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GEOTHERMAL SYSTEMS IN THE AKINOMIYA AREA, NORTHEAST JAPAN

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ABSTRACT

The authors have been investigating the characteristics of geothermal systems in the Akinomiya geothermal area under the Geothermal Development Promotion Survey by New Energy and Industrial Technology Development (NEDO) since 1996. Five investigation wells (N8-AY-1, N8-AY-2, N9-AY-3, N9-AY-4 and N9-AY-5) have been drilled. NEDO (1997, 1998) has discussed the results of this project in detail. We have conducted a geological survey on the surface, the cores and cuttings observation, FMI (Fullbore Formation Microimager) logging, gravity and electromagnetic surveys. As results of our investigations, we can deduce the geology, the geologic structure and the fracture systems. Using temperature logging and thermoluminescence, we clarified the temperature structure and the thermal regime. We have used X-ray diffraction to clarify the distribution of hydrothermal alteration on the surface and underground. We have examined the geochemistry of the geothermal discharge fluids and hot spring waters, Hg content, pressure logging, reservoir pressure monitoring, and pressure transient tests. Based on these surveys, we can infer the thermal structure, geochemical features, reservoir pressure and permeability near the wells. In this paper, we discuss the geology, structure, fracture systems, heat structure, reservoir pressure, geochemistry, and geothermal fluid flow, and also discuss the conceptual model and characteristics of hydrothermal convection systems in the area.

1. INTRODUCTION

The Akinomiya geothermal area is located in the southeastern part of Akita prefecture (Fig.1). The eastern part is inside the Kurikoma national park. NEDO has been executing the geological survey, geophysical survey, logging, geochemical survey and drilling of five investigation wells under the Geothermal Development Promotion Survey (Survey C) in the area since 1996. In the surrounding areas, several investigation wells have been drilled also by NEDO under the Geothermal Development Promotion Survey in Yuzawa-Ogachi area from 1982 to 1984 (NEDO,1985) and Wasabizawa area from 1993 to 1997 (NEDO,1994;1996). A few wells have been drilled by Central Research Institute of Electric Power Industry (CRIEPI) under the Project of Hot Dry Rock Generation Technology. A production well (T-501) which has been supplying hot water to the Ogachi town was drilled by Japan Metals & Chemicals Co. LTD. (JMC). To the north of the area, Uenotai geothermal power station of 27.5 MWe has been in operation since 1994 by Tohoku Electric Power Inc. (TEP) where Akita Geothermal Energy Co., Ltd. (AGECO) is a steam supplier. In the Akinomiya Geothermal Development Promotion Survey, the highest temperature from the logging (Standing Time=108 days) in N8-AY-1 is 287.9℃ at –563m a.s.l. (above sea level). Steam of 68.1 t/h (tons/hour) and hot water of 127.7 t/h (at atmosphere pressure) were confirmed from the production test of well N9-AY-3.

2. RESULTS AND DISCUSSION

2.1 Geology

The stratigraphy is divided into the basement rocks of the Pre-tertiary, the Tertiary rocks, and the Quaternary rocks in ascending order. The basement rocks of Pre-Tertiary mainly consist of granodiorite, mylonite and schist. The Tertiary rocks are divided into three formations which are named Semi Formation, Yakunaigawa Formation and Torageyama Formation. The Semi Formation mainly consists of andesitic tuff breccia and conglomerate. The Yakunaigawa Formation mainly consists of pyroclastic rocks, andesite lava, siltstone and sandy shale. The Torageyama Formation mainly consists of pyroclastic rocks and siltstone. The formation is subdivided into two rock units by the key bed of siltstone. The Quaternary Takamatudake Volcanic Rocks consist of dacite lava. And some andesite dikes intrude into the Pre-tertiary and the Tertiary formations.

2.2 Geological Structure

We have confirmed the geological structure by the comparison with the well geology. The boundary of the basement rocks and the Tertiary rocks are confirmed at 557m a.s.l. in N8-AY-1, -650m a.s.l. in N8-AY-2, 554m a.s.l. in N9-AY-3, -472m a.s.l. in N9-AY-4, below -584m a.s.l. in N9-AY-5, and below -1160m a.s.l. in N58-YO-8. The depth of the basement rocks is changeful, the largest difference of altitude is more than 1700m. This geological structure is controlled by fault systems which strike the northwest, northeast, and east-west (Fig.1).

Detailed gravity prospecting and 3D modeling were carried out in the area. The high gravity gradient are identified by the distribution of the bouguer anomaly (Fig.1). The Pre-tertiary rocks and the Tertiary rocks are high density and low density respectively. So the gravity structure indicates the distribution of the basement rocks. The high gravity gradient in the direction extending from N8-AY-1 to N8-AY-2 suggests the largest structure in the area (Fig.1). There are the high gravity area on the east and the low gravity area on the west to this structure. The low gravity area on the west, named the Akinomiya low gravity zone, indicates the collapse structure of the basement rocks. We presume that this high gravity gradient indicates the location of the high angle fault which is the boundary between the Tertiary rocks and the Pre-tertiary rocks. The high density body at shallow level under Mt. Hirakata is estimated by the 3D modeling of gravity data. We presume that this high density body is andesite dike.

The tensor CSMT (Controlled Source MagnetoTelluric), tensor MT (MagnetoTelluric), TDEM (Time Domain ElectroMagnetic Method) and their joint analysis (1D analysis) were carried out at the area. The electric basement is deep on the west over the high gradient of electric basement to the southwest of N8-AY-1. The area of deep electric basement corresponds to the collapse structure of the basement rocks which is estimated by the high gravity gradient.

On the basis of the above results, We presume that the main geological structure is collapse structure which is characterized by the block of the basement rocks (Fig.2).

2.3 Fracture Systems

As mentioned above, the main geological structure in the area is the collapse structure of the basement rocks. The boundary between the Tertiary rocks and the Pre-tertiary rocks is the fault contact at -650m a.s.l. which is recognized by the core observation of N2-AY-2 (Fig.2). The fault dips about 70 °. So the collapse structure is formed by the high angle faults. These faults are related with lost circulation and feed points in the wells (Fig.1).

The fractures with vein minerals in the Tertiary rocks are recognized to develop at some elevation by the core observation of N58-YO-8, N8-AY-2, and N9-AY-5 (Fig.2). However, these fractures are impermeable because of the little lost circulation in drilling. The number of fractures in the Pre-tertiary rocks are five times as many as the fractures in the Tertiary rocks by the core observation of N58-YO-8, N8-AY-1, N8-AY-2, and N9-AY-5. And the number of fractures in the Pre-tertiary rocks are more than that in the Tertiary rocks by FMI logging in N8-AY-1 and N8-AY-2. The fractures in the basement rocks from 500m a.s.l. to -300m a.s.l. strike the northeast-east and the north, and dip the southeast and the west respectively. The fractures in the basement rocks from -400m a.s.l. to -500m a.s.l. strike the northwest and dip the northeast or southwest. These strikes and dips are recognized by FMI logging in N8-AY-1. The feed points in the Pre-tertiary rocks are recognized in N8-AY-1, N8-AY-2, and N9-AY-3 by the production tests. The vugy mineral veins around the dike are recognized to develop by the spot core observation in N9-AY-3 and N9-AY-4. The feed points are recognized around the dike by the production test of N9-AY-3.

There is the high gravity gradient to the northwest of N8-AY-1, east of N9-AY-3 and northeast of N9-AY-4. When N9-AY-3 penetrated the high gravity gradient area, we recognized the lost circulation of more than 1533.3 l/min (Figs.1 and 2). And we recognized vugy mineral veins and dacite dikes by the spot core observation. So we presume that the high gravity gradient indicates the structures of faults and dikes, and the distribution of permeable fractures.

The high gradient of electric basement are identified by the distribution of the resistivity structure (Fig.1). The high gradient of electric basement is confirmed by the lost circulation in N9-AY-3, around the upper Takakura stream, to the southwest of N8-AY-1, and around N9-AY-4 (Fig.1). So we presume that the high gradient of electric basement indicates the distribution of permeable fractures because to the correspondence of the lost circulation location.

On the basis of above results, we presume that the permeable fractures in the area are the high angle faults to be formed by the collapse structure, the fractures to develop in the Pre-tertiary rocks and around the dike.

2.4 Hydrothermal Convection Systems

<u>Thermal Structure</u>

Hydrothermal alteration is examined by using the X-ray diffraction method on the rock samples. The acid altered zone which consists of kaolinite with partly alunite is distributed on the surface (Fig.1). The region of the kaolinite altered zone is mainly distributed around the Arayu area where many fumaroles are present. The paleodose by the thermoluminescence method in this area is less than 100 Gy. The other region of kaolinite altered zone are distributed at the Takakura stream and Mt. Hirakata. The Tertiary rocks and Pre-tertiary rocks in the underground are mainly greenish and belong to chlorite altered zone. The chlorite zone presumably consists of green tuff alteration and hydrothermal alteration. The acid altered zone with kaolinite is intermittently distributed in some elevation where many mineral veins develop (Fig.2). The distribution of these acid altered zone is restricted to the Tertiary rocks. Most of wairakite in the underground is confirmed at the depth of lost circulation and feed points (Fig.2). So we presume that the wairakite is related with the permeable fractures in the area.

The apparent resistivity by the electric logging is varied in the basement rocks. The fracture and lost circulation zones in the basement rocks at N8-AY-1 and N9-AY-4 indicate the low apparent resistivity. The depth of electric basement by the electromagnetic method and their 1D analysis is varied. The resistivity structure is divided into high resistivity near surface, low resistivity at 0-100m a.s.l. and high resistivity at deeper. Or it is divided into low resistivity near surface and high resistivity at deeper. The surface around N8-AY-2 and from the surface to 0m a.s.l. around N9-AY-4 indicate the low resistivity. These areas correspond to the distribution of acid altered zone on the surface. And the region of the lost circulation zone in N9-AY-3 where indicates the low resistivity. The low resistivity areas correspond to the altered zone and the distribution of fractures.

According to the temperature profiles, the area toward Mt. Yamabushi and Mt. Takamatsu are high temperature area of above 250 ℃ (Figs.1 and 2). The region above 250 ℃ contain N8-AY-1, N9-AY-3, N9-AY-4 and the area from T-501 to Arayu. So we presume that there is the heat source around Mt. Yamabushi and Mt. Takamatsu.

The thermoluminescence ages of acid altered zone at the Arayu area and Mt. Hirakata are 0.05 Ma and 1.58 Ma respectively. So it is inferred that the decline of hydrothermal activity started to west.

Reservoir Pressure

We estimated the distribution of reservoir pressure from the temperature and pressure logging data. Based on the straight line correlation of the relation between feedpoint pressure and depth, it is inferred that the area reservoir is liquid dominated.

Geochemistry

There are many fumaroles and hot springs in the area (Fig.1). Most fumaroles are in the are of shallow basement rocks. The Arayu area is the largest fumarole with acid altered zone in the area. The hot springs of naturally spouting water are distributed at the Arayu area, the Yunomata hot spring and the river-bed on the right bank of the Yakunai river. The hot spring waters are divided into the group of Yunotai, Denjo, Arayu, Yunomata, Hoju and Kanayama by chemical species, such as pH, Cl, SO_4, HCO_3. The Cl concentration is continuously decreasing to northwestward along the fault on the right bank of the Yakunai river. Most geothermal discharge fluids in the area are classified into the Cl-type. The main cation and anion of discharge fluids from the wells are Na+K and Cl respectively. The discharge fluids and hot spring waters show 900-1300 kJ/kg in enthalpy and 100-2200 mg/kg in Cl concentration. The discharge fluid from N8-AY-1 has the highest enthalpy and Cl concentration which are 1300 kJ/kg and 2200 mg/kg respectively.

The δD and δ^{18}O of discharge fluids from N8-AY-1 and N9-AY-4 show –68 ‰ and about 10 ‰ respectively. This stable isotope ratio are the same as T-501 and N8-WZ-9, and it show the middle value in the area. The δD of the N5-WZ-2, N7-WZ-7, N7-WZ-7, N57-YO-3 and T-41 are heavier than N8-AY-1, T-501 and N8-WZ-9. And the δD of N5-WZ-1, the hot spring of Takamatsu, the discharge fluids from the Uenotai (T-44, T-49, T-50, T-51) are lighter than N8-AY-1, T-501 and N8-WZ-9.

Fluid Flow

Because of the high Cl concentration in the discharge fluids from the southern part, we suppose the flow of geothermal fluid from the heat source as shown in Fig.3. According to the relation between enthalpy and Cl concentration of the discharge fluids from 52E-AM-1 and hot spring waters at Yunotai and Denjo, we suppose that the hot springs of Yunotai and Denjo are formed by mixing of the geothermal fluids similar to 52E-AM-1 and the shallow groundwater. These fluids flow in the shallow level along the Yakunai river toward the northwest (Fig.3). The Cl concentration of the geothermal discharge fluids are changeful in the northern area (Fig.3). The Cl concentration is highest at N8-AY-1, and decreasing toward the northeast (Fig.3). According to the geochemical feature of the discharge fluid from N8-AY-1, the original geothermal hot water possible flow around N8-AY-1. The feed point of N8-AY-1 is related to the fractures associated with the collapse structure, which are the most important fractures in the area. The δD of the discharge fluids is lighter than the surface waters. So we think that the original waters of the discharge fluids are not the surface waters in the area.

According to the temperature profile by logging, it is estimated that the hydrothermal convection system develops below 0m a.s.l. in the area. The hydrothermal convection type of temperature profile is distributed on the east and north, and the high temperature zone are distributed the same area. So we presume that the hydrothermal convection system and the heat source develop around Mt. Yamabushi and Mt. Takamatsu. The area of the hydrothermal convection system corresponds to the upheaval of the basement rocks and the high gravity area. It is inferred that the boundary of hydrothermal convection system is located on the west of N8-AY-1, around N8-AY-2 and between T-501 and N57-YO-5. In the thermal conduction area on the west, temperature is low and the basement rocks are collapsed.

We estimated the permeability near the wells by the pressure transient test. The values of the permeability (Permeability thickness product) are $0.01\text{-}169 \times 10^{-12} m^3$. Wells N8-AY-1, H9-AY-3 and N9-AY-4 are very productive, permeability thickness product of these wells is more than $10^{-12} m^3$. These wells are located in the area of high temperature hydrothermal convection system. The feed points of these wells are the fractures associated with the collapse structure and the dike, and in the basement rocks.

3. CONCLUSIONS

(1) The main geological structure is collapse structure which is characterized by the block structure of the basement rocks. The collapse structure is controlled by high angle faults. The basement rocks are collapsed to the west of these faults. There are many fractures near these faults.
(2) Permeable fractures relate to the collapse structure and the dike, and develop in the Pre-tertiary rocks.
(3) Fractures in the Tertiary rocks develop in some elevations. The distribution of these fractures corresponds to the distribution of the kaolinite acid altered zone.
(4) The hydrothermal convection area corresponds to the upheaval of the basement rocks in the eastern part. The heat source is around Mt. Yamabushi

and/or Mt. Takamatsu where are high temperature and hydrothermal convection area.

(5) The thermal conduction area corresponds to the subsidence of the basement rocks in the western part. We think a little flow of hot water in the Tertiary rocks.

(6) The geothermal fluids appear to flow from the heat source to the Yakunai river in the Pre-tertiary rocks, and then up along the fractures within the collapse structure and in the Pre-tertiary rocks.

(7) The hot spring waters around Yunotai and Denjo flow in the shallow level along the Yakunai river toward the northwest.

(8) The discharge fluids are not related to surface waters in the area.

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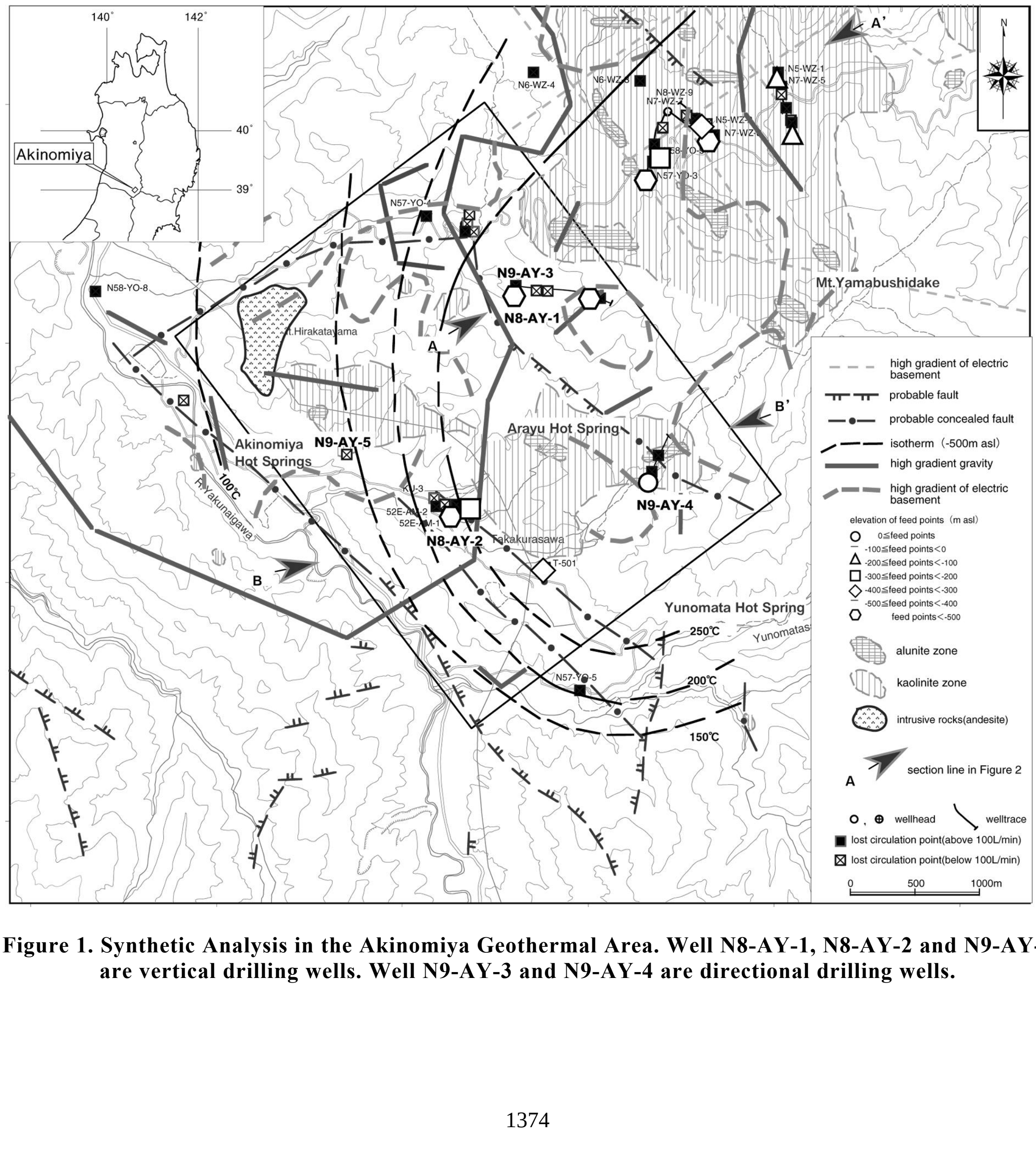

Figure 1. Synthetic Analysis in the Akinomiya Geothermal Area. Well N8-AY-1, N8-AY-2 and N9-AY-5 are vertical drilling wells. Well N9-AY-3 and N9-AY-4 are directional drilling wells.

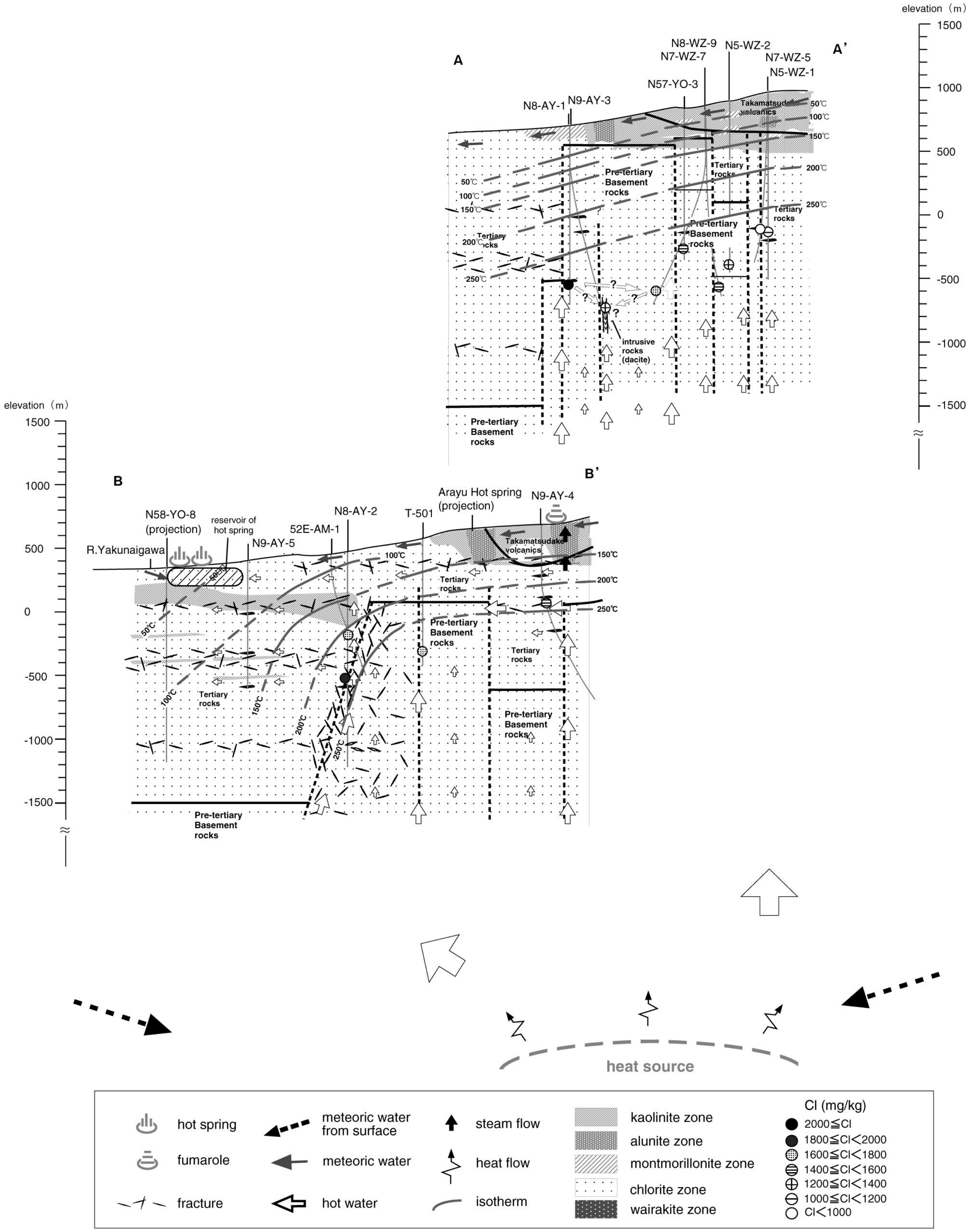

Figure 2. Geothermal Conceptual Model in the Akinomiya Geothermal Area (see Fig.1 for the position of cross section). We presume that the geothermal fluids flow from A-A' section to B-B' section (see Fig. 3).

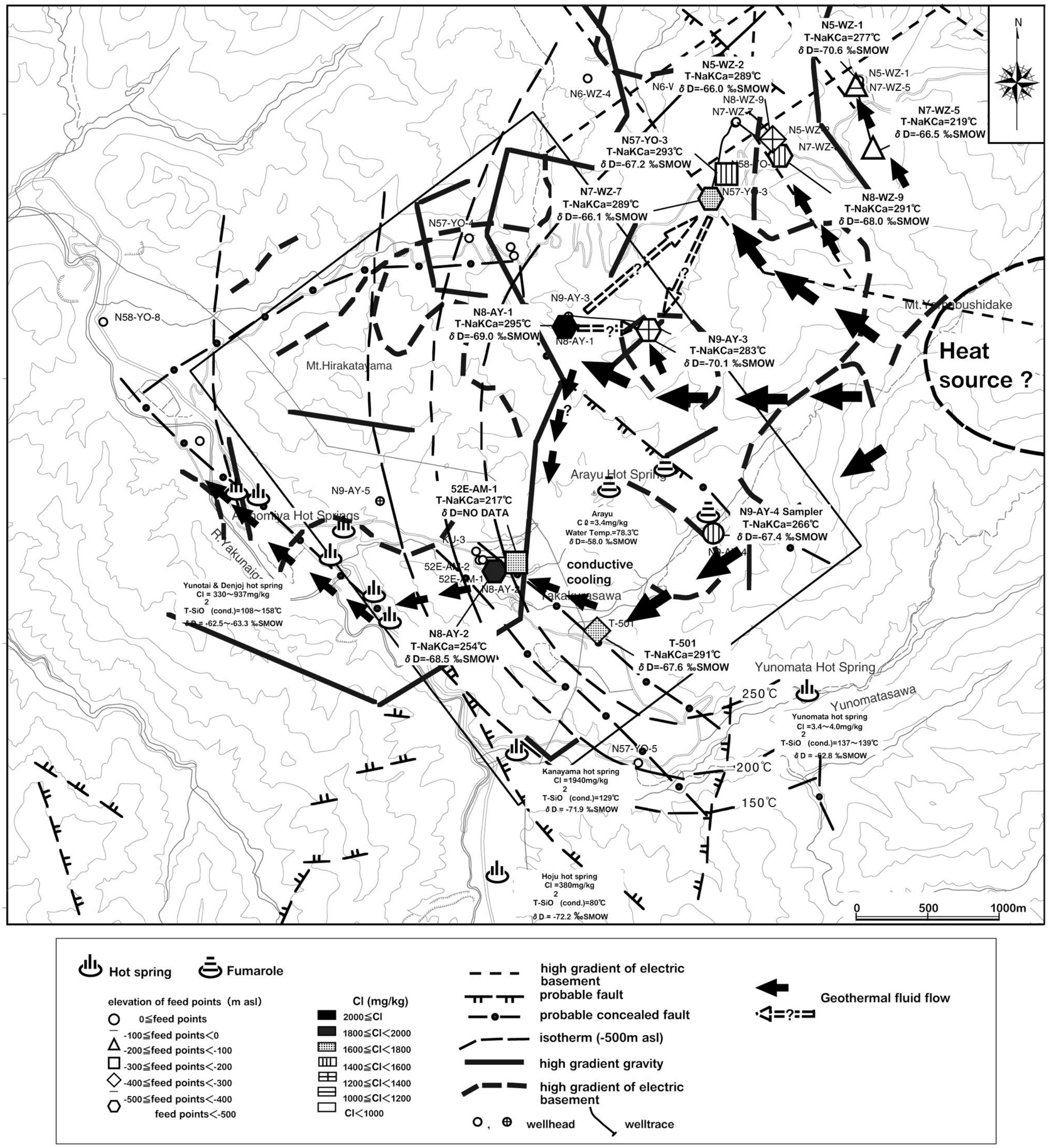

Figure 3. Schematic Map of Geothermal Fluid Flow in the Akinomiya Geothermal Area. On the basis of the geochemistry, geological structure, fracture systems and isotherm, we presume the geothermal fluid flow. The solid and open arrows show the geothermal fluid flow. We presume that the heat source is around Mt. Yamabushi.