ESTIMATING DEEP ENVIRONMENTS OF JAPANESE HYDROTHERMAL SYSTEMS BASED ON GEOCHEMICAL DATA FROM GEOTHERMAL POWER **PLANTS**

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ABSTRACT

Slow progress of geothermal power generation development in Japan (the total capacity will be 550MWe by 2000) has been caused fundamentally by restrictions to the exploitation at the national parks and hot-spring resort areas, in which most promising geothermal areas are located. Deep levels (deeper than about 2500m) of the shallow hydrothermal systems under exploitation are expected to be forthcoming targets to develop for the next decade(s). Two kinds of geochemical methods were applied to characterize and to evaluate the deep environments. (1) Static method: Chemical and isotopic composition data of non-reactive components in production fluids were analyzed in terms of dominant heating mechanisms, fluid origins and reservoir rock types for the above hydrothermal systems. Based on the results, the Group 1 areas (Onuma, Sumikawa and Ogiri) were estimated to be most promising with favorable fluid chemistry and large-scale reservoir development at the depth for the conventional-type power generation. (2) Dynamic method: Chemical history data, especially long-term tracer monitoring data, from the Onuma geothermal power plant were systematically analyzed through single-box-model numerical simulations, as a test case. The results indicated that the exploited shallow reservoir, with a very limited amount of circulating fluid, is supplied with high-temperature waters from the depth, supporting the estimations by the static method.

1. INTRODUCTION

Geothermal energy development is expected to be very promising in Japan where about 240 Quaternary volcanoes and more than 3800 hot-spring areas are nation-widely distributed. However, the actual advance of power generation using geothermal resources has been much slower than expectations of the governments. In 1994, eleven conventional-type geothermal power plants, using steams separated from thermal fluids from natural hydrothermal systems, are in operation with a total capacity of about 300MWe (Table 1 and Figure 1). Seven new power plants of the same type will be at work by the year 2000, increasing the total capacity to about 550MWe.

This slow progress has been caused fundamentally by restrictions to the exploitation at the national parks and hot-spring resort areas, in which most active volcanoes and most promising geothermal areas are located. At present, deep levels (deeper than about 2500m) of the shallow hydrothermal systems at the above areas, which have been already exploited or under exploitation, are generally expected to be forthcoming targets for the power generation development in the next decade(s). In these circumstances, New Energy and Industrial Technology Development Organization **(NEDO)** has been conducting the Deep-seated Geothermal Resources Survey since 1992, in co-operation with Ministry of International Trade and Industry (MITI), in order to clarify the deep conditions of the hydrothermal systems through drilling a 4000m-class deep well at the Kakkonda area, Northeast Japan (e.g. Sasada et al., 1993; Yagi et al., 1994).

Estimating the deep environments of the geothermal areas is very important, because drilling deep wells is not only very expensive, but also very risky. The objectives of this paper are to classify and to evaluate the deep environments of the above hydrothermal systems based on geochemical data from the exploited shallow reservoirs. The shallow reservoirs are developed mostly in the Neogene to Quaternary volcanic and pyroclastic rocks, but the basement rocks, composed mainly of pre-Neogene detrital marine sedimentary rocks and/or granitic rocks, were partly exploited or are expected to underlie in a close distance in most of the areas. Accordingly, the environments in the basement rocks are the main objects to analyze.

Table 1. Outlines of geothermal power plants in Japan (after The Japan Geothermal Energy Association (1994) and Saito (1993)).

Area no. & symbol	Name of geothermal power plant	Capacity (MWe) *0	Development company	Operation (since)	Max. well depth (m)	Max. well temp. (°C)
Hokkaido						
1 A	Mori	50.0	Donan Geoth. Ener.*1	1982	3000	280
Northeast Honshu						
2 B	Sumikawa	(50.0)	Mitsubishi Materials*2	(1995)	2500	320
3 C	Onuma	9.5	Mitsubishi Materials	1974	1800	230
4 D	Matsukawa	23.5	Japan Metals & Chem.	1966	1500	300
5 E	Kakkonda	50.0	Japan Metals & Chem.*2	1978	1600	270
6 F	Kakkonda II	(30.0)	Tohoku Geoth. Ener.*2	(1996)	3000	350
7 G	Uenotai	27.5	Akita Geoth. Ener.*2	1994	2200	340
8 H	*Onikobe*	12.5	Electr. Power Devel.	1975	1500	290
9 I	Yanaizu-Nishiyama	(65.0)	Okuaizu Geoth. Ener.*2	(1995)	2700	340
Kyushu						
10 J	Suginoi	3.0	Suginoi Hotel	1980	400	?
11 K	Takigami	(25.0)	Idemitsu Geoth. Devel.*3	(1996)	3000	260
12 L	Otake	12.5	Kyushu Elect. Power	1967	1900	240
13 M	Hatchobaru	55.0	Kyushu Elect. Power	1977	3000	290
14 N	Hatchobaru II	55.0	Kyushu Elect. Power	1990	3000	290
15 O	Oguni	(25.0)	Electr. Power Devel.	(?)	1900	250
16 P	Kirishima Kanko Hotel	0.1	Daiwabo Kanko	1984	400	?
17 Q	Ogiri	(30.0)	Nittetsu Kagoshima Geoth. Ener.*3	(1996)	2000	230
18 R	Yamakawa	(30.0)	Kyushu Geoth. Ener.*3	(1995)	2600	370

*0, As totals, ca. 299MWe in 1994 and ca. 530MWe in 1996; *1, with Hokkaido Elect. Power; *2. with Tohoku Elect. Power; *3, with Kyushu Elect. Power.

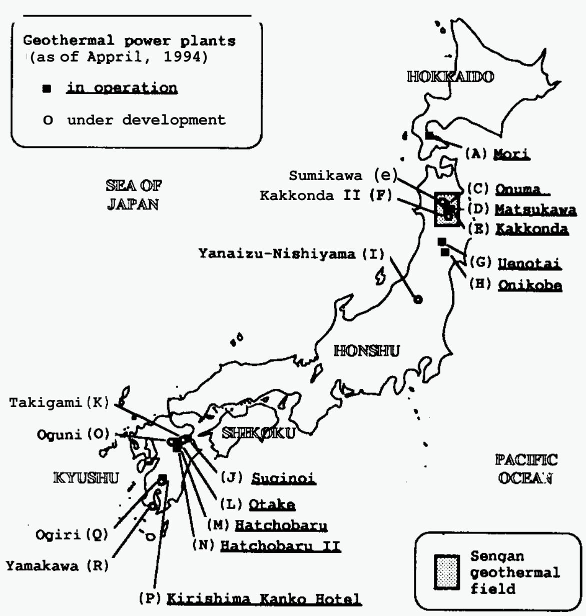

Figure 1. Distributions of geothermal power plants in Japan.

Two kinds of geochemical analysis methods, static and dynamic, were applied and tested along the objectives.

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2. CONCEPTUAL MODELS FOR DEEP ENVIRONMENTS OF EXPLOITED HYDROTHERMAL SYSTEMS IN JAPAN

The temperatures at depth are reasonably believed to be higher than those of exploited shallow reservoirs. Hence, two points are probably most important for the geothermal exploitation of the deeper levels. (1) If geothermal fluids exist at depth, are their chemical properties appropriate for commercial power generation? (2) Are deep reservoirs large and productive enough for commercial development? Figure 2 shows four conceptual models, which were simplified for the exploited Japanese hydrothermal systems.

Concerning the above (1), the horizontal axis of Figure 2 shows the differences between hydrothermal systems heated by molten and/or consolidated magmas at depth. The left and right side figures, *two* for each, show the systems heated by thermal conduction (D type), and those heated by magmatic fluid injection (I type), respectively. The chemical properties of the geothermal fluids from the deep levels of the I-type systems are estimated to be more corrosive than those of the D-type systems, because the magmatic fluids tend to be highly acidic, saline and/or gas-rich.

Concerning the above (2), the vertical axis of Figure 2 shows differences in potential for large-scale reservoir deveiopment at depth in typical basement rocks. The top and bottom side figures show detrital marine sedimentary rock basements (R-type), and granitic rock basements (B-type), respectively. The capacity for storing geothermal fluids is expected to be better in coarse detrital sedimentary rocks, with substantial effective porosity and permeability, than in granitic rocks, though fracture distributions could be more critical for the development and the productivity of the deep reservoirs.

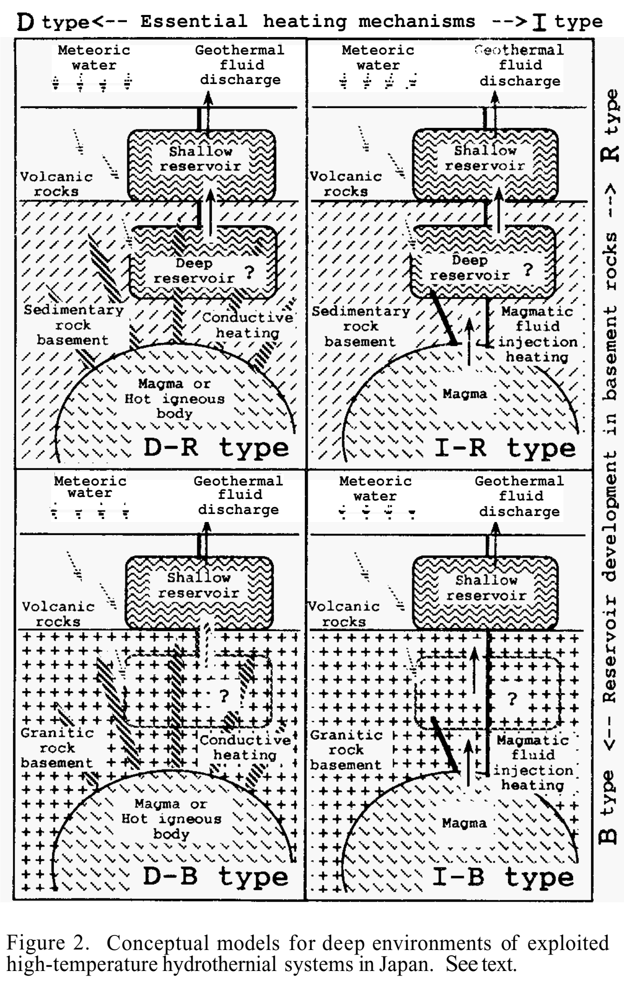

Figure 2. Conceptual models for deep environments of exploited high-temperature hydrothernial systems in Japan. See text.

The D-R type deep environment is probably the most promising for the large-scale development of the conventional-type power generation with chemically suitable high-temperature fluids mainly of meteoric-water origin. The D-B type deep environment is probably dominated by the Hot Dry Rock type resources with partly developed hydrothermal systems mainly of meteoric-water origin along fracture zones. In contrast, the I-B type deep environment is probably dominated by corrosive high-temperature fluids mainly of magmatic origin, along the fracture zones, and the commercial exploitation of the systems could be very difficult. However, the I-R type deep environment, in which geothermal fluids mostly of magmatic origin may be of better quality owing to the reactions with reservoir rocks and the mixing with ground waters of meteoric-water origin, could be conveniently exploited.

3. APPLICATION OF STATIC ANALYSIS METHOD

In order to classify and to evaluate the deep environments of the exploited Japanese hydrothermal systems, along the above conceptual models, isotopic compositions of waters, non-reactive gas compositions, and compositions of non-reactive soluble components for production fluids from the shallow reservoirs are useful. Especially, $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$ values (e.g. Craig, 1963; Kusakabe and Matsubaya, 1986; Giggenbach, 1992b), He/Ar and N_2/Ar ratios (e.g. Matsuo et al., 1978; Kiyosu, 1986; Yoshida, 1986; Giggenbach. 1992a; Kita et al., 1993), and Cl concentrations and B/Cl ratios (e.g. Ellis and Mahon, 1964, 1967; Shigeno and Abe, 1983, 1986; Shigeno, 1992a) are probably most beneficial. The papers that reported the above compositions of production fluids for Japanese geothermal power plants were listed in APPENDIX. In some of the areas, all or some of the components have not been reported yet.

Figures 3, 4 and 5 show the diagrams for the relationships of $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$, log(He/Ar) and $\log(N_2/Ar)$, and log(Cl) and log(B/Cl), respectively, for the above data. For Figures 6 and 7, the area symbols were plotted for the average values of the components in log(He/Ar)-log(B/Cl) and $\Delta^{18}O(H_2O)$ (oxygen isotope shift from the local meteoric water to the geothermal fluid) -log(B/Cl) diagrams, respectively. Table 2 summarizes six groups classifying the exploited hydrothermal areas based on their chemical similarities of the production fluids shown in Figures 3 to 7. The deep environments of the four groups, 1, 2, 3, and 4, are estimated to correspond to the conceptually modeled deep-environment types, D-R, D-B, D/I-B and I-B (see Figure 2), respectively, as discussed

Table 2. Deep environments of exploited hydrothermal systems in Japan. classified and estimated by the geochemical static method.

Group no.	Geothermal power plant (symbol)	6D (H_2O) shifts	$\delta^{18}O$ (H_2O) shifts	He/Ar & N_2/Ar ratios	Cl concent-rations	B/Cl ratios	Estimated deep environments
1	Sumikawa (B), Onuma (C), Ogiri (Q) & (Kakkonda (E))	LL	**L**	L	L	H	D-R type
2	Kakkonda (E), Oguni (O) & Takigami (K)	LL	L	(L)	L	**M**	D-B type
3	Onikobe (H), Hatchobaru (M) & Otake (L)	LL	**M**	(M)	**M**	**M**	D/I-B type
4	Yanaizu-Nishiya-ma (I) & Mori (A)	H	HH	HH	H	**M**	I-B type
5	Yamakawa (R)	**H**	H	-	HH	L	? *1
6	Matsukawa (D)	LL	**M**	**M**	LL	**HH**	? *2

For the chemical characteristics; HH: very large/very high: H: large/high; **M:** intermediate; L: small/low; LL: very small/very low *(See Figures 3 to 7)*. Refer to the text and Figure 2 for the estimations of the deep environments; Estimated dominant essential heating mechanism- **D:** thermal conduction from magma and/or hot igneous body; *I:* magmatic fluid injection from depth; Estimated reservoir development in basement **rocks- R: more** promising (in marine sedimentary rock basement); B: less promising (in granitic rock basement). *1 Due to the seawater-related system at the shallow level; *2 Due to the vapor-dominated system at the shallow level.

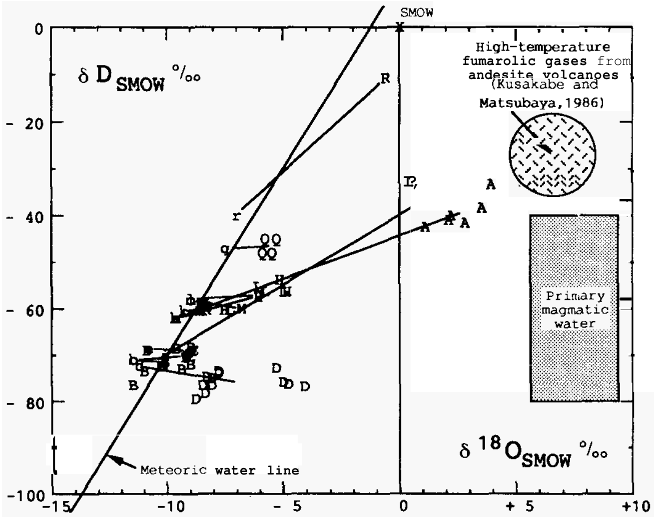

Figure 3. $\delta D(H_2O)$-$\delta^{18}O(H_2O)$ relationships for production fluids of geothermal power plants in Japan. Refer to Tables 1 and 2 for the area symbols (small letters, averages of meteoric, surface and ground waters; capital letters, reservoir fluids).

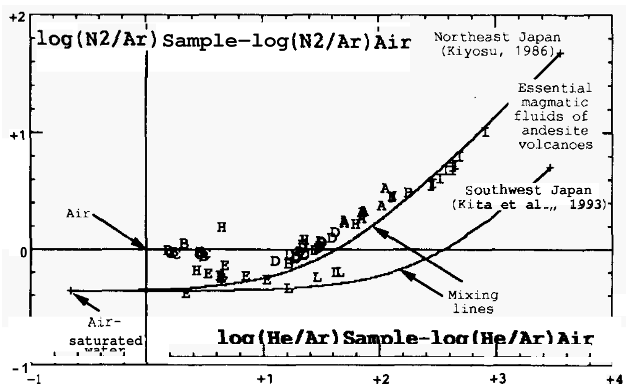

Figure 4. He/Ar-N_2/Ar relationships for production fluids of geothermal power plants in Japan. Refer to Tables 1 and 2 for the area symbols. Fumarolic steams from the Otake area (Kita et al., 1993) were shown by L for comparison.

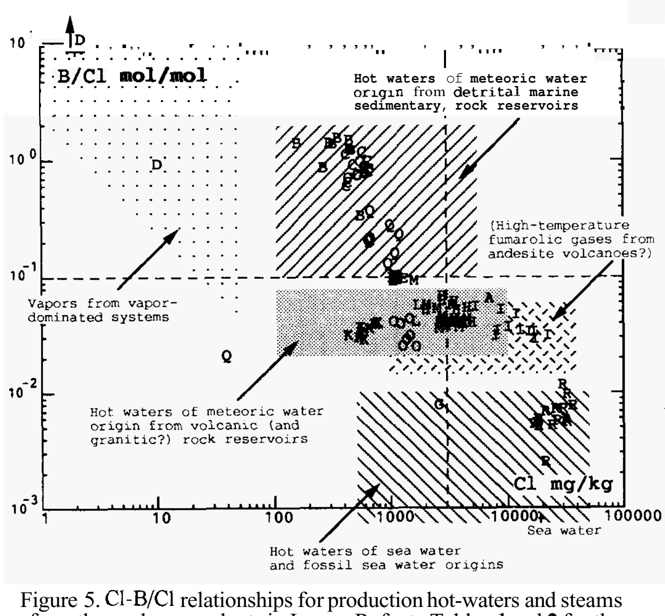

Figure 5. Cl-B/Cl relationships for production hot-waters and steams of geothermal power plants in Japan. Refer to Tables 1 and 2 for the area symbols. Five domains, which indicate dominant reservoir fluid phases, water origins and reservoir rock types, were modified from Shigeno and Abe (1983,1986) and Shigeno (1992a).

below. The correlations between the groups and the types are shown with areas in Figure 7, and with dashed lines in Figures 5 and 6 for references.

For the Group 1 areas, where the $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$ shifts are small, and the He/Ar and N_2/Ar ratios and the Cl concentrations are low, the dominant origin, and heating mechanism of the thermal fluids are expected to be meteoric water, and thermal conduction from magmas and/or young igneous bodies, respectively. The high B/Cl mol ratios of 0.2 to 1 of the thermal waters from the shallow reservoirs composed mainly of the volcanic rocks indicate that the exploited hydrothermal systems of this group have deep and large roots in the basements composed mainly of detrital marine sedimentary rocks (Shigeno and Abe, 1983; Shigeno, 1992a). The systems of this group at the Onuma, Sumikawa and Ogiri areas, corresponding to the D-R type of Figure 2, are probably most promising for the conventional-type power generation using geothermal fluids of moderate quality from large-scale deep reservoirs

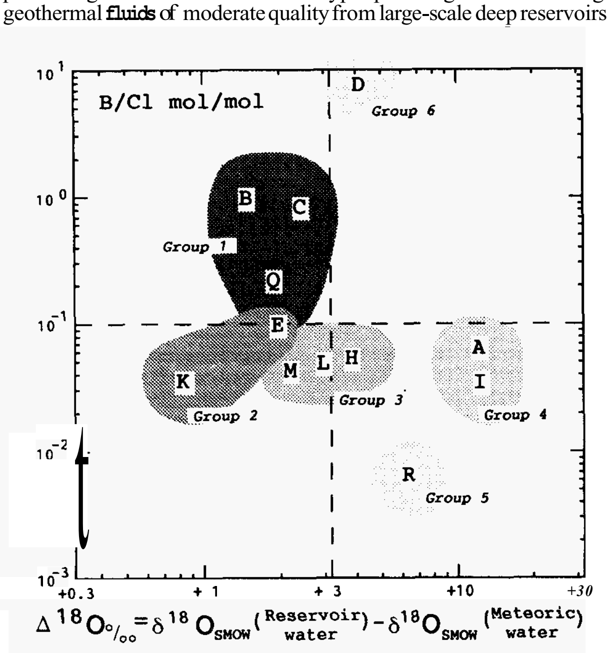

Figure 6. $\Delta^{18}O(H_2O)$-B/Cl relationships for average production fluids of geothermal power plants in Japan. Refer to Table 1 for the area symbols and Table 2 for the group numbers.

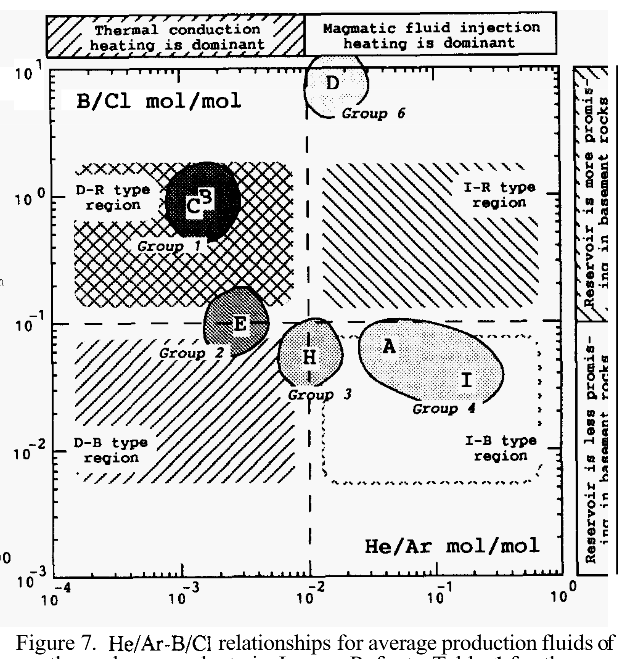

Figure 7. He/Ar-B/Cl relationships for average production fluids of geothermal power plants in Japan. Refer to Table 1 for the area symbols, Table 2 for the group numbers, and Figure 2 for the conceptual deep-environment types of the exploited shallow reservoirs in Japan.

in the exploited areas. The Kakkonda area does not typically belong to the Group 3, but could be included in this group.

For the Groups 2 and 3 areas, where the $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$ shifts are small to intermediate, and the He/Ar and N_2/Ar ratios and the Cl concentrations are low to intermediate, the dominant origin and heating mechanism of the thermal fluids are expected to be meteoric water and thermal conduction from magmas and/or young igneous bodies, respectively, as discussed for the Group 1 areas. However, the intermediate B/Cl ratios of 0.02 to 0.08 of the thermal waters indicate that the developments of the large-scale deep reservoirs in the basements (in the detrital marine sedimentary rocks) are less promising than those for the Group 1. Hot Dry Rock exploitation technology could be necessary for power generation using the deep systems of these groups, which correspond to the D-B to D/I-B types in Figure 2, though the deep environments probably vary, better or worse for the exploitation, area to area.

For the Group 4 areas, where the $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$ shifts are very large, and the He/Ar and N_2/Ar ratios and the Cl concentrations are very high, the dominant origin and heating mechanism of the thermal fluids are expected to be magmatic waters and their injection from magmas, respectively. The intermediate B/Cl mol ratios of 0.03 to 0.08 of the thermal waters suggest that the developments of large-scale deep reservoirs in the basements (in the detrital marine sedimentary rocks) are less promising than those for the Group 1 areas. The conventional-type power generation could be difficult using the deep systems of this group at the Yanaizu-Nishiyama and Mori areas, which correspond to the I-B type in Figure 2, because of more hostile qualities of the geothermal fluids and less developed reservoirs than the exploited shallow levels.

For the Group 5 and 6 areas, the deep environments of the exploited shallow reservoirs are less clear. For the Group 5, Yamakawa area located very near the sea coast, the very high well-logging temperatures up to about 370°C (Table 1) suggest contribution of the magmatic-fluid injection type heating mechanism. But, contribution of sea water to the exploited reservoir (refer to Figures 3 and 5), and absence of the He/Ar and N_2/Ar ratio data made the interpretation difficult. For the Group 6, Matsukawa area, where a vapor-dominated system is developed at the shallow reservoir, the relatively high He/Ar and N_2/Ar ratios suggest that the magmatic-fluid injection type heating mechanism contributes at depth.

4. GEOTHERMAL SYSTEMS OF THE ONUMA AND SUMIKAWA AREAS

The static analysis revealed that the Onuma and Sumikawa areas belong to the Group 1, and their deep environments are probably of the D-R type that is expected to be most promising for the conventional-type power generation in a large scale. The Onuma and Sumikawa areas, which are separated about 1.5km in the E-W direction, are located in the Sengan geothermal field, Northeast Japan (Figure 1). Mainly, Mitsubishi Materials Co. has been conducting geothermal exploration and exploitation in and around these areas since 1965 (see Table 1). Results of the geothermal studies for these areas were reported, for example, by Yora et al. (1973), Kubota (1985), Sakai et al. (1986), Kimbara et al. (1987), Shigeno and Abe (1987), Maki et al. (1988), Ueda et al. (1991), and Sakai et al. (1993).

The deep environments of the hydrothermal systems in these areas could be summarized, based on the above reports and the results of the static analysis as follows (see Figure 8). (1) These areas are located in the Hanawa graben of N-S trend (about 5km wide), which are partly rimed by the Paleozoic to Mesozoic detrital marine sedimentary rocks at the surface. The deep reservoirs are estimated to occur in the fractured sedimentary-rock basements, though the exploited shallow reservoirs are developed mainly in the Neogene volcanic, pyroclastic and intrusive rocks. (2) The deep reservoirs are estimated to be heated mainly by thermal conduction from the magmas and hot igneous bodies of the two Quaternary (active) andesite composite volcanoes, Hachimantai and Akita-Yakeyama, located closely to the east and west of the areas. (3) The deep reservoir waters are probably recharged mainly by meteoric water, and partly by magmatic fluids as shown for the shallow reservoir at the Sumikawa area (Ueda et al., 1991). (4) The shallow and deep reservoirs at the Onuma and Sumikawa areas are probably connected. A large-scale reservoir of more than $3km^3$ at the depth was estimated to develop by the data analysis of the pressure transient test of the 2500m-deep SN-7D (SC-1) well located in the eastern part of the Sumikawa area (e.g. Ishido, 1990).

5. APPLICATION OF DYNAMIC ANALYSIS METHOD

In most of the geothermal power plants in Japan, hot waters produced after steam separation have been reinjected to the reservoirs mainly for the purpose of environmental protection. At most of these plants, long-term monitoring of production fluid chemistry as well as artificial tracer tests have been conducted. These chemical history data are very helpful not only to understand the condition changes in the exploited shallow reservoirs for long-term stable operation, but also to evaluate the deep environments of the hydrothermal systems for further exploitation. However, the long-term chemical history data have not been published yet in details for most of the exploited areas.

Concerning the Onuma geothermal power plant, Ito et al. (1977, 1978) reported the results of a series of tracer tests using I ion, and Kubota et al. (1989) showed the long-term changes of the I concentrations and of the major solution compositions for the production fluids. The very high B/Cl ratios of the production fluids (see Figures 5 to 7) have been almost constant or slightly increasing. Ito et al. (1978), Matsubaya and Kubota (1987) and Kubota et al. (1989) tried to estimate macroscopic parameter values for the exploited shallow reservoir using single box models.

Shigeno et al. (1992b, 1993) performed more systematic analysis for the above data through single-box-model numerical simulations with algorithms to obtain automatically the optimum estimation values for the macroscopic parameters. Figure 9 shows the single box model for the Onuma area, which was used for the simulation analysis, and the optimum combination of the macroscopic parameter values estimated. Figure 10 shows the best fits of the measured and simulated temporal changes of the specific enthalpy, and the Cl and I concentrations for the average production fluids at the Onuma power plant.

For the Onuma geothermal power plant (10MWe in capacity), the total amount of the geothermal fluids produced during 1970-1987 was about 6.8×10^{10}kg, but the mass of the hot waters convecting in the exploited shallow reservoir was estimated to be only 3.2×10^{9}kg. Neither recycling of the reinjected hot water (about 58% of the production fluid mass) nor cold sweep of heat stored in the reservoir rocks by ground waters of meteoric-water origin has been sufficient to produce these large outflows of water, chemical components, and heat from the shallow reservoir. This suggests that the deep environments of the Onuma area is prosperous enough to supply the shallow reservoir with the large amount of the high-temperature waters (neutral Na-Cl type with low salinity and very high B/Cl ratios) that have compensated for the large outflows caused by the geothermal exploitation (Shigeno et al., 1992b, 1993). This result is concordant to the previously obtained model of the deep environments for the Onuma and Sumikawa areas (Figure 8).

The geochemical dynamic analysis methods, which would be more useful by improving simulation models and algorithms, could be applied to other exploited hydrothermal systems in Japan to evaluate the deep environments. The models obtained by the static analysis are expected to be greatly improved by the dynamic analysis in future.

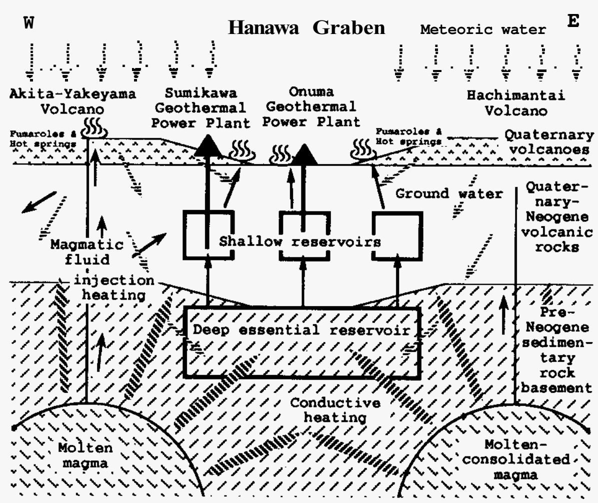

Figure 8. Conceptual hydrothermal-system model of the Onuma and Sumikawa areas, Northeast Japan. See text.

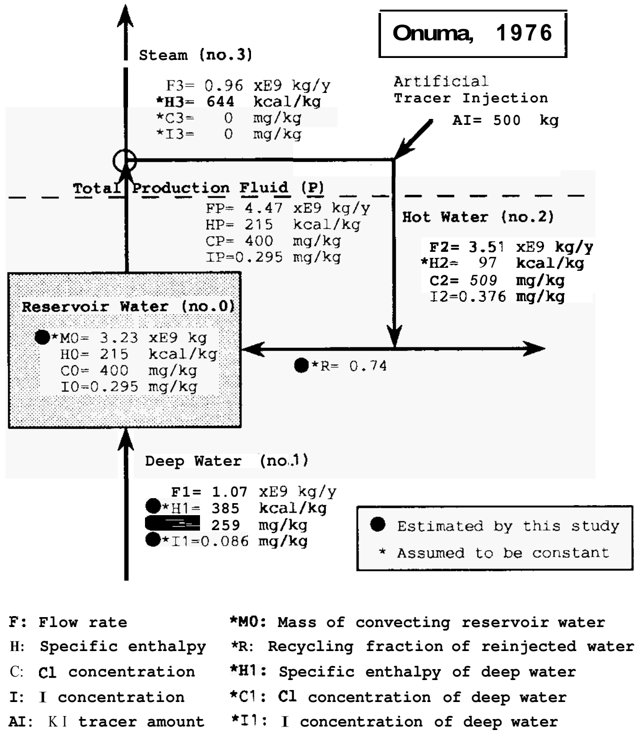

Figure 9. Optimum combination of macroscopic parameter values for the Onuma hydrothermal system estimated by single-box-model numerical simulation analysis based on chemical history data of the total production fluids (after, Shigeno et al. (1992b, 1993)). This box model is after Matsubaya and Kubota (1987) and Kubota et al. (1989).

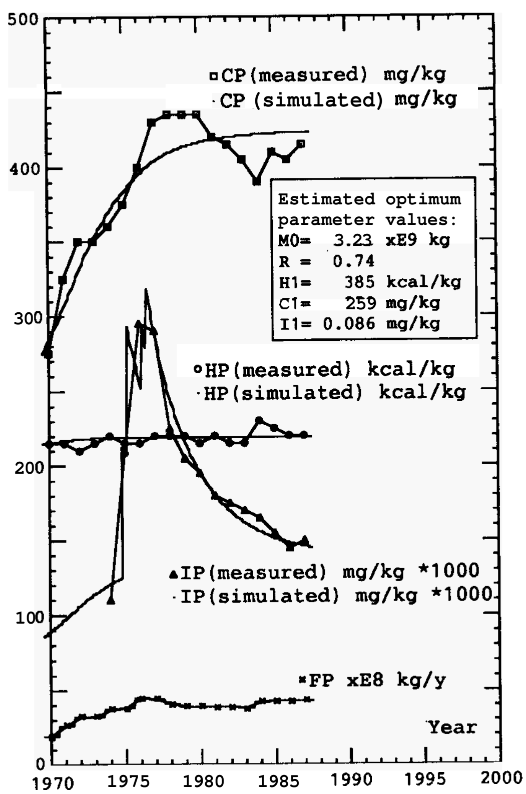

Figure 10. Best-fit temporal changes for specific enthalpy (HP), Cl concentrations (CP) and I concentrations (IP) of the total production fluids from the Onuma hydrothermal system obtained by single-box-model numerical simulation analysis (after Shigeno et al. (1992b, 1993)). Measured temporal changes are after Kubota et al. (1989). Refer to Figure 9 for the estimated parameters.

6. CONCLUSIONS

Slow progress of geothermal power generation development in Japan (the total capacity will be 550MWe by 2000) has been caused fundamentally by restrictions to the exploitation at the national parks and hot-spring resort areas, in which most promising geothermal areas are located. Deep levels (deeper than about 2500m) of the shallow hydrothermal systems already exploited or under exploitation are expected to be forthcoming targets to develop for the next decade(s), though drilling such deep wells would be very expensive and risky.

In this paper, the environments of the deep levels were conceptually modeled, and divided into four types in terms of dominant heating mechanisms closely related to fluid properties and potential reservoir development controlled by rock types distributed at depth. Two kinds of geochemical analysis methods, static and dynamic, were applied to characterize and to evaluate the deep environments for the above geothermal areas along the conceptual models.

For the static method, chemical and isotopic composition data of non-reactive components in production fluids were summarized for the above hydrothermal systems. The geothermal areas were divided into six groups, and their deep environments were correlated to the above types. The Group 1 areas (Onuma, Sumikawa and Ogiri) were estimated to be most promising with favorable fluid chemistry and large-scale reservoir development at the depth for the conventional-type power generation.

For the dynamic method, chemical history data, especially long-term tracer monitoring data, from the Onuma geothermal power plant were systematically analyzed through single-box-model numerical simulations, as a test case. The results indicated that the exploited shallow reservoir, with a very limited amount of circulating fluid, is supplied with high-temperature waters (neutral Na-Cl type with low salinity and very high B/Cl ratios) from the depth, supporting the model for the Onuma area estimated by the static method and previous studies. The dynamic method could be improved and applied to other exploited areas for better evaluation of the deep environments.

The results obtained by the two geochemical methods were concordant, suggesting that the Group 1 areas are very promising for conventional-type large-scale power generation using the deep hydrothermal systems. Drilling deep exploration wells of 4000m-class at these areas is requested for rapid progress of geothermal power generation development in Japan during the next decade(s).

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APPENDIX

References to original papers **reported** $\delta D(H_2O)$ and $\delta^{18}O(H_2O)$ values, **He/Ar** and N_2/Ar ratios, Cl concentrations and B/Cl ratios for production fluids of geothermal power plants in Japan.

	Area symbol	Geothermal power plant	Literature
1	**A**	Mori	Yoshida (1990J), Yoshida (1991E), Chiba (1991E).
2	B	Sumikawa	*Sakai* et al. **(1986J),** Ueda **et** al. (1991E), Chiba (1991E).
3	C	Onuma	Yora et al. (1973J), Sakai (1977E), Sakai et al. (1986J), Shigeno & **Abe** (1987J).
4	D	Matsukawa	Kiyosu (1983E), Matsubaya et al. (1985J), Shigeno & **Abe** (1987J), Yoshida & Ishizaki (1988E), Hanano et al. (1989J).
5	E	Kakkonda	Matsubaya et al. (1985J), Shigeno & **Abe** (1987J), Kiyosu & Yoshida (1988E), Kasai et al. (1990J).
6	F	**Kakkonda II**	------------------------------
7	***G***	Uenotai	Kuriyama (1985J), Naka et al. (1987J), Matsubaya et al. (1988E), Naka and Okada (19927).
8	H	Onikobe	Kiyosu (1986J), Kiyosu (1986E), **Abe** et al. (1989J).
9	**I**	Yanaizu-Nishiyama	Nitta et al. (1987J), **Seki** (1991E).
10	J	**Suginoi**	------------------------------
11	K	Takigami	Hayashi et al. (19881). Takenaka & Furuya (1991E).
12	L	***Otake***	Mizutani (1972E), Shigeno et al. (1985J), Ncda et al. (1985J), Kita et al. (1993E).
13	M	Hatchobaru	Manabe & Ejima (1984J), Shimada et al. (1985J), Shigeno et al. (1985J), Ncda et al. (1985J), Hirowatari (1991E).
14	N	**Hatchobaru II**	------------------------------
15	**O**	Oguni	Noda et al. (1985J), Fujita **& Abe** (19881).
16	**P**	**Kirishima** Kanko Hotel	------------------------------
17	Q	Ogiri	Kcdama & Nakajima (19881). **Shimizu et** al. (1988E).
18	**R**	Yamakawa	Yoshimura et al. (1985J), Akaku et al. (1991E).

E: in English J in Japanese (mostly with English abstr.)
The papers listed here **were** not included in the REFERENCES.