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RECENT GEOTHERMAL ACTIVITY IN JAPAN

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ABSTRACT

The recent tentative assessment of the Geological Survey of Japan indicates a production potential for electricity from high-temperature hydrothermal convection systems of more than 20,000 MWe for 30 years. However, by 1986, the total installed capacity of the operating geothermal power plants is only 214.6 MWe.

In this paper, together with the presentation of the Japanese activity of exploration and development of geothermal energy, brief review of nation's research effort is made with the special reference to the following geoscientific study.

- study on the nationwide resource assessment
- in-depth study on the prominent geothermal field looking for deeply seated resource

1. INTRODUCTION

Energy requirements in Japan are constantly increasing with the economic growth and the advance of living standards of the people. More than fifty five percent of her energy requirement is met by crude oil which almost entirely come from abroad. As the long term energy policy, the high degree of dependence on crude oil for the energy supply must be reduced, and the development of alternative energy sources as well as energy saving should be promoted. Japan is situated within the Circum Pacific Volcanic Belt and has about one hundred seventy Quaternary volcanoes, among which sixty seven are active. A lot of active geothermal fields have been found within volcanic zones. Geothermal resources are expected to be an abundant domestic energy resources.

According to the Japanese long term energy policy issued in 1987, it is expected that, in 2000, the total installed capacity of the geothermal power plant (utility owned) will increase to 2,400 MWe and the electricity production of geothermal power plant will account for two percent of total electricity production.

At present, the total installed capacity of geothermal power plant (utility owned) is only 180 MWe. Although the situation surrounding the development of new energy sources is quite severe today because of low oil prices, the government has made a continuous effort to achieve the target of long term energy supply plan. Geological Survey of Japan is actively involved in geothermal research program on resources exploration and assessment in nationwide and regional scale.

2. ROLE OF GEOTHERMAL ENERGY AS ONE OF THE DIVERSIFIED ENERGY SOURCE

It is supremely important problem to secure steadily dependable energy supply source. Development of alternative energy and the diversification of the energy source should be systematically promoted. Geothermal energy is one of the attractive domestic energy source in Japan available with current technology and is also expected to increase the potential of available energy with the further exploration and assessment and with further research and development of utilization technology.

2.1 Assessment of nation's geothermal resources.

A proper role for geothermal energy as a significant alternative energy source would be enhanced by an understanding of the nature, distribution and magnitude of the Nation's geothermal resources. Assessment of the magnitude and distribution of the Nation's geothermal resources is essential to make a plan of long term energy supply policy.

In Japan, the first quantitative assessment of high temperature (>150°C) hydrothermal convection system in nationwide scale was made by Geological Survey of Japan (Miyazaki, Y. et al., 1986). In this assessment, data obtained in the nationwide geothermal resources survey and other geological, geophysical and geochemical information acquired by Geological Survey of Japan were exclusively used. The assessment was carried out for fifteen blocks (Fig. 1) by use of essentially the same methodology applied to the assessment of hydrothermal convection systems with reservoir temperatures more than 150°C in USGS, Circular 790. (Brook, C. A. et al., 1979).

As a proper treatment of this assessment, (a) gravity basement data were used to determine the depth to the bottom of the geothermal reservoir, and (b) Curie isothermal depth was used to determine the underground temperature distribution (Okubo, Y. et al., 1985 a) assuming linear geothermal gradient, constant surface temperature (5°C) and Curie temperature of 500°C. Curie temperature of 500°C may be reasonably adapted from the comparison with existing well temperature data (Okubo, Y. et al., 1985 b). The upper limit of reservoir is taken as 150°C isothermal surface obtained from above-mentioned temperature distribution.

No.	Name of Block
1	Southern Kyushu
2	Northern Kyushu
3	Sanin
4	Kii
5	Nobi
6	Hokuriku
7	Tokai
8	Kan-to, Koshinetsu
9	Southern Tohoku
10	Central Tohoku
11	Northern Tohoku
12	Western Hokkaido
13	Central Hokkaido
14	Northern Hokkaido
15	Eastern Hokkaido

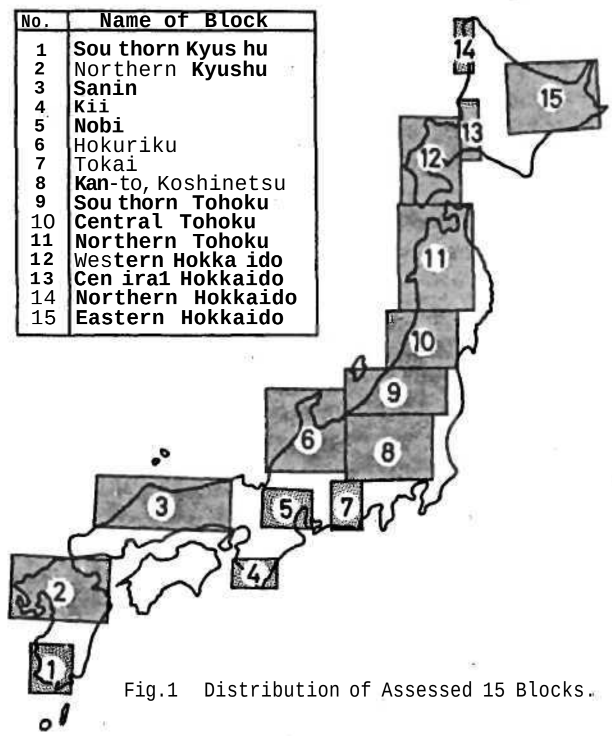

Fig.1 Distribution of Assessed 15 Blocks.

For the assessment work, the volume method is chosen assuming the rock volumetric specific heat to be $2.5J/cm^3$ /"C and the reservoir porosity, to be 15%, so volumetric specific heat of rock plus water to be $2.7J/cm^3$/<>C within the geothermal reservoir. The reference temperature is the mean annual temperature and for simplicity is assumed to be constant 15"C for the entire territory.

Data in calculation are used the 500m grid-data value on depth of top and bottom of reservoir and vertical distribution of reservoir temperature obtained from already described procedure. The assessment work was exclusively limited to the area of 15 blocks, in which the depths of gravity basement and of Curie point temperature could be deduced from the data of nationwide geothermal resources survey.
The final electrical energy is calculated for all hot-water system which is greater than 150°C. This calculation is also made assuming that the reinjection temperature of final state of hot-water system is atmospheric (15°C) instead of condenser temperature (say, 40"C). For these reason, the current assessment value (Table 1) shows a theoretical maximal value.
The studied area is 186,079 km^2, which covers a half of total territory of Japan, but includes almost all promising geothermal area. The total estimated amount of electrical production is 20,540 MWe for thirty years. Although this assessment work is tentative, this is a first nation's geothermal resources assessment which has been done by using systematically acquired data.

Ho. of Block	Name of Block	Araa of Block Mi	Reanoir Area la*	Ratio M	Reanolr Volsa	Raaanoir Dnlhn 10"J	AellaUa Wort 10"J	Blaclrttal Baaru MWatoJfcr.
1	Southern Kyushu	7. 755	132	1.7	73	31.5	1.6	680
2	Northern Kyushu	16.220	460	2.8	246	110.1	5.8	2.450
3	Sanin	8.232	57	0.7	25	11.2	0.6	250
4	Kil	2.948	O	0	O	0	O	0
5	Nobi	5.861	0	0	0	0	0	O
6	Hokuriku	14.463	0	0	0	0	0	O
7	Tokal	1O.8O3	0	O	0	0	0	O
8	Kan to. Koahlnetsu	28.559	752	2.6	271	112.9	S.6	2.37O
9	Southern Tohoku	18.800	518	2.8	147	58.8	2.8	1.200
10	Central Tohoku	15.91O	233	1.5	123	53.9	2.8	1.180
11	Northern Tohoku	22.427	668	3.O	479	216.1	11.4	4.81O
12	Western Hokkaido	14.697	547	3.7	326	147.8	7.8	3.320
13	Central Hokkaido	6.831	O	0	O	0	O	0
14	Northern Hokkaido	1.481	0	O	O	O	0	0
15	Eastern Hokkaido	11.092	868	7.8	412	187.8	10.1	4.280
	Total	119.797	4.235	3.5				2O.S4O

Table 1. Result of Assessment for High Tenperature (>15(fc) Geothermal Resources.

2.2 Long-term energy supply and demand outlook

Based on the change of the energy situation and the industrial structure, Japanese government has revised the long-term energy supply and demand outlook. According to the revised interim report issued from the advisory committee of the Energy Council in 1987, the total amount of energy consumption is estimated to be 490 million kiloliter oil equivalent (M.kl.O.E.) in 1995 and 540 M.kl.O.E. in 2000. The utilization of geothermal energy including non-electric application is expected to be 2.0 M.kl.O.E. in 1995 and 4.4 M.kl.O.E. in 2000 (Table 2).

According to the interim report issued from the Electric Utility Council in 1987, the total amount of electric power demand is estimated to decrease in comparison with the last outlook issued in 1983. The revised outlook of supply and demand of electric power production is shown in Table 3. The anticipated structure of power generating facilities based on the revised electric supply and demand outlook is also shown in Table 4.
According to this plan of the construction of power generation facility, the total capacity of electric power from geothermal energy is expected to be 1,000 MWe in 1995, and 2,400 Mwe in 2000. At present, there are nine geothermal power plants in operation whose total capacity is 214.6 MWe, but the total capacity of the utility owned geothermal power plants in operation is only 180 MWe.

Fiscal Year	Caifuf.)		1995		2000		derive)	
		X		%		X		X
Coal CM Tonnes)	1O3.9	C18.3)	121.0	C18.3)	136.0	C18.7)	15O.0	C19~)
Nuclear CGW)	25.8	(9.5)	41.5	(13.4)	53.5	(15.9)	65.0	C18~)
Natural GaaOl.lcl)	42.8	(9.9)	55.0	(11.1)	58.0	(10.8)	60.0	C1O~)
[Doasstlc(B.c.m> "1	2.1		3.6		4.2			
[LNC CM Tonnes) J	28.8		36.0		38:0			
Hydro Power (GW)	35.8	(4.2)	42.3	C 4.5)	•a. a	(4.4)	48.5	C 4—)
iNatural fie—	2O.2		23.0		24.5		26.0	
j Pumped storame	15.6		19.5		21.0		22. S	
Geothermal (M.kl)	0.4	(0.1)	2.0	(0.4)	4.4	(O.8)	6.0	(1~)
New Plud Oil	5.5	(1.3)	12.5	(2.5)	24.5	(4.5)	40.0~52.0	(7~9)
Oll CM kl)	246.0	(56.8)	245.0	C49.7)	242.0	C45.0)	240.0~	C42~)
[Domestic (M.kl)	0.7		1.3		1.6			
[LPC CM Tonnes)	16.2		18.0		19.0			
Total CM kl)	433.O	(1OO)	490.0	C100)	540. O	(100)	58O.O	C1OO)

Note:l£of crude «oil contalaa 9250 keal value.

Table 2. National Iong-Term Energy Supply and Demand Outlook (revised, Oct. 1987)

Fiscal Year	1986 (actual)		1995		2000		2005 (tentative)	
		%		%		%		%
Nuclear	167.3	(27.8)	269.0	(35.4)	348.0	(40.1)	425.0	(44.5)
Coal	56.8	(9.4)	92.0	(12.1)	118.0	(13.6)	160.0	(16.8)
LNG	130.4	(21.7)	164.0	(21.6)	164.0	(18.9)	155.0	(16.2)
Hydro Power	79.6	(13.3)	97.0	(12.7)	106.0	(12.2)	115.0	(12.1)
Natural flow	72.51	(12-1) I	86.O	C11.3)j	93.0	(10.7)	1OO.O	<1O.5>
Pumped storage	7.0	IC 1.2) I	11-O	lC 1.4) I	13.O	(I.S> I	15.pl	(1.6)
Geothermal	1.1	(0.2)	6.0	(0.8)	lll.U	(1.7)	"Sold	" 7i'j
Oil	140.4	(23.3)	110.0	(14.5)	95. O	(11.O)		
LPG	2.8	(0.5)	3.0	(0.4)	3.O	(O.3)	7O.O	< 7.3)
Others	23.0	(3.8)	19.0	(2.5)	19.0	(2.2)		
Total	601.5	C1OO)	76O.O	UOO)	868.0	C1OO)	955.0	C1OO)

(Electric Utility Council)

Table 3. Structure of Power Production (TWh) (Oct. 19871

Fiscal Y—r	Caofufl)		1995		2000		(tensive)	
Nuclear	25.68	(16. §)	41.00	(21.5)	53. OO	C25.S)	65.00	C27.I)
Coal	11.69	C 7.4)	18.00	C 9.3)	23. OO	CIO. 8)	33.00	C14.1)
LNC	29.23	(18.5)	41.00	<21.1)	43.OO	C20.3)	44.00	C18.8)
Hydro Puwoi'	34.54	<21.8)	41.OO	C21.2)	44. OO	(20.8)	47. OO	(20.1)
Natural flow	18.98	(12.0)	21.50	(11.1)	23.00	(10.8)	24.50	<1O. 5)
i Pumped storasa	15.56	C 9.8)	19.50	CIO. 1)	21.OO	(10.0)	22.50	(9.6)
Geothermal	0.18	C O.I)	1.00	C 0.5)	2.40	C 1.1)	5.00	(2.1)
OilsLPG	56.94	C36.O)	52.00	(26.8)	46.60	(22. O)	40.00	(17.1)
Total	158.26	C1O0)	194.00	C100)	212.OO	(100)	234.OO	(1OO)

CElectric Utility Council)

Table 4. Structure of Power Generating Facilities (GW) (Oct. 1987)

3. GEOTHERMAL ENERGY UTILIZATION UPDATE OF JAPAN

3.1 Geothermal power plants in Japan

At present, nine geothermal power plants with a total generating capacity of 214.6 MWe are in commercial operation, as shown in Table 5. The annual electric power production from these geothermal power plants reaches totally 1.39 TWh in 1987. Among them, geothermal power plants of electric utilities are five plants, whose total capacity is 180 MWe, and whose total annual power production was 1.115 TWh in 1987. The share of this geothermal power production is only 0.2 percent of total power production by electric utilities in 1987. However, the share of geothermal power production is expected to increase to 0.8 percent (power production 6 TWh) in 1995 and to 1.7 percent (power production 15 TWh)in 2000.

Nan of Paw Plant	taUurlad Caocity MW	tmial tomtf Production MWh	foisa Pbw MW	type	Data Into Operatic
Mori	50.0	177.926	33. OO	D.F.	1982. Nov.
Kakkonda	50.0	323.454	49.60	S.F.	1978.May
Onikobe	12.5	63.149	9.OO	S.F.	1975. Mar.
Otake	12.5	85.427	11.12	S.F.	1967. Oct.
Hatchobaru Unit 1	55.0	465.797	55.O0	D.F.	1977. June
Utilities Total	18O.O	1.115.753	157.12		
Onuma	9.5	76.758	9.60	S.F.	1973.June
Natsukaxa	22.0	184.538	22.5O	D.S.	1969. Oct.
Susinoi	3.O	15.736	2.15	S.F.	1981. Aug.
Klriahima Infl. Hotel	0.1	0.683	0.10	S.F.	1984. Feb.
Industry Owned Total	34.6	277.715	34.35		
Grand Total	214.6	1.393.468	191.47		

Table 5. Geothermal Power Plants in Operation (March 31, 1988)

At present, expansion^plans for operating geothermal plants are under way for Hatchobaru Unit 2 (55MWe; Kyushu Electric Power Co., Inc.; commencement of operation in 1989), and Kakkonda Unit 2 (50 MWe; Tohoku Electric Power Co., Inc. and Tohoku Geothermal Energy Co., Ltd.; commencement of operation in 1992).
Some geothermal power plants are under preparation or planning in promising geothermal fields such as Sumikawa (Akita Pref.), Uenotai (Akita Pref.), Okuaizu (Fukushima Pref.), Takigarni (Oita Pref.), Oguni (Kumamoto Pref.), Kirishima (Kagoshima Pref.), and Fushime (Kagoshima Pref.). The total generating capacity of these power plants is anticipated to reach more than 200 MWe. Consequently, more than 300 MWe geothermal power plants would be put into operation within several years, and total capacity of operating geothermal power plant could be expected to be exceeding 500 MWe around 1995.

3.2 Direct uses of geothermal energy in Japan

Direct use of intermediate and low temperature geothermal fluid as a source of heat energy is widely applied. Recently, diversified uses of these geothermal fluid are being attempted. In particular, utilization for fish breeding and greenhouse horticulture are increasing rapidly. First analysis for the three basic parameter; inlet-water temperatures, flow rates and load factors, in direct use of geothermal energy has been made (Sekioka, M., 1984, 1986). Total heat load of geothermal direct uses in Japan is estimated 82.9 MWt.

4. GOVERNMENT EFFORT FOR DEVELOPMENT OF GEOTHERMAL ENERGY

To attain the target of national policy for long term energy supply and demand, the Ministry of International Trade and Industry (MITI) is making various efforts to promote geothermal energy development. The Agency of Industrial Science and Technology (AIST), MITI, initiated the national program, named Sunshine Project, in 1974 to accelerate the development of new energy technologies. The Agency of Natural Resources and Energy (ANRE) belonging to MITI also started various measures designed to industrialize geothermal energy development in 1974. In 1980, the New Energy Development Organization (NEDO) was established as the nuclear body for promotion of the project. NEDO also conducts the resource survey under consignment and subsidy from MITI.

4.1 Government assistance for commercial development of geothermal resources

The Agency of Natural Resources and Energy has encouraged to accelerate geothermal resources development by granting of subsidies for drilling cost and low interest loans to private enterprise. Under subsidy from ANRE, NEDO conducts the pioneering resources survey, named, Survey to identify and promote geothermal development, in the areas which are deemed geothermally promising but are still risky for commercial development due to lack of data.

4.2 Government plan for research and development of geothermal energy technologies

This development program of geothermal energy technologies is concentrated on following three item.
(a) Development of resources exploration and exploitation technologies.
The main objective of this program is to develop the technology for exploration and assessment of geothermal resources. Research on development of anti erosion-corrosion material for casing pipe and surface pipe and on multipurpose utilization technology for geothermal resource are also included within this program.
(b) Development of electric power generation system using intermediate temperature geothermal water.
The objective of this program is to develop the binary cycle geothermal power generation systems by making efficient utilization of geothermal hot water which blows out in abundance with vapor. Two types of lMWe test plant were constructed in 1977. From a result of operational studies of these plants, researches have been continuously conducted to date towards design and construction of a lOMWe demonstration plant. As a study of elementary technologies to make a conceptual design of lOMWe plant, researches on material for geothermal plant, on working fluids, on sealing of turbine shafts of working fluid turbine, on high-efficiency heat exchangers and on thermodynamic cycles were conducted. (Sunshine project promotion headquater, 1986).
(c) Development of hot dry rock power generation system.
With a view of developing the technology for creating an artificial fluid circulation system and extracting heat energy from hot dry rock, NEDO has participated in the joint international research and development program to promote the Phase 2 Hot Dry Rock project at Fenton Hill in the United States of America from Oct. 1983 to Sept. 1986. From 1984, NEDO has "also undertaken the nation's program on development of component technology for hot dry rock project in order to demonstrate the economic feasibility of such system. Test field is selected in the Hijiori geothermal field, Yamagata prefecture, northeastern Japan, where geothermal exploratory well SKG-2 of depth 1802m, BHT 253C° was drilled. This project will be continued until 1991 to develop the hot dry rock energy extraction system of 5 to 10 MWt of thermal output (T. Tomita et al.,1988).

5. GEOTHERMAL RESEARCH PROGRAM OF GEOLOGICAL SURVEY OF JAPAN

The goal of the geothermal research program of the Geological Survey of Japan is to improve our understanding of the nature, distribution, and energy potential of the Nation's geothermal resources. Progress toward these goals is sought mainly through multidisciplinary earth-science research that is designed to characterized the geological, geophysical, geochemical and hydrological factors that control geothermal systems. The current geothermal research program of GSJ is divided into three major items.
(a) Basic study on nationwide and regional geothermal resources assessment.
(b) Comprehensive multidisciplinary studies of major geothermal areas aiming at exploration and assessment of deeply seated geothermal resources.
(c) Research on exploration and assessment technology of deep geothermal resources.

5.1 Basic study on nationwide and regional geothermal resources assessment.

1) The extensive geothermal activity is indicated by the existence of numerous hot springs and fumeroles, and most of them are located within the Quaternary volcanic areas. One hundred eleven sites of steam fumeroles, boiling point springs and hot springs having a temperature above 90°C are identified from the documentation study. The area having such high temperature thermal manifestation can be considered to be promising for geothermal power production. Geological Survey of Japan conducted the three years nationwide reconnaissance survey over thirty area selected from above-mentioned one hundred eleven sites data sine 1973. Agency of Natural Resources and Energy has also conducted the structural drilling for sites selected from the result of this reconnaissance survey since 1974. After the completion of this reconnaissance survey, two hundreds of promising geothermal field were selected. (K. Sumi, 1987).
Until now, Nation's geothermal resources assessments have been carried out several times. (K. Sumi, 1987). In these assessment, several different approaches were included, i.e., surface thermal flux method, magmatic heat budget method, the stored volume of geothermal fluid method, etc. However, these estimates are empirical and are derived from the insufficient data under the inaccurate assumption.

2) Nationwide geothermal resources survey to acquire the basic data on the geothermal resources of all over the Japanese islands was conducted by NEDO with the cooperation of Geological Survey of Japan from 1980 to

1983. The objective of this survey is to delineate the geothermally promising areas by use of airborne geophysical, satellite remote sensing and gravimetic methods (K. Ogawa, 1985). Geological Survey of Japan, which took charge of the analysis and integration of the results of these surveys, started to develop the geothermal information database system SIGMA (System for Interactive Geothermal Mapping and Assessment) since 1980, in order to make the nationwide and regional geothermal resources assessment map by use of the data of the nationwide geothermal resources survey, other geological, geophysical and geochemical information acquired by Geological Survey of Japan and the government owned geographical information. (N. Hanaoka et al., 1986, Y. Yano et al., 1987).
Therefore, SIGMA has been designed to accept various application program for a standard retrieving and displaying (menu system), data manipulation and atlas production. The final goal of this research program is to publish a'geothermal potentiality assessment map of Japan by using the geothermal data base system SIGMA. Geological Survey of Japan has made tentatively the nationwide geothermal resources assessment with the limited existing data and has been doing the continuous effort to improve and develop a quantitative method for geothermal resources assessment in a regional scale by using the newly acquired data from the nationwide geothermal resources survey phase 2 which are related to the young volcanisum (including radiometric age determination), fluid geochemistry and reservoir distribution, and by making the supplemental field survey and the compilation of the well data.

5.2 Comprehensive multidisciplinary studies on prominent geothermal area.

For the purpose of the investigation on the possibility of the utilization of the deeply seated high temperature geothermal resources, the survey project of large-scale deep geothermal resource was originally planned as a part of the Sunshine Project and promoted as a national project under the financial support of the Agency of Natural Resources and Energy from 1978 to 1986. This project (MITI, 1987) implies unconventional and inexperienced items in respect to the assessment of deep geothermal resources and its exploration. MITI requested the Geological Survey to provide full assistance (Hase, H. et al., 1985). The Hohi geothermal area, which is located in the Kuju volcanic region on the border between Oita-Kumamoto Prefectures, is one of the most prominent active geothermal areas and was selected as the survey area of this project. In this area, Otake (12.5 MWe) and Hatchobaru unit 1 (55MWe) power plants are in operation and other power stations are planned.
Research work on the appraisal of the geothermal system in the Hohi geothermal area was initiated by Geological Survey of Japan since 1980. In this project, surface geological survey, gravity survey and aeromagnetic survey were conducted over a wider region from Beppu, Kuju volcano to Aso volcano to clarify the regional structural setting. The target area for the drilling survey in the Hohi geothermal project is about 200 km centered at Mt. Waita (elevation: 1,500 m). Various survey items expected to be useful for geothermal exploration were applied in and around this area. The drilling survey includes seven "intermediate" depth drilling ranging from 1,100 m to 1,800 m depth (DW series structural drilling), and five deep drilling ranging 2,500 m to 3,000 m depth (DY series drilling for test well).
The multidisciplinary research work on the appraisal of this geothermal area was attempted through modeling of the geothermal system using the geothermal data base system SIGMA of the Geological Survey, in which whole geological, geophysical and geochemical data obtained for the Hohi geothermal survey were filed and processed. In this project, prior to start of the survey, numerous geothermal models both in Japan and abroad were studied to make the most reasonable initial working model for deeply seated geothermal resources. In the initial working model, the structural setting of

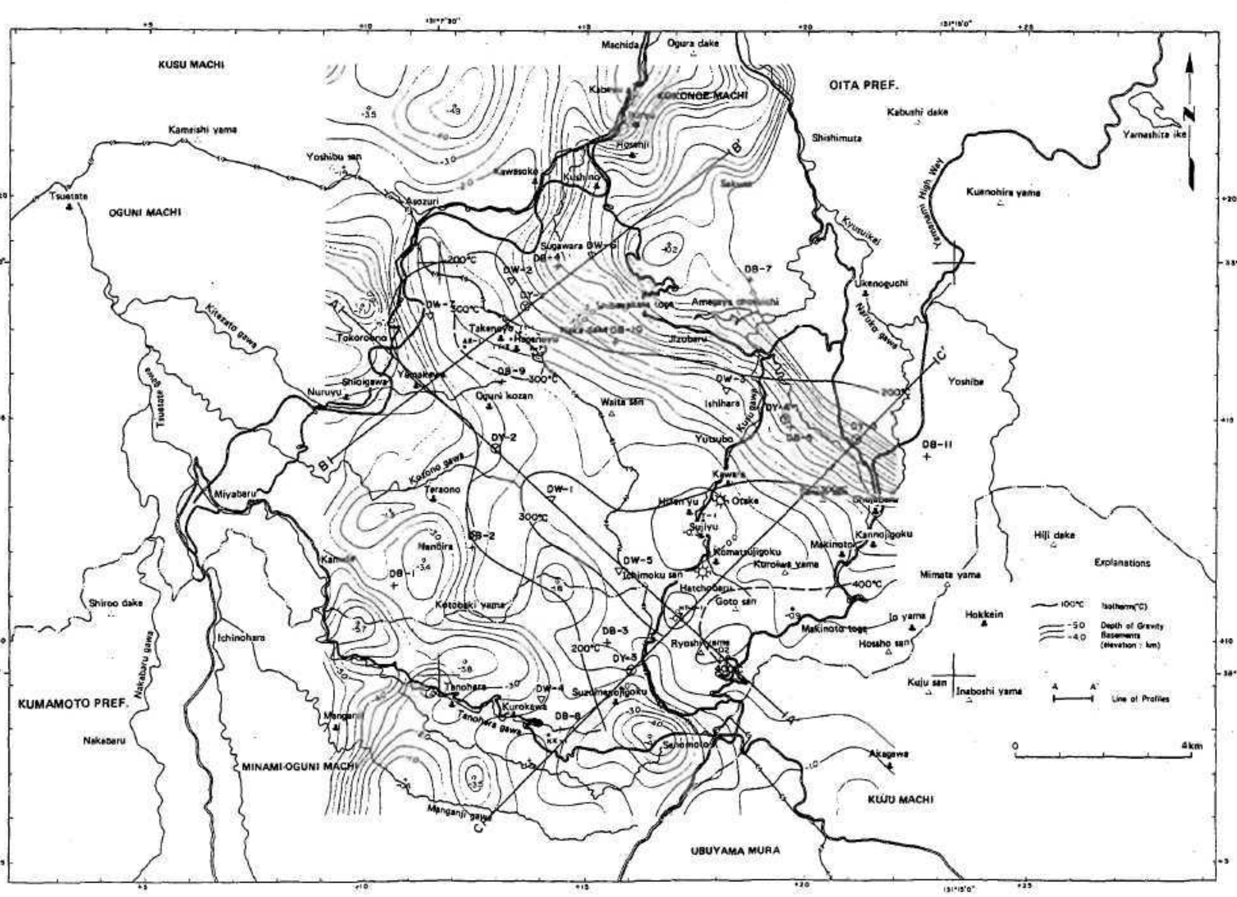

Fig.2 Map of Isothermal Ctontour, Depth of Gravity Basanent and locations of Wells and Power Stations (after MITI, 1987)

the most promising deeply seated geothermal resources is considered to be that located in and around the large domal structure formed by intrusion of high temperature rock body originated from reactivated magma in the caldera of extinct large volcanoes.

The results of the 1st phase survey (surface survey and DW-1, 2, 3 and 4 drilling survey) revealed that the Kuju uplift belt of basement, corresponding to gravity high, are trending northwesternly in the central area (see, Fig. 2), and that known geothermal fields such as Otake, Hatchobaru, Takenoyu, and Haganoyu are located in and around the uplift belt. The uplift belt seems to correspond to that of hot dry rock caused by reactivated magma as defined in the initial working model. At this stage, drilling survey program (DY-1, 2 and 3) was planned to identify geothermal resources in Kuju uplift belt. The DY-2 (2,401 m depth) and the DY-3 (2,303 m depth) wells reached to the basement rock consisting of impermeable schists and granitic rock of Cretaceous age, 1,880 m depth and 1,460 m depth respectively, and showed linear temperature increase suggesting conduction dominated geothermal environment. The DY-1 (2,618 m depth) showed the convection type temperature distribution with maximum temperature 202.7°C at 700 m depth. From the results of this drilling survey and magnetotelluric survey, it can be considered that Kuju uplift belt is not due to the reactivated magma of young volcanic rocks (Kuju volcanic rocks) and is older than that of the initial working model. Based on such idea that the heat source associated with the Kuju volcanic activity is distributed not only in the Kuju uplift belt but also extended towards the Shishimuta subsidence belt, corresponding to gravity low, which is located in northeastern side of the Kuju uplift belt, the initial working model was revised. This means that deeply seated geothermal reservoir would be possibly distributed within the Shishimuta subsidence belt and the transitimal zone between Kuju uplift belt and Shishimuta subsidence belt, ie. Jizobaru area (Fig. 2). Results of the additional magnetotelluric survey and study of age determination on young volcanic rocks have also supported this idea. According, deep test wells DY-5 (3,200 m depth, deviated well) and DY-6 (3,000 m depth, vertical well) were located in the western part of Jizobaru area. These wells showed the lost circulation at the depth of 2,600 m and 2,300 m, respectively, and the maximum temperature of 270°C to 280"C were obtained at both wells. These results have supported the new working model and the schematic figure of reservoir distribution shown in Fig. 3.

Although the extent of the entire geothermal system has not yet been made clear, deeply seated hydrothermal convention system has been identified at the depth of 2.5 km and over.

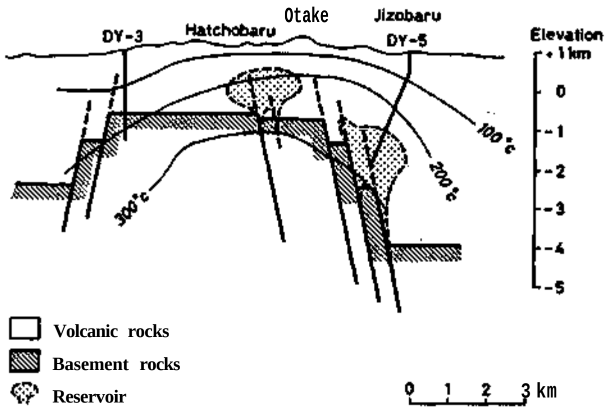

Fig.3 Schematic Figure of Reservoir Distribution (C-C" profile)

Geological Survey of Japan has been conducting similar kinds oj research works in the Sengan (K.JJirobara et al., 1987) and the Kurikoma (E. Yamada et al.,1988) areas since 1980 with the cooperation of NEDO. The Sengan geothermal area (62 km x 55 km), which is located in the Hachimantai volcanic region on the border between Akita and Iwate Prefecture, is one of the prominent active geothermal area. Geothermal power plants, Matsukawa (22 MWe), Onuma (9.5 MWe) and Kakkonda (50 MWe) are in operation and Sumikawa and other power station are planned in this area. Kurikoma geothermal area (50 km x 68 km) is also one of the prominent active geothermal area, where Onikobe power plant (12.5 MWe) is in operation and Kaminotai and other geothermal field are under development.

Geological Survey of Japan has been active in the development of methods for geothermal exploration. Development of electric and electromagnetic technique to determine the geometry of geothermal system and of passive seismic technique to investigate hydrothermal system and underlying magma , bodies are performed. Research on radiometric dating of igneous rock, geobarometric study of volcanic rock and thermal historical study of geothermal systems by hydrothermal rock alteration are also carried out.

6. CONCLUSION

Delay of commercial geothermal development is mainly due to technological and institutional uncertainties. Concerning with the technological problem, national R & D program has started since 1974 and promoted continuously. In terms of the problem on resource exploration and assessment, intensive research works have been done in Geological Survey of Japan with the cooperation of other governmental and non-governmental organization. To develop the exploration systems for regional and deep geothermal resources, in-depth multidisciplinary studies have been carried out in three prominent geothermal areas, i.e., Hohi, Sengan and Kurikoma areas.

From the integrated data analysis on geological, geophysical and geochemical data obtained from the surface and the wells in these areas, better understanding and modeling of hydrothermal system have made good progress.

These R S D works and the financial support from the government are a great help to reduce the exploration risk. The major impediments to commercial development are legal barrier and institutional uncertainty. In Japan, most of the identified potential geothermal field are found in national park and are subject to the restrictions of the National Park Law, etc. Geothermal development within national park requires permission by the Director General of the Environment Agency prior to exploration and development. It often takes considerable time before permission is given. On the other hand, the Hot Spring Law stipulates that people who wish to drill a well in the vicinity of a hot spring resort have to obtain permission from the respective Prefectural Governor. Before giving permission, the Governor must take the matter to the Hot Spring Council whose members are mainly local bath-owners. Under the circumstances, the Governor's permission would not to be easily obtained because the definition of geothermal resources and the geothermal ownership right have not yet been clear.

The alleviation of many institutional constraints is required to accelerate commercialization in time to help meet the long-term nation's energy supply plan.

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