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NATURAL CONVECTION SYSTEM AT THE OHNUMA-SUMIKAWA GEOTHERMAL FIELD, NORTHEAST JAPAN

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ABSTRACT

A number of wells were drilled, and downhole temperature and pressure surveys were conducted to identify the major feed point of geothermal fluid, and to determine the subsurface distribution of pressure and temperature in and around the developing area. The isothermal map reveals that the heat source in the area is probably seated beneath the volcanic chain. The pressure distribution provides important insights concerning the general characteristics of the natural-state flow pattern in the area. Based on the subsurface isobars map, the natural-state convection system in the area is estimated as follows:

(1) It is virtually certain that a vapor-dominated flow region is present in the southern part of the reservoir system at a depth extending from the lower part of the caprock.
(2) The up-flow zone of the geothermal fluid is located in the southern part of the area. The down-flow zone is in the northern part of the developing area, as a whole, forming a large convection cell.

A study of the natural-state flow pattern based on field data is being examined to design the most suitable field development scheme.

INTRODUCTION

Prior to the oil crisis that occurred in 1973, Mitsubishi Metal Corporation (MMC) commenced geothermal exploration in 1965 aimed at power generation to be used for domestic power consumption on the northern slope of the Hachimantai volcanic region.

To delineate the most potential area, various exploration methods were employed and a number of wells were drilled covering around 30 km^2. The borehole field in the area was classified into four sectors—Sumikawa, Ohnuma, Taninainuma, and Kuraazawa-gawa—from the south to the north.

The Ohnuma 10 MWe power plant was installed in the latter part of 1973, and power has been transmitted to MMC's Akita zinc refiner since 1974. Exploitation of the Sumikawa field commenced after commissioning of the Ohnuma power plant in 1981. Up to the present, six production wells distributed in the southern part of the Sumikawa field are intended to supply steam to a 50 MWe power plant, which will be installed in the near future. The Taninainuma field has been developed for the direct use of waste water from the Ohnuma wells, while the Kumazawagawa field was also investi-gated to survey subsurface temperature and pressure gradient in the early stage of exploitation.

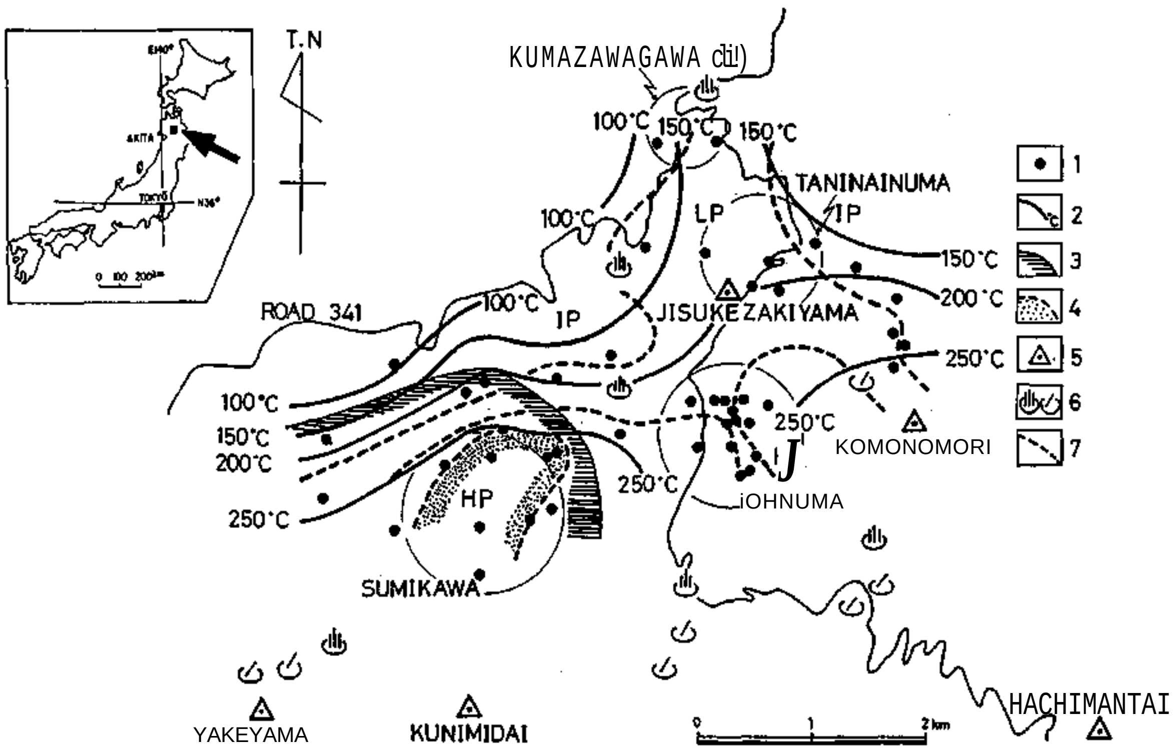

Figure 1. Outline map at the Ohnuma-Sumikawa geothermal area (modified from Kubota, 1985). 1: locality of well bottom, 2: isotherm at sea level, 3: distribution area of unconsolidated lacustrine sediment, 4: vapor-dominated area, 5: volcano, 6: geothermal manifestation, 7: distribution of permeability; IP: impermeable, LP: low-permeable, HP: permeable

RESERVOIR CHARACTERISTICS

Well localities, subsurface temperatures, permeability distribution, etc. are illustrated in Figure 1, and a summary of each well field is listed in Table 1.

The Ohnuma-Sumikawa geothermal reservoir is a liquid-dominated type with a two-phase zone overlying the liquid phase in its natural state.

Results of the geoscientific exploration and deeply drilled wells provided the following information on the geological structure and reservoir characteristics as suggested by Kubota (1985).

(1) North-south structure characterized by a dual series of graben and uplifted zones was formed in the regional district of the Hachimantai area. The east-west trending volcanic chain connects Mt. Hachimantai and Mt. Yakeyama, which are active volcanoes intersecting with north-south structure at the southern part of the Ohnuma-Sumikawa geothermal reservoir.

The Pre-Tertiary basement has not yet to be confirmed even with the deepest well (2486 m) in the area. The lowest formation identified is granodiorite, which intrudes into the Tertiary formation.

(2) Subsurface temperatures appear to be highest to the south, implying that the thermal anomaly is closely associated with the east-west volcanic chain located to the south in the area. It is believed that deep heat sources in the area itself underlie the volcanic chain.

(3) Underground pressures are approximately uniform throughout the area at depth. In the shallower parts of the area, vertical pressure distribution is characterized by a substantially subhydrostatic gradient. The Quaternary volcanics and lacustrine sediments serve as relatively impermeable caprocks for the two-phase or vapor-dominated geothermal system.

(4) Fluid flows principally through an extensive network of fractures. While drilling, regions of lost circulation are frequently encountered within the high-temperature zone, but fractures within the cooler parts of the area are sealed with vein materials. The fracture system was formed by volcanic activity, and self-sealing has occurred within the cold-water recharge area.

TEMPERATURE PROFILE

Static temperature profiles as to the depth of each well field are shown in Figure 2.

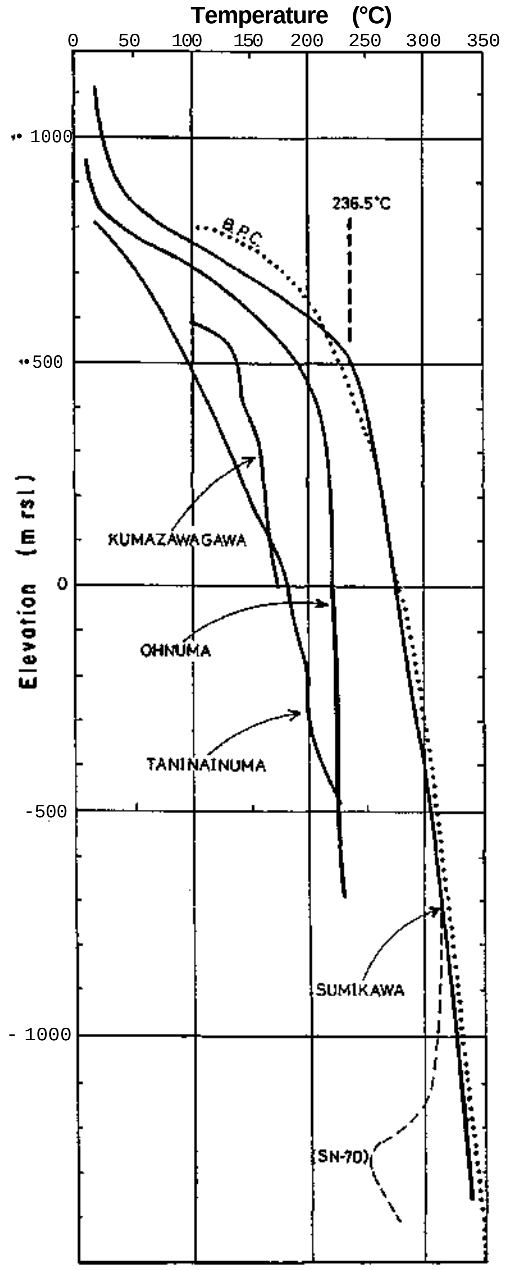

Figure 2. Temperature profile of each field.

Table 1. Summary of each well field at the Ohnuma-Sumikawa geothermal area.

LOCALITY		SUMIKAWA	OHNUMA	TANINAINUMA	KUMAZAWAGAWA
NUMBER OF WELLS		11	13	6	3
DRILLED DEPTH(m)	Min.	448	635	710	80
	Max.	2486	1768	1406	701
BOTTOM ELEVATION (mrsl)	SHALLOWEST	+576.2	+ 300	+ 149	+523
	DEEPEST	-1400.4	-778	-513	-11
LOST CIRCULATION INDEX (m^3/hr/m)		0.274	0.241	0.089	ND
STATIC TEMP.	WELL	SA-2	0-1 OR	K-2	0-2T
	ELEV.(mrsl)	-836	-535	-355	-10
	TEMP.(°C)	317	226	236	176
	ELAPSED TIME(hrs)	261	*EST	*EST	529

*EST : estimated from HORNER plot

The Sutnikawa field shows highest temperatures of the subsurface in the area; its maximum of 317°C was measured at an elevation of -840 mrsl, at the bottom of Well SA-2. The temperature profile below +400 mrsl is nearly equal to the boiling curve with depth. A low-temperature anomaly at -1220 mrsl of the deepest hole, Well N61-SN-7D, was measured 4248 hours after an injection test, but the anomaly still may not have been reached to be considered as static. The temperature profile above +600 mrsl suggests a conductive heat transfer through impermeable formations, and the shallowest temperature profile shows a cold ground aquifer. Vertical temperature gradient in the north of the Sumikawa field is low, similar to a temperature pattern in the Ohnuma field.

One characteristic in the Ohnuma field is that the temperature profile for depth below +400 mrsl scarcely increases any further, the maximum temperature being 225°C at the bottom (-263 mrsl) of Well 0-2R. The temperature profile in the shallow formation has not been determined as a result of a lack of data.

Temperature in the Taninainuma well field linearly increases with depth, showing a tendency to be higher below -500 mrsl than that in the Ohnuma field. In variation, the temperature profile of Well K-l in the south of the field is similar in pattern to the Ohnuma field, and temperature in the northwestern part in this field is around 20°C lower than in the central part.

The borehole temperature in the central part of the Kumazawagawa field is approximately 40°C higher than in the western part of the field, which is almost equal to geochemical temperature determined from natural weak-saline hotspring water.

PRESSURE PROFILE

Reservoir pressure at the feed point is plotted against elevation, as shown in Figure 3. It can be clearly recognized that the pressure profile of each field differs.

In the Sumikawa well field, the pressure profile below +400 mrsl is nearly equal to the saturated pressure profile of the pure water column, and vapor pressure above +400 mrsl is approximately 3.1 MPa in which the specific enthalpy of vapor is highest in a saturated state. Then, pressure Ps (MPa) against elevation H (mrsl) for a liquid-dominated reservoir is given by equation (1), which is the same as the equation for the saturated pressure profile of the pure water column given by Hass (1971).

$$Ps = 0.1 \times 0.1897 \times (800-H)^{0.8719} \qquad ...(1)$$

In the Ohnuma field, feed point pressure only before operation of the power plant is also shown in Figure 3. The shallowest one, Well 0^7T, suggests the presence of a two-phase reservoir from a low vertical pressure increase. Correlation of pressure Po (MPa) against elevation H (mrsl) is given by the following:

$$Po = (785.7-H) \times 769.8 \times 10^{-5} \qquad ...(2)$$

Pressure profiles for depth in the Taninainuma field Pt (MPa) and the Kumazawagawa field Pk (MPa) are written as equations (3) and (4), respectively.

$$Pt = (566.3-H) \times 933.9 \times 10^{-5} \qquad ...(3)$$
$$Pk = (590.5-H) \times 924.4 \times 10^{-5} \qquad ...(4)$$

Pressure at the shallow cold aquifer in volcanic rocks is also plotted in Figure 3. Deep pressure extrapolated from this shallow profile is far higher than that of the geothermal reservoir.

PERMEABILITY PROFILE

Lost Circulation Index (LCI), indicating reservoir permeability, is defined as equation (5).

$$LCI = Ql/Lv \qquad ...(5)$$

where, Ql is lost circulation flowrate (m^/hr) and Lv is vertical drilled depth (m).

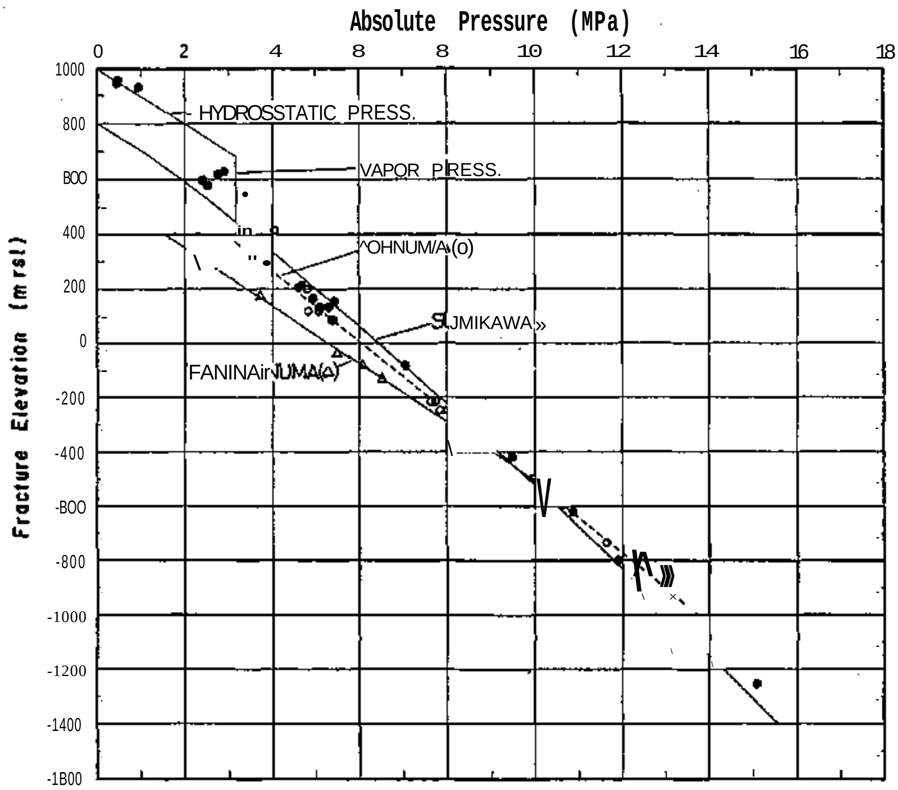

Figure 3. Pressure profile of each field.

The LCI for every well field is plotted against elevation at every 100 m depth as shown in Figure 4, and horizontal distribution of permeability estimated from LCI is illustrated in Figure 1, High-LCI is frequently encountered within the high-temperature zone.

Observable in the Sutnikawa field are two low-LCI zones of +700 to +900 mrsl and -200 to +400 mrsl, the former zone corresponding to the layer of weakly consolidated lacustrine sediment; however, the latter zone is not related to the distribution of geological formations.

Also estimated in the Ohnuma field are two low-LCI zones, constituting above +500 mrsl and -200 to -500 mrsl. These low-permeabile zones are not associated with geological succession.

The Taninainuma field is the lowest in permeability, indicative of LCI values in three well fields. Two impermeable zones are also marked above +400 mrsl and -200 to -500 mrsl, completely unassociated with subsurface geology.

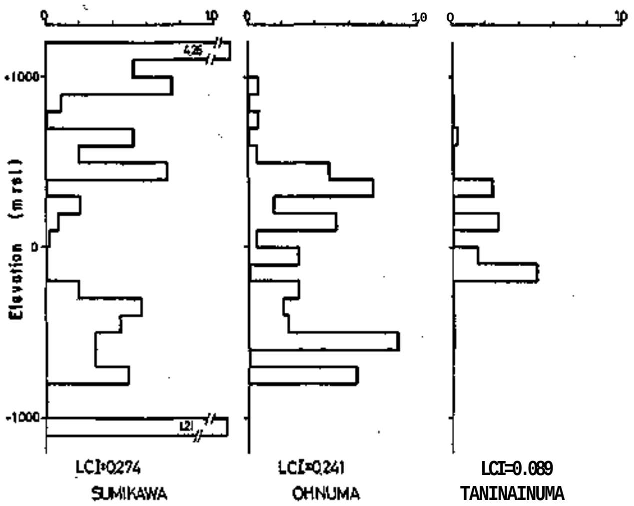

Figure 4. Vertical profile of LCI (Lost Circulation Index).

FLUID POTENTIAL

Fluid potential ($) is the resultant of the force acting (1/px grad P) and gravity potential (U) as shown in equation (6).

$$\text{grad } \$ = 1/px \text{ grad } P + \text{grad } U \quad ...(6)$$

Thermal fluid moves in the direction of the fluid potential gradient vector. Pressure gradient (grad P) is estimated from equations (1) through (4), and saturated fluid density (p) is given from the subsurface temperature profile shown in Figure 2.

Fluid potential gradient and its direction computed at each well field are shown in Figure 5. Up-flows are inferred at the Sumikawa, Taninainuma, and Kumazawagawa fields. In the steam cap zone developed at the shallow part of the reservoir, the fluid probably flows upward, while down-flow is estimated at the Ohnuma field, and at an elevation of around 0 mrsl of the Sumikawa field.

NATURAL CONVECTION SYSTEM

The convection system in a natural state of the geothermal field has been defined from numerical and laboratory experiments. In this study, a convection system of the Ohnuma-Sumikawa geothermal field is preliminarily discussed by an approach from temperature and pressure data measured at the fields.

Since a number of wells have been drilled in the fields—Sumikawa, Ohnuma, and Taninainuma, a reservoir pressure profile can be estimated by relating with pressures measured at feed points. On the basis of pressure distribution projected on an orthogonal plane to the volcanic chain to the north, the isobar dips toward the southern volcanic chain at a deeper level, and toward the north at a shallower level, as shown in Figure 5. The shallow part of the Kumazawagawa field is a little higher in pressure than that in the Taninainuma field. The upper impermeable zone has been mapped near an isobar of 2 or 3 MPa, acting as a caprock of the vapor-dominated reservoir and as a barrier to prevent an infiltration of cold surface water. As shown in Figure 5, distribution of the

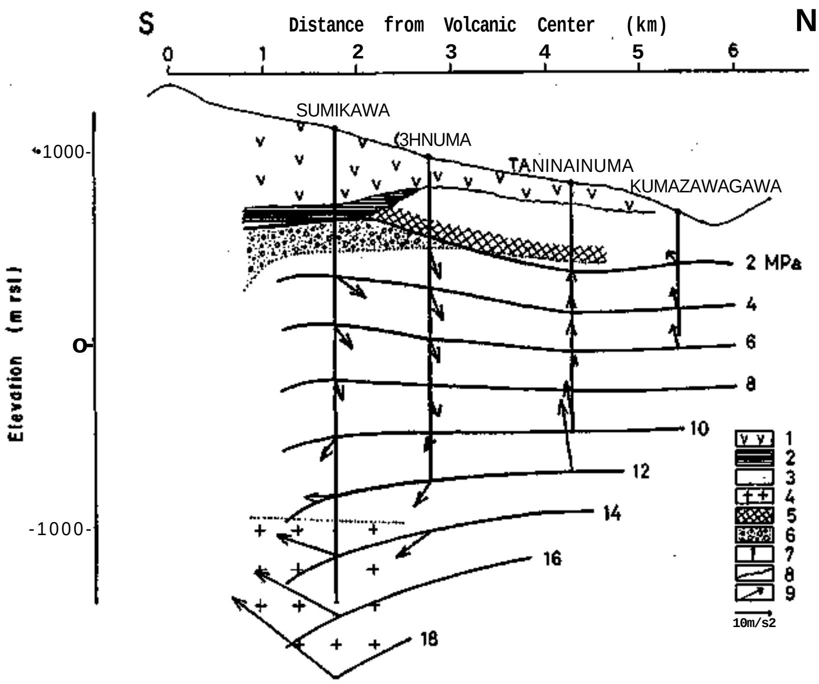

Figure 5. Fluid potential map profiled on the section from volcanic center to north. 1: Quaternary volcanics, 2: unconsolidated lacustrine sediment, 3: Tertiary formation, 4: granodiorite, 5: low-permeable/impermeable 6: vapor-dominated reservoir, 7: well, 8: isobar, 9: fluid potential and its vector.

impermeable zone does not correspond to the geological formation, therefore, there is a possibility that the impermeable zone was formed by self-sealing.

The geothermal fluid flows upward above the heat source situated beneath the volcanic chain, and the fluid flow changes to down-flow about 3 km from the volcanic center. Features of the temperature profile at the Ohnuma field also suggest the presence of down-flow. Another up-flow zone, in the Kumazawagawa field, is sighted 5 km from the volcanic chain, where subsurface temperature is chemically detected to be above 200°C. This convection cell might have been taken place as the result of another deep heat source, or it might have been formed by vying between potential flow and thermal convective flow, as shown in numerical simulation by Yusa (1983).

The vapor-dominated reservoir, closely related to the up-flow system, and depth of the bottom of the vapor zone, will similarly increase to the south toward the heat source. Both the isobar and isotherm also may dip southward.

The horizontal distribution of subsurface temperature probably indicates that low-temperature zones in the northwest and northeast areas to the Ohnuma field are recharge areas of cold water. A deep recharge flow is probably situated at a level below -2 km rsl.

The convection system previously mentioned is conceptually illustrated in Figure 6. The natural-state convection system estimated in this study, based on field data, is qualitatively consistent with the three-dimensional numerical study in the Sumikawa field of Maki et al. (1988).

From this study, aimed at proposing a natural convection system, the most promising area to develop the geothermal resources will be selected to choose an area showing minor differences in temperature along the fluid flow line, because the self-sealed zone probably results mainly from scaling of SiO_2 or $CaCO_3$ as a consequence of temperature changes.

CONCLUDING REMARKS

A number of wells were drilled, and downhole temperature and pressure surveys were conducted to identify the major feed point of geothermal fluid. Based on the subsurface isobars map, the natural-state convection system in the area is estimated as follows:

(1) It is virtually certain that, a vapor-dominated flow region is present in the southern part of the reservoir system at depth, extending from the lower part of the impermeable layer.
(2) It is also recognized that the up-flow zone of the geothermal fluid is located in the southern part of the area where an east-west trending volcanic chain exists, and the down-flow zone is in the northern part of the developing area, as a whole, forming a large convection cell.
(3) Another small convection cell has been formed far from the volcanic center, resulting from a related deep heat source or vying between potential flow and thermal convective flow.

Study of the natural-state flow pattern is being investigated, aimed at designing the most suitable field development scheme.

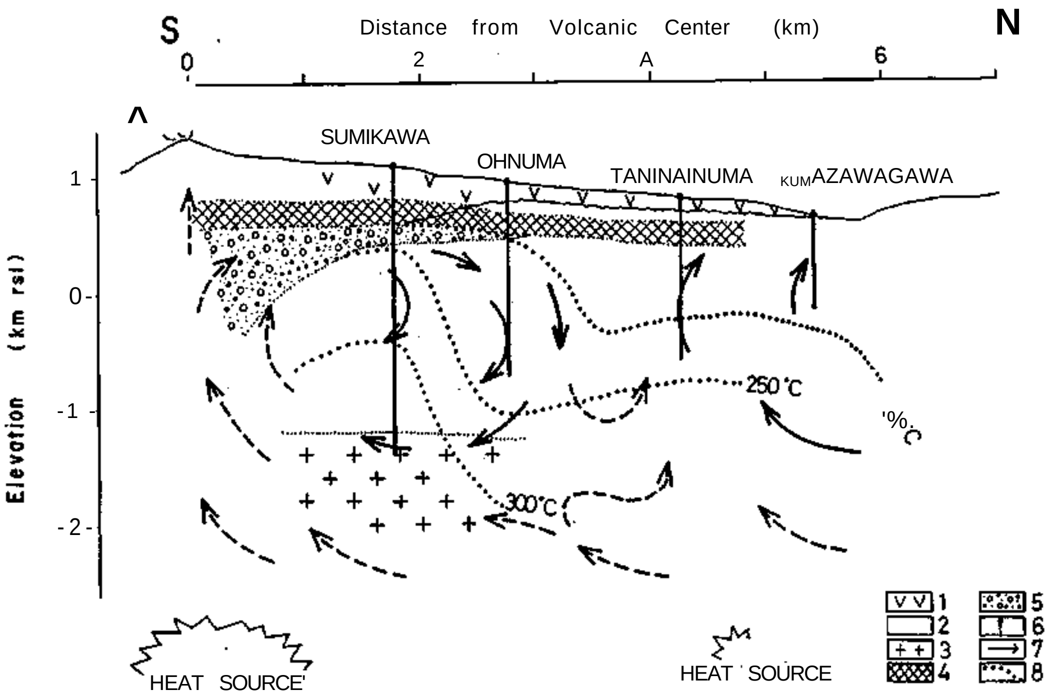

Figure 6. Schematic profile for natural convection system of the Ohnuma-Sumikawa geothermal area. 1: Quaternary Volcanics, 2: Tertiary formation, 3: granodiorite, 4: low-permeabile/ impermeable zone, 5: vapor-dominated reservoir, 6: well field, 7: flow line determined and estimated, 8: isotherm.

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