzan¹²⁾ which is only 30 kms to the west. As shown in Table 13, enrichment of chloride ion in a mixed type solution had started in Feb. 1938, 5 years before the activity of Showashinzan, although nothing exact was known before. Fig. 1 shows that concentration of chloride ion increased gradually from a minimum value. And it is seen that enrichment of the element reached the maximum point right after the formation of Showashinzan.

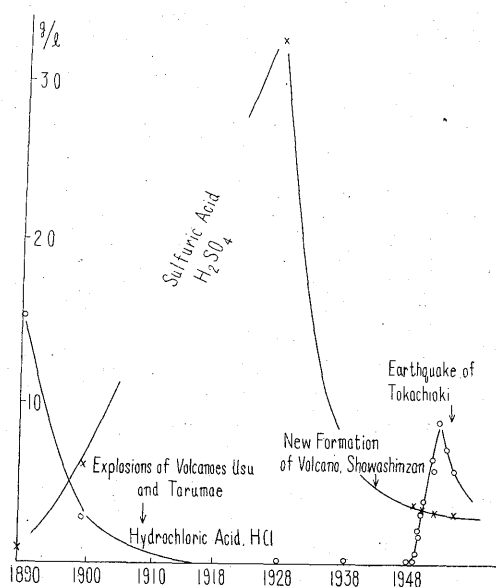


Fig. 1 Variation of Noboribetsu Volcanic Activity, Analytical Result of Hot River Water

differentiations. It has been confirmed that its geochemical properties change in accordance with variation in activity. In this paper, the changes of the chemical composition of the original hydrothermal solution on which the activity depends have been analysed with special reference to such variations. It is found that there exists endo-magmatic hydrothermal differentiation among chemical components. This is a fact which has never been observed so clearly in other activities.

By analysing the specific figures of Na/Cl and Ca/Cl ratios, and of chloride ion concentration, it becomes possible to get clues about the inner cause of the activity change. Moreover, it also becomes possible in Noboribetsu to make preliminary forecasts of future variations⁶⁾ as much as 20 months before their occurrence, by the application of this new evidence.

Therefore, in our country which abounds with many volcanoes and related hot springs, the

Furthermore, Noboribetsu volcanic activity seems to be least active during 1910 and 1930. Neighbouring volcanoes, Tarumae¹³⁾ and Usu¹⁴⁾, however, had their explosions in 1909 and 1910 respectively. And it should be noticed that analytical data show an abnormal enrichment of chloride ion in Death valley's activity in 1900, 10 years before these explosions and several years after the previous explosion of Tarumae in 1894.

Elucidation of such a relation between Noboribetsu and neighbouring volcanic activities must depend on future investigations.

Conclusions

The hydrothermal activity in Noboribetsu corresponds to the last stage of a series of Kuttara volcanic activities, and shows the very distinct exo-and endo-magmatic hydrothermal

completion of this investigation may throw some light upon true preliminary forecasts of volcanic activity by means of geochemical methods, i.e. by the analysis of the chemical components exhaled by volcanoes through their craters or neighbouring hot springs.

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登別火山活動により放出される化合物中に観察された熱水分化

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要 旨

北海道登別の温泉活動は倶多楽火山活動の終熄に相当するものである。倶多楽火山活動のおもなものは西山・中央火山・同カルデラ・北山・日和山・舟見山の生成および大湯沼・地獄谷の爆發であるが、両爆裂火口内およびその外壁直下で本邦屈指の規模をもって温泉活動が続けられている。この登別温泉活動は、(1) 放出エネルギーが著しく大きく、(2) 噴気孔および温泉から噴出湧出される化学成分の相互間に完全な Exo-magmatic Hydrothermal Differentiation が存在し、(3) 温泉活動の消長に応

じ Endo-magmatic Hydrothermal Differentiation も観測されるという3つの特徴をそなえている。すなわちこの地域の温泉活動は見掛け上噴気孔・酸性泉・中性食塩泉さらに熔融硫黄の噴出等による複雑な径路でエネルギーを放出しているが、放出される化学成分の量および相互間の比は活動根源の状態を反映している。

本報告では、地球化学的方法によって、前に述べた(1)～(3)の特殊性を解析するとともに、登別温泉活動の消長と同時発生的な他の地質現象(昭和新山の生成)、地球物理学的現象(十勝沖地震の発生)との相関関係の存比に触れる。