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CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE WASABIZAWA GEOTHERMAL FIELD, AKITA PREFECTURE, JAPAN

Masaru Suzuki[1], Masao Futagoishi[2], Tsuneshi Inoue[1], Keiichi Yamada[3], Kosei Obara[4], and Toshio Fujino[5]
[1]Dowa Mining Co., Ltd., 1-8-2 Marunouchi, Chiyoda-ku, Tokyo 100-8282, JAPAN
[2]New Energy and Industrial Technology Development Organization (NEDO), 1-1-3 Higashi Ikebukuro, Toshima-ku, Tokyo 107, JAPAN
[3]Dowa Engineering Co., Ltd., 5-10-5 Shinbashi, Minato-ku, Tokyo 105-0004, JAPAN
[4]Japan Metals and Chemicals Co., Ltd., 1-3-6 Saien, Morioka-shi, Iwate-ken 020-0024, JAPAN
[5]West Japan Engineering Consultants, Inc., 2-1-82 Watanabe-dori, Chuo-ku, Fukuoka-shi, Fukuoka-ken ,JAPAN

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ABSTRACT

A conceptual hydrogeologic model of the Wasabizawa geothermal field was developed prior to the application of a numerical simulation. This conceptual model was based on an updated analysis of a significant amount of data gathered during recent extensive exploration and well testing by New Energy and Industrial Technology Development Organization (NEDO). Except for the eastern quarter of the Wasabizawa area, which has a very thick deposit of Tertiary pyroclastics (Ohtoriyazawa Formation), the area is considered to be part of the southeastern extension of the Okumaemori uplift with NE- and NW-trending faults. Well test results show that fluid production is from fractures in the lower Ohtoriyazawa Formation (wells WZ-1 and WZ-5), and metamorphic and granitic basement rocks in the uplifted zone (wells WZ-2, WZ-6, WZ-7, WZ-9 and YO-3). Based on the chemistry of geothermal fluids produced during flow tests, two water types were defined in the Wasabizawa area: low Cl waters (about 400mg/l at reservoir conditions) were produced from wells WZ-1, WZ-6, and possibly WZ-5; high Cl waters (1,000 ~ 2,000mg/l) were produced from wells WZ-2, WZ-7, WZ-9, and YO-3. Both types are thought to migrate through different paths that are controlled by high-permeability zones along NW-trending faults, as indicated by subsurface temperature contours above –200 meters (msl). Temperature distribution at shallow depths also shows a high-temperature trend toward the Akinomiya area, indicating a possible subsurface discharge toward the southwest. All temperature maps show a horizontal component of recharge from the SE direction. Static temperature profiles in the Wasabizawa wells indicate that there is upflow as well as the horizontal flow. It is, therefore, suggested that the geothermal fluids migrate into the area from a deep source located in the direction of Mt. Yamabushi and Mt. Takamatsu.

1. INTRODUCTION

The Wasabizawa area, located at the southeastern corner of Japan's Akita Prefecture (Fig. 1), was selected by the New Energy and Industrial Technology Development Organization (NEDO) to conduct its new exploration program "Survey C" of the Geothermal Development Promotion Survey. In addition to detailed geological, geophysical, and geochemical explorations, nine wells with depths ranging from 1,069.1m to 1,701.5m were drilled between 1993 and 1997. Six of those wells are slim holes designed mainly to investigate subsurface geology and temperature. Short-term flow tests were conducted for four slim holes: WZ-1, -2, -5 and –6. Two large holes (8-1/2 inches at the bottom), WZ-7 and –9, were provided for long term flow tests, during which medium size hole WZ-8 was used as a reinjection well of hot water. Robertson-Tait et al. (1990) discussed heat source and fluid migration concepts at the nearby Uenotai geothermal field, using a significant amount of data obtained by Dowa Mining Co., Ltd., Akita Geothermal Energy Co., Ltd. and NEDO. Our paper reviews the conceptual hydrogeologic model of the Wasabizawa reservoir, based on the previous study and data obtained during NEDO's Wasabizawa exploration project. The geological structure and subsurface temperature distribution are discussed by Inoue et al. (2000) in a companion paper in this volume.

2. GEOLOGICAL SETTING

As discussed by Inoue et al. (2000), the Wasabizawa area is structurally divided into two major zones, with shallow Pre-Tertiary basement (YO-3, WZ-2, -3, -4, -7, -8 and –9) and very thick Ohtoriyazawa Formation at the eastern corner of the project area, as represented by wells WZ-1 and –5. It is also suggested that the regional geological structure, including the Wasabizawa and Uenotai areas, is mainly controlled by NE-SW and NW-SE trending fault systems; the subsurface temperature distribution is strongly affected by the fractures along NW trending faults.

3. FLUID CHEMISTRY

Table 1 shows the chemical composition of the Wasabizawa well samples. Table 2 shows the concentration of B and Cl in water samples from Wasabizawa wells, an Akinomiya well (T-501), and hot springs. The samples from wells YS-1, WZ-1, -5, and –6 have relatively higher B/Cl ratios than those from other wells. It should be noted that YS-1, WZ-1, and WZ-5 produced thermal fluids from fractures in very thick pyroclastic rocks of Miocene age. Samples from wells YO-3, WZ-2, -7, and –9, which are located in the uplifted zone, and the produced thermal fluids from Pre-Tertiary basement rocks have B/Cl ratios less than 0.01.

Figure 3 is an enthalpy – Cl diagram of the data shown in Table 2, which were corrected to reservoir conditions. It is suggested that the deep-seated parent water has a composition very close to that in wells T-501, WZ-7, and WZ-9 (Cl = 1,800 mg/kg with an enthalpy of 320 kcal/kg). It appears that the other well samples plot along a line indicating mixing of the high temperature parent water and more dilute water, but this assumption still has some uncertainties. Only one Uenotai well (T-49) is plotted on the graph. Robertson-Tait et al. (1990) suggested that the parent fluid of Uenotai well samples has a higher enthalpy (345kcal/kg) and much lower Cl (650mg/kg), which distinguish it from Wasabizawa water.

Figure 4 is a diagram showing deuterium and oxygen^{18}O in the Wasabizawa, Uenotai, and hot spring waters. The line $\delta D = 8 \times \delta^{18}O + 22$ is the local meteoric water line (Matsubaya and

Uchida, 1990). Each well sample represents water at reservoir conditions. The Wasabizawa thermal fluid samples from wells WZ-7 and WZ-9 lie at about $\delta D = -60.8\ ^{o}/_{oo}$ and $\delta^{18}O = -9.8\ ^{o}/_{oo}$. The thermal fluids of the Uenotai wells have much lower δD ($-70\ ^{o}/_{oo}$).

3. CONCEPTUAL HYDROGEOLOGICAL MODEL

Figure 5 shows the derivation of major water types based on the chemistry of well and hot spring waters. The deep-seated geothermal fluid is neutral. High Cl, low B/Cl water is ultimately of meteoric origin. The Wasabizawa waters are divided into two types. The Wasabizawa (1) water has high Cl (1,000 ~ 2,000mg/kg) and a low B/Cl ratio as represented by wells WZ-2, -7, -9, and YO-3. These wells were drilled in the uplifted zone and the production zones are located in Pre-Tertiary basement rocks. The Wasabizawa (2) water has much lower Cl and slightly lower enthalpy as represented by wells WZ-1, -5, and –6. Those wells are located in a NW-SE trending graben that has a thick sequence of Tertiary volcanics and pyroclastics. The Wasabizawa (2) water is possibly derived from the same fluid source as the Wasabizawa (1) water, but this is still uncertain. The reservoir water in the Uenotai system is distinct from Wasabizawa waters; it is thought to be derived by mixing of deep-seated fluid with low Cl and relatively high B-Cl Kijiyama water. Another distinct type is magmatic steam with a significant amount of HCl and H_2S. This is found at the Kawarage area, which structurally separates the Wasabizawa and Uenotai areas.

Figure 6 is a schematic cross section showing the subsurface geology, temperature, and dominant fluid flow directions. All maps showing the subsurface temperature distribution in the Wasabizawa and Uenotai areas have temperature contours that open in the SE direction, indicating that the source of heat and geothermal fluid lie in that direction (Inoue et al., 2000). The static temperature profiles in some of the Wasabizawa wells indicate that upflow of thermal fluid occurs below sea level. The high temperature trend shown in the map at each elevation also indicates the existence of horizontal fluid migration. In the project area, the Wasabizawa (1) and (2) waters appear to migrate in a SE to NW direction through separate fracture zones along the fault system extending in the same direction.

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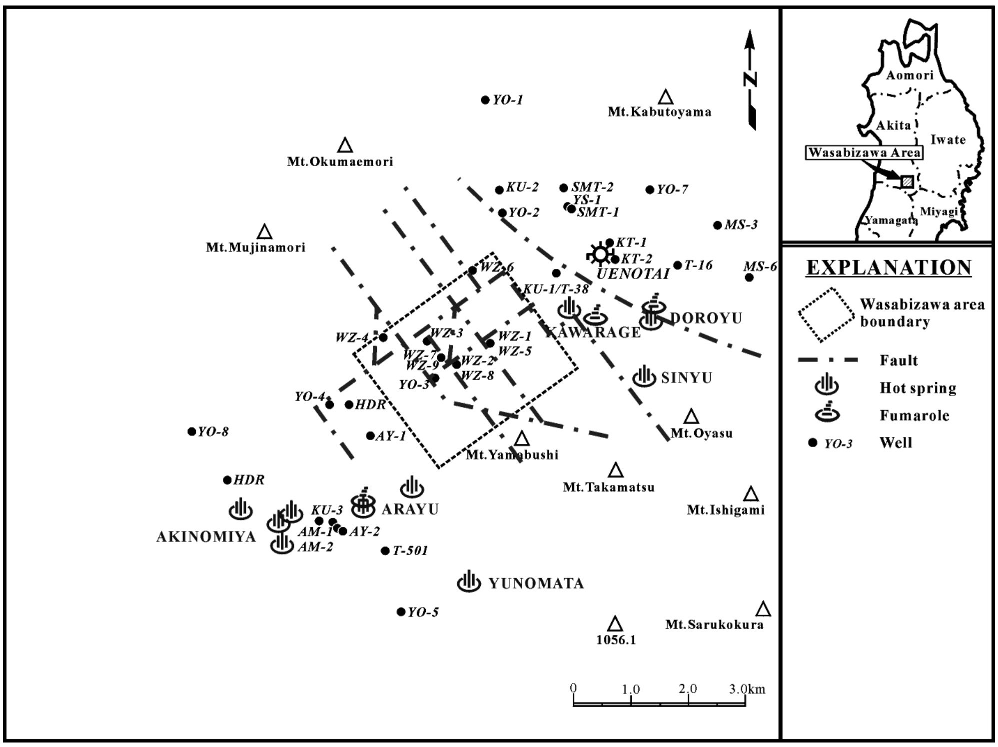

Figure 1. Map showing the Wasabizawa area and location of assumed faults

Table 1. Chemistry of Wasabizawa well samples

Name of Test Well	N5-WZ-1	N5-WZ-2	N7-WZ-5	N7-WZ-6	N7-WZ-7			N8-WZ-9			N57-YO-3
Date of Sampling	94/10/03	94/09/07	96/07/31	97/04/29	97/09/10	97/09/22	97/10/04	97/06/16	97/07/04	97/07/30	83/10/03
pH	9.3	8.7	9.2	9.4	8.9(25.0)	8.7(23.9)	8.6(18.5)	8.7	8.8	8.9	8.2
RpH	9.3	8.7	9.2	9.3	7.9(25.9)	7.8(20.3)	7.7(24.6)	8.6	8.5	8.6	
Electric Conduct. µS/cm					8,340	8,650	9,260	7,850	7,610	7,480	
SiO_2 mg/l	478	894	501	820	959	960	886	906	931	907	778
Cl mg/l	1,620	2,010	472	604	2,600	2,680	2,850	2,380	2,320	2,270	2,339.7
SO_4 mg/l	57.5	40.0	209	70.5	24.2	24.8	26.9	40.8	37.4	37.6	12.3
HCO_3 mg/l	33.6	16.2	10.5	20.9			17.0	13.3	24.8	22.2	39.6
CO_3 mg/l							0.5	0.5	1.2	1.8	
F mg/l	4.06	5.17	7.31	8.5	3.98	3.67	4.09	4.40	3.55	3.47	
Na mg/l	1,010	1,180	389	402	1,480	1,530	1,600	1,370	1,310	1,340	1,489
K mg/l	197	250	55.0	77	340	358	378	322.0	312	300	485
Ca mg/l	6.08	5.34	16.9	4.3	16.4	19.8	19.0	13.5	12.5	8.47	89.2
Mg mg/l	0.01	<0.01	1.48	0.01	<0.01	<0.01	0.03	0.02	<0.01	<0.01	0.08
Fe mg/l	0.05	0.04	0.03	0.01	<0.01	0.03	0.08	0.03	0.01	0.01	0.2
Al mg/l	<0.01	4.11	0.82	1.86	0.30	0.44	0.36	0.63	0.60	0.68	0.4
As mg/l	1.39	0.55	0.044	0.26	1.03	0.8	0.69	0.75	0.45	0.61	0.338
B mg/l	10.9	4.81	1.43	4.81	5.79	5.89	7.23	6.27	5.99	5.92	3.9
Li mg/l	2.22	4.56	0.81	1.3	5.71	5.27	5.51	5.01	4.71	4.55	
$T\text{-}CO_2$ mg/l	28.0	12.2	8.5	17.8	<10	<10	12.7	10	18.8	17.0	
H_2S mg/l	3.8	0.34	3.3	3.26	0.64	0.68	0.78	<0.5	<0.5	<0.5	2.7
$\delta D(H_2O)$ ‰ SMOW	-45.5	-55.6	-62.8	-57.7	-60.6	-59.9	-59.4	-61.3	-61.9	-62.1	-59.0
$\delta^{18}O(H_2O)$ ‰ SMOW	-5.9	-8.4	-10.2	-8.9	-8.6	-8.7	-8.3	-8.8	-8.8	-8.8	-7.1
$\delta^{18}O(SO_4)$ ‰ SMOW	-3.6	+4.1	-1.7	-5.8	-3.7	-3.9	-4.2	-5.4	-5.7	-5.3	
$\delta^{34}O(SO_4)$ ‰ CDT	+15.7	+17.4	+13.7	+19.5	+21.0	+21.2	+21.1	+21.2	+21.5	+21.0	
$\delta^{13}C(CO_2)$ ‰ PDB	-14.9	-18.1	-23.6	-17.2	-22.8	-22.8	-21.9	-15.7	-20.1	-18.8	
Thoritium ^3H TR	<0.6	1.3±0.2	2.0±0.2	1.0±0.3	0.5±0.2	0.4±0.2	1.8±0.2	<0.3	<0.3	<0.3	26.8±0.38

Table 2. Chemistry of Wasabozawa, Uenotai and Akinomiya wells, corrected to the reservoir condition

Well Number	Date of Sample	Cl			B		B/Cl Ratio	δD ‰	$\delta^{18}O$ ‰	Thermo-meter	Logging Temp.	Formation Temp.	Enthalpy	
		mg/kg	correctd	mmol/kg	mg/kg	mmol/kg							KJ/kg	Kcal/kg
N5-WZ-1	93/10/03	1620	364	10.3	2.5	0.23	0.022	-70.6	-11.0	282	286	-----	1230	293
N5-WZ-2	94/09/07	2010	1380	38.9	3.4	0.31	0.008	-65.9	-10.4	291	295	-----	1290	307
N7-WZ-5	96/07/31	472	405	11.4	3.1	0.29	0.025	-66.5	-10.9	248	254	-----	1076	257
	96/08/05	790	671	18.9	2.4	0.22	0.012	-----	-----	253	254	-----	1105	264
N7-WZ-6	97/04/29	604	418	11.8	4.31	0.40	0.034	-65.6	-10.4	263	261	-----	1110	265
N7-WZ-7	97/09/10	2600	1986	56.0	4.43	0.41	0.009	-64.8	-9.8		278	-----	1312	313
	97/09/22	2680	1947	54.9	4.28	0.396	0.007	-65.4	-10.0		278	-----	1312	313
	97/10/04	2850	1854	52.3	4.70	0.435	0.008	-65.1	-9.8	294	278	-----	1312	313
N8-WZ-9	97/06/16	2380	1561	44.0	4.43	0.41	0.009	-65.6	-10.0	272	273	292	1301	311
	97/07/04	2320	1642	46.3	4.30	0.40	0.009	-65.8	-9.9	293	273	292	1301	311
	97/07/30	2270	1604	45.2	4.22	0.39	0.009	-66.6	-9.9	304.9	273	292	1301	311
N57-YO-3	83/10/01	2340	991	28.0	1.7	0.16	0.006	-74.0	-10.0	-----	273	-----	1200	287
T-501	94/09/29	2770	1580	44.6	3.9	0.36	0.008	-64.0	-9.9	308	-----	-----	1400	334
AM-1	78/10/07	2200	1780	-----	-----	-----		-----		201		-----	858	206
T-49	-----	885	566	-----	-----	-----		-70.5	-10.8	285	-----		1240	297
YS-1	-----	-----	146	4.1	1.8	0.17	0.041	-70.8	-10.4	218	-----		930	223

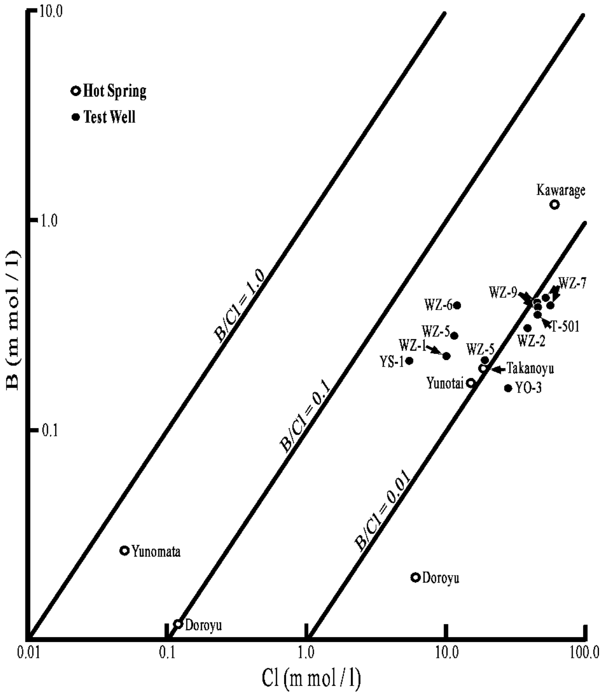

Figure 2. Diagram showing B/Cl ratio

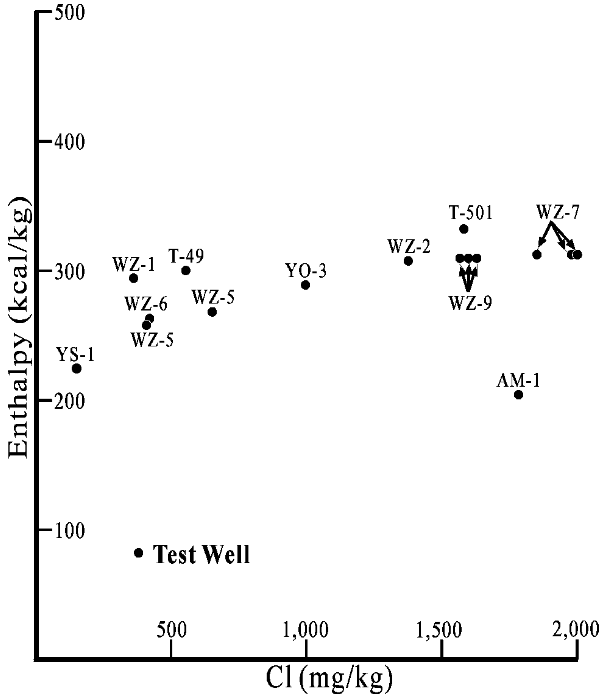

Figure 3. Enthalpy – Cl diagram

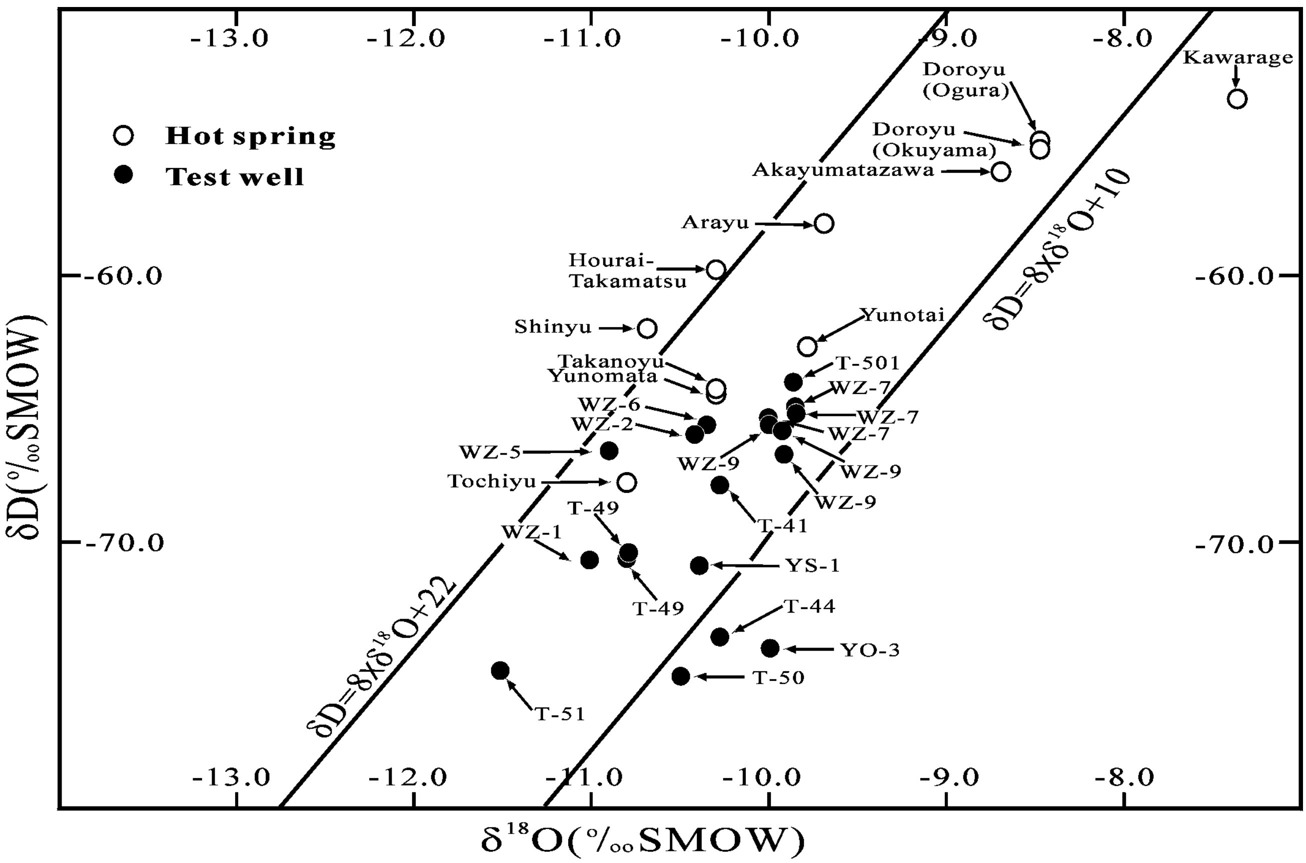

Figure 4. Relation between deuterium and oxygen ^{18}O

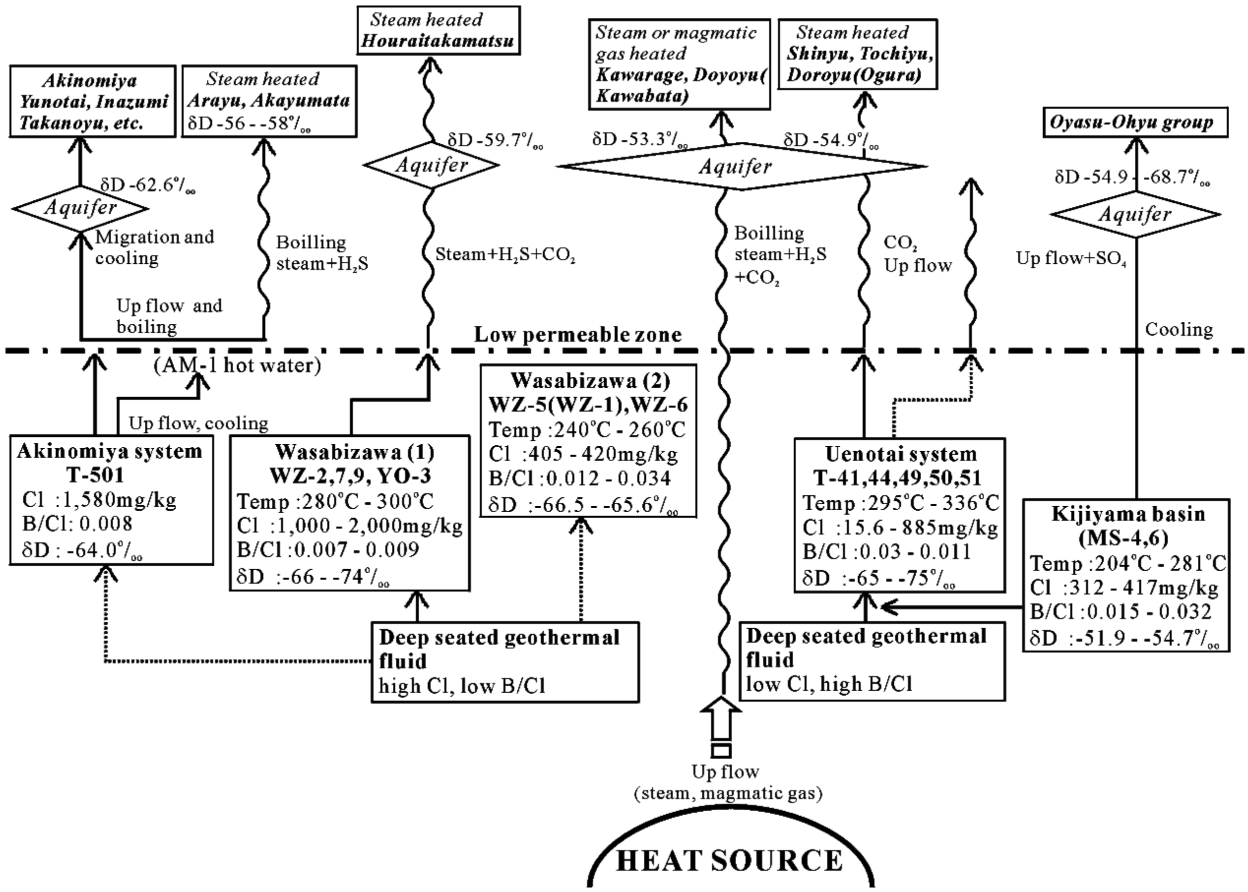

Figure 5. Estimated derivation of major water types

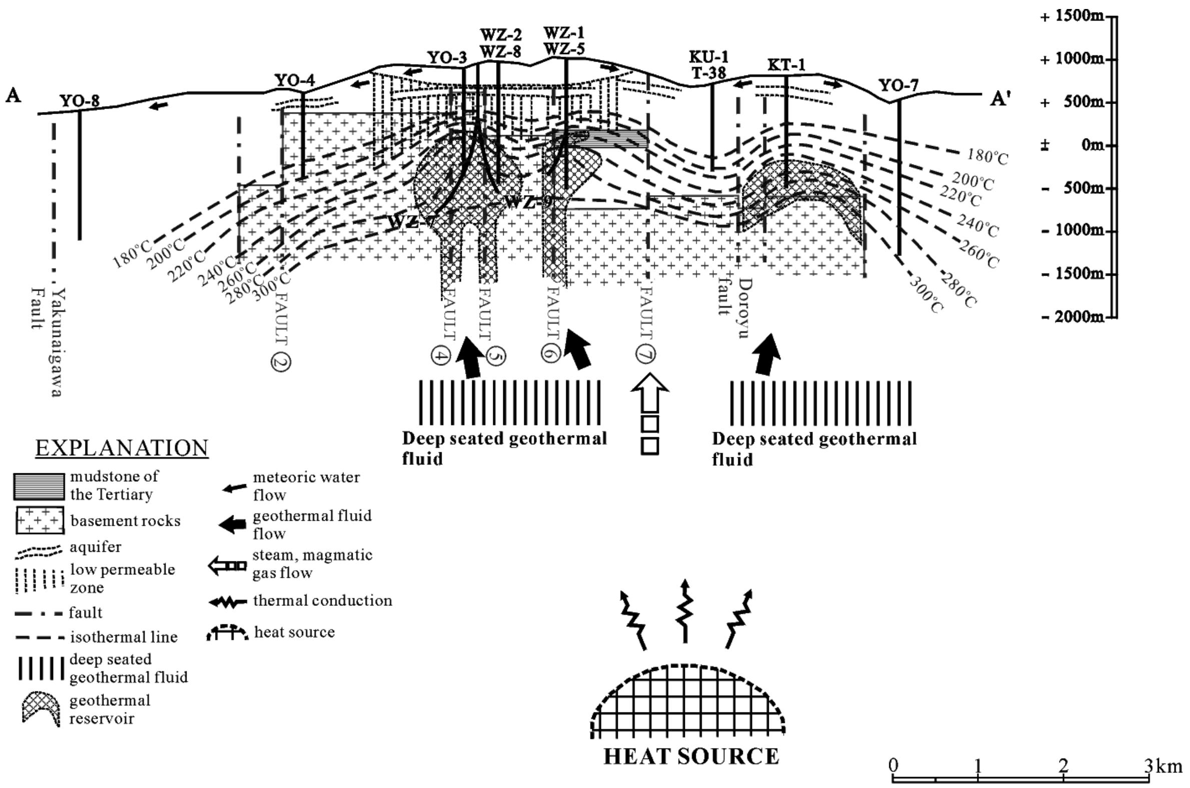

Figure 6. Schematic geological cross section of Wasabizawa and Uenotai areas