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A SUMMARY OF RESULTS OF THE IEA TASK ACTIVITIES OF DEEP GEOTHERMAL RESOURCES

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ABSTRACT

The IEA task of Deep Geothermal Resources started in 1997 as a four-year collaborative program with participation by five countries: New Zealand, the UK, the USA, Switzerland, and Japan, and one international organization (EC) under the IEA Geothermal Implementing Agreement GIA. The task consists of three subtasks: A) Exploration Technology and Reservoir Engineering; B) Drilling and Logging Technology; and C) Material Evaluation Program. The task activities are carried out under the leadership of the task and subtask leaders designated and approved by the Operating Agent (OA) and Executive Committee, respectively. The New Energy and Industrial Technology Development Organization (NEDO) is acting as OA, and is responsible for organizing task meetings, workshops, and field trips in collaboration with the participants. Information networks on each subtask were established and an official web site was opened in order to exchange information among the participants. Several kinds of data related to deep geothermal resources have been collected and stored on the web site. In accordance with the work programs, the OA held four technical sessions and conducted three field trips to the USA, Mexico, New Zealand and Italy.

1. INTRODUCTION

The IEA Geothermal Implementing Agreement (GIA) went into effect after signing by five participating countries (New Zealand, United Kingdom, United States, Switzerland, Japan) and one international organization (European Commission) on March 10, 1997 in Sendai, Japan. Subsequently, three additional countries (Mexico, Australia, and Greece) joined the GIA in June 1997. The task of Deep Geothermal Resources was proposed and developed as an IEA international collaborative program by Japan. Before the start of GIA, Japan circulated questionnaires to geothermal experts to solicit their ideas for developing the work plans of the task.

2. OUTLINE OF THE TASK

2.1 Significance of the Task

The utilization of deep geothermal resources could effectively increase the capacity for geothermal power generation. However, there are many difficulties in the exploration, drilling, production and maintenance of deep geothermal resources because such reservoirs are located at great depth and their temperatures and pressures are likely to be quite high compared with shallower reservoirs. Therefore, the exchange of information and collaboration on recent technical progress and scientific discoveries are very significant steps toward the practical use of deep geothermal resources.

2.2 Purpose and Period of the Task Activities

The aim of this task is to exchange information and conduct collaborative research among the participants on the commercial development of deep-seated geothermal resources. These activities can be anticipated to produce significant benefits for the participants. The task is planned as a four-year program. It will be terminated in March 2001.

2.3 Definition of Deep Geothermal Resources

Annex IV attached to the GIA defines 'Deep Geothermal Resources' as geothermal resources located at a depth of 3,000 m or deeper. Many such deep-seated geothermal resources are expected to lie underneath shallower reservoirs that have already been developed in many countries.

2.4 Components of the Task

This task is composed of three subtasks that cover several aspects of deep-seated geothermal resource identification and development.

• Subtask A: Exploration Technology and Reservoir Engineering.

The objective of subtask A is to evaluate exploration techniques used to identify deep structures in geothermal systems. This subtask includes geophysical exploration, geological and geochemical exploration, geothermal modeling, and reservoir engineering.

• Subtask B: Drilling and Logging Technologies.

Subtask B is aimed at collaboration on drilling and logging technologies necessary for developing deep geothermal resources through information exchanges and the construction of a common use database.

• Subtask C: Material Evaluation Program.

Subtask C is focussed on collaborative research on materials performance in deep-seated and magma-like geothermal systems.

NEDO acts as the Operating Agent (OA) for this task. Task and subtask leaders approved by the Executive Committee (ExCo) are responsible for arranging yearly work plans and conducting the work programs. Five countries (Australia, Mexico, New Zealand, the USA, and Japan) took part in the task. To date, information exchanges and collaboration among the participating countries have been accomplished through meetings, workshops, field excursions, and the Internet.

3. TASK ACTIVITIES IN EACH YEAR

3.1 Activities in 1997

The first task meeting was held as a side meeting of the NEDO International Geothermal Symposium on March 12, 1997 in Sendai, Japan. Twenty-eight experts from seven countries attended the meeting. The OA held the second task meeting on October 14, 1997 in San Francisco, CA, USA. The meeting was held as a side meeting of the 1997 GRC Annual Meeting. The number of attendees was 20 experts from five countries.

The OA organized a technical session on "Deep Geothermal Resources" at the NEDO International Geothermal Symposium. Sixteen papers were submitted from seven countries. A technical session "IEA Contributions to Geothermal Development" was also held at the 1997 GRC Annual Meeting. At the session, nine papers were presented from four countries. Following the GRC meeting, the OA arranged a field trip to the Salton Sea, USA and Cerro Prieto, Mexico in order to collect and exchange information about the present status of deep geothermal development in both areas. The field trip was conducted from October 17 to 20. Ten experts from three countries participated.

The OA distributed a questionnaire to 14 representatives of six countries to assess the OA's ideas about an Internet database. The OA, however, concluded that it was premature to develop a full-scale database because of the low availability of data. Instead, the OA designed an official web site for the exchange of information among the participants and the storage of data collected.

3.2 Activities in 1998

The OA organized a technical session, "IEA Deep Geothermal Resources", at the 20th New Zealand Geothermal Workshop on November 12, 1998. More than 14 papers were presented from three countries. The OA then conducted a field trip to Wairakei, Rotokawa, Mokai, Ohakuri, Ohaaki, Waiotapu, and White Island on November 14 to 16 to investigate the present status of deep geothermal resources in New Zealand. Fifteen experts from six countries joined the trip, which was guided by colleagues from New Zealand.

An official web site (http://www.ieageo.or.jp) for the task was opened in April 1998. Progress reports and technical information concerning the three subtasks are given on the web site. Annual reports of GIA, country reports presented by the participants, reports of IEA-related field trips and progress reports of the "Deep Geothermal Resources Survey" project by NEDO are also available on this web site. A file server on the ftp site, which enables the exchange of digital data between the participants, has been installed to provide access to various data on the Internet. A bibliographic database on deep geothermal resources can be accessed on the web site by the title of the paper, author, year of publication, or journal name (Fig. 1). The OA updates the contents of the database whenever the participants provide new data.

3.3 Activities in 1999 and 2000

The OA organized a technical meeting in Pisa, Italy on November 10, 1999 in close cooperation with geothermal experts from the ERGA group of ENEL. Following the meeting, a field trip to Larderello, Monte Amiata and Latera was conducted on November 11 and 12. Eleven experts participated from Mexico, New Zealand, Italy and Japan. The task activities will be continued in 2000 and the participants will report their results at the World Geothermal Congress (WGC) 2000 to be held in Japan in May to June 2000.

4. SUMMARY OF THE RESULTS OF EACH SUBTASK

4.1 Subtask A

One of the major topics of this subtask is to model deep geothermal systems from several fields in the world. The subtask activities are focussed on a comparative study of exploration methods, conceptual models, and numerical models of these fields. The following nine research programs were proposed from New Zealand, Mexico, Italy, and Japan:

• Exploration techniques for deep geothermal resources and their modeling by Tosha, Koide, Ohminato and Doi (NEDO, Japan);

• Geothermal modeling of deep geothermal resources by Muraoka, Shigeno and Ishido (GSJ, Japan);
• Fluid inclusions in deep geothermal system by Sawaki, Sasaki, and Sasada (GSJ, Japan);
• Modeling of deep geothermal resources at Larderello by Gianelli, Manzella and Puxeddu (IIRG, Italy);
• The deep metamorphic reservoir of the Larderello-Travale geothermal field by Baldi, Bertini, Dini, and Fiordelisi (ENEL, Italy);
• Characterisation of TVZ geothermal heat source regions by Christenson, Wood, and Arehart (IGNS, New Zealand);
• Numerical modeling of deep geothermal systems by Ishido and Yano (GSJ, Japan);
• Modeling chemical transport and reactions in deep geothermal reservoirs by Weir, White, and Kissling (IRL, New Zealand);
• Development of an expert system for assessment and management of geothermal fields under production by Iglesias, Arellano, and Rodriguez (IIE, Mexico);

A small spreadsheet-type database of deep geothermal fields and wells is also planned for the web site. It will include only published data collected by the OA, because the availability of data from the commercial geothermal sector is very restricted. Figure 2 shows an example of published temperature-depth profiles of deep geothermal wells in the world. If the temperature of a deep geothermal well exceeds 380°C, the upper crustal rocks will reach a plastic condition as seen in the inflection point of the temperature profile of WD-1a, Kakkonda, Japan (Muraoka et al., 1998). Therefore, the useful exploitation temperature of deep geothermal resources will have an optimum value that will not necessarily be the highest temperature attainable.

4.2 Subtask B

The work program of this subtask consists of three items: a) review of the drilling and logging data stored in the database; b) exchange of R/D information provided by each participant; and c) integration and future recommendations.

Five research programs were proposed for technical information exchange from Japan, Mexico and the USA.
• Development of polycrystalline diamond compact (PDC) drill bits for downhole motor drilling (NIRE, Japan);
• Development of drilling technology for deep-seated geothermal resources (NEDO, Japan);
• Development of an advanced geothermal drilling system (AGDS) (Pajarito Enterprises, USA);
• Development of production technology for deep geothermal resources (NEDO, Japan);
• Borehole logging based on optical fiber technology (IIE, Mexico).

The results of cooperative work can be summarized as follows. An information network was established to promote mutual information exchange among the members. Thirteen members from seven countries are participating in the network. Information concerning geothermal drilling and logging technologies has been collected from 147 published papers and stored in a database on the web site. These papers are classified into seven categories, including problem assessment during drilling (11), drill bits (9), materials (3), new drill systems (32), logging technology (27), general reports on deep geothermal resources (9), and others (3).

To compare the time distributions of drilling programs at different fields, the drilling data contained in the database was subdivided into six job categories: drilling and tripping, lost circulation treatment and other problems, casing cementing, logging and coring, well tests, and others. Figure 3 shows the results of classifying, according to these categories, information from a number of papers that discuss geothermal well drilling in several different countries. The data summarized in Figure 3 indicate that the drilling operation itself and lost circulation treatment, taken together, account for about 70% of the time spent in a typical geothermal drilling operation. Rather than simply use these six categories, however, more useful information about the significance of the various drilling-related activities might, perhaps, be obtained by establishing a set of drilling job classifications that will be accepted by the entire drilling industry.

The following interesting research areas are envisaged as part of the future work recommendation for this subtask:
• A downhole percussion drilling system driven with mud circulation; and
• Technology transfer from the oil and gas industries to the geothermal industry of technologies such as casing drilling and the small exploration rig now being effectively employed in Italy.

These technologies will contribute to reducing the costs of drilling deep geothermal wells in high temperature environments and in hard rocks.

4.3 Subtask C

Prior to the start of the materials evaluation subtask activities, preliminary questionnaires were distributed to materials experts to prepare a draft work plan for this subtask. Based on responses received from seven countries, we reviewed the state-of-the-art of materials with regard to deep geothermal development, fluid chemistry, and corrosion in aggressive fluids. As a result of the review, the following potential research topics were selected for the subtask:
• High temperature corrosion and utilization of deep geothermal energy systems, by Lichti, (MPT, New Zealand);

• Materials for geothermal energy utilization, by Sanada (TNIRI, Japan);
• Investigation of casing and pipeline corrosion in geothermal plants, by Tosha (NEDO, Japan).

The participants from Japan and New Zealand visited each other's organizations in order to exchange information on materials and fluid chemistries. Mutual visits and discussions were also carried out between the participants and other parties, including geothermal companies, in the Philippines, the USA, and Japan.

Chemical data on geothermal fluids were compiled from published papers in order to develop databases for deep geothermal wells and wells discharging acidic fluids. References concerned with fluid chemistry and materials performance experiences in geothermal fields were also compiled from scientific journals published in the last ten years. Over 160 papers were gathered from relevant journals such as Geothermics, GRC Transactions, Geochemical Journal, Journal of the Japan Geothermal Energy Association, etc. These references are stored and available on the web site.

Corrosion models were developed to predict the materials performance requirements under downhole conditions and the need for corrosion control. Figure 4 shows a comparison of corrosion in a two-phase flow regime compared to static autoclave test results at 137°C. Corrosion of all materials was independent of the flow turbulence at pH 4.5, whereas the corrosion is more severe in turbulent flow at pH 3.2 and 2. Materials performance data were also collected from the following environments: geothermal wells discharging acidic fluids in Japan and the Philippines, acidic wellhead applications in the USA, and acidic hot springs associated with volcanoes in New Zealand. These data were incorporated into the database concerned with material guidelines for utilization of deep-seated geothermal fluids. The guidelines will be used in order to select materials suitable for deep-seated and aggressive geothermal systems.

4.4 Research Project by NEDO on the "Deep-seated Geothermal Resources Survey"

NEDO started a research project named "Deep-seated Geothermal Resources Survey" in 1992. Initially, it was a six-year program but it was later extended for three more years. The purpose of this project is to evaluate the possibility of the utilization of deep-seated geothermal resources at a depth of 3-4 km by drilling a deep well in the Kakkonda geothermal field in northern Japan, where two power plants, Kakkonda I and II (80 MW in total) are in operation. This project is expected to provide substantial information relevant to the IEA deep geothermal task activities.

The NEDO project can be divided into four stages. During the first stage, a deep well, WD-1a, was drilled through shallow reservoirs and encountered the Quaternary granite (Kakkonda granite) at 2,860 m. The bottom-hole temperature at 3,729 m was estimated to be higher than 500°C (as shown in Fig. 5), because pure tellurium metal with a melting point of 449°C was fused when it was lowered to the bottom of the well. Fluid with a high Cl concentration (39wt. %) was found near the bottom of the hole, but the permeability there was found to be quite low. Various advanced drilling techniques such as a top drive drilling system and a mud cooling system were used in the WD-1a wellbore in order to penetrate the high-temperature formations that were encountered.

During the second stage, sidetrack drilling was attempted at a depth of 2,200 m in WD-1a, targeted toward deep reservoirs. When the sidetrack well, WD-1b, penetrated rocks near the top of the granite at 2,963 m, vapor-rich fluids with excess enthalpy were discharged.

The third stage was designed to integrate the research results from the Kakkonda field. The fourth stage began in 1999 as an extended two-year program to assess the deep-seated geothermal resources in Japan by applying the results obtained at Kakkonda to other exploited fields in Japan. This project is scheduled to be completed in FY2000.

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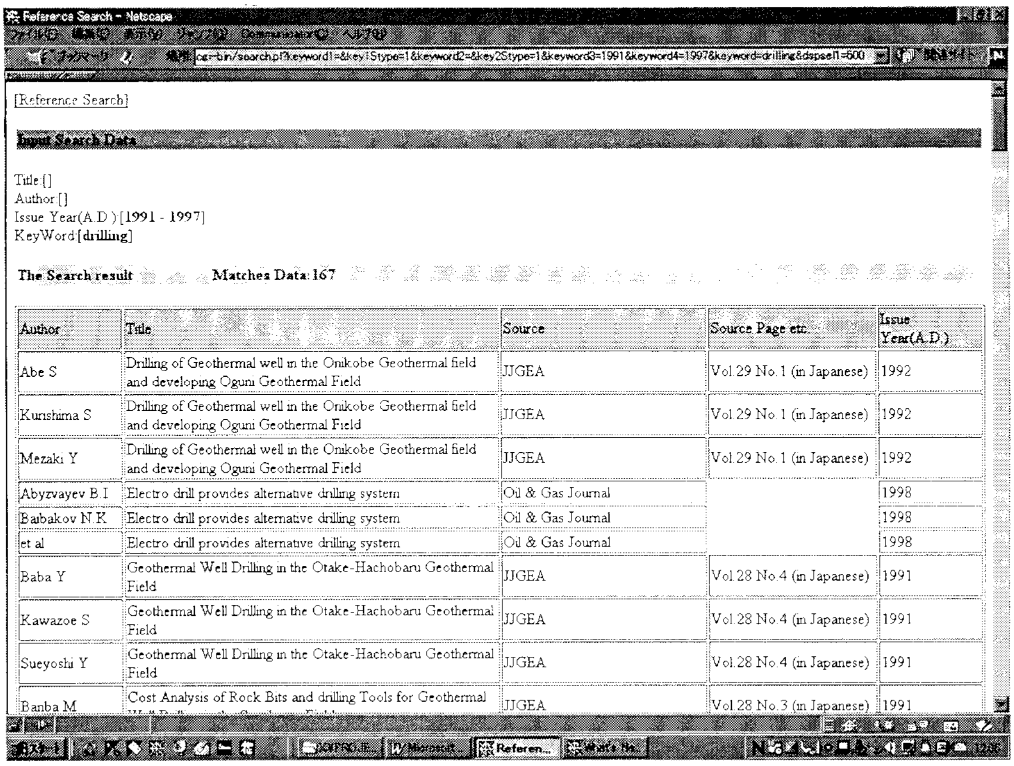

[Reference Search]

Input Search Data

Title:[]
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Issue Year(A.D.):[1991 - 1997]
KeyWord:[**drilling**]

The Search result **Matches Data**:167

Author	Title	Source	Source Page etc.	Issue Year(A.D.)
Abe S	Drilling of Geothermal well in the Onikobe Geothermal field and developing Oguni Geothermal Field	JJGEA	Vol.29 No.1 (in Japanese)	1992
Kurishima S	Drilling of Geothermal well in the Onikobe Geothermal field and developing Oguni Geothermal Field	JJGEA	Vol.29 No.1 (in Japanese)	1992
Mezaki Y	Drilling of Geothermal well in the Onikobe Geothermal field and developing Oguni Geothermal Field	JJGEA	Vol.29 No.1 (in Japanese)	1992
Abyzvayev B I	Electro drill provides alternative drilling system	Oil & Gas Journal		1998
Babakov N K	Electro drill provides alternative drilling system	Oil & Gas Journal		1998
et al	Electro drill provides alternative drilling system	Oil & Gas Journal		1998
Baba Y	Geothermal Well Drilling in the Otake-Hachobaru Geothermal Field	JJGEA	Vol.28 No.4 (in Japanese)	1991
Kawazoe S	Geothermal Well Drilling in the Otake-Hachobaru Geothermal Field	JJGEA	Vol.28 No.4 (in Japanese)	1991
Sueyoshi Y	Geothermal Well Drilling in the Otake-Hachobaru Geothermal Field	JJGEA	Vol.28 No.4 (in Japanese)	1991
Banba M	Cost Analysis of Rock Bits and drilling Tools for Geothermal	JJGEA	Vol.28 No.3 (in Japanese)	1991

Fig. 1. Bibliography database in the website (http;//www.ieageo.or.jp)

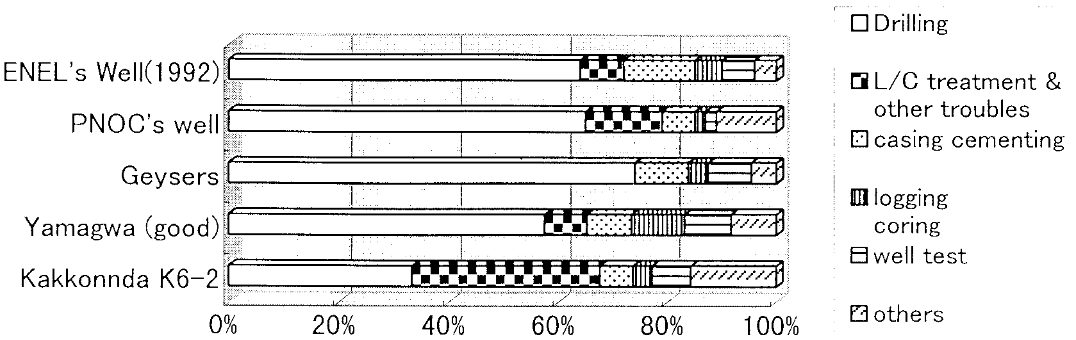

Fig. 3. Time ratio (%) of each job category of drilling work in geothermal fields

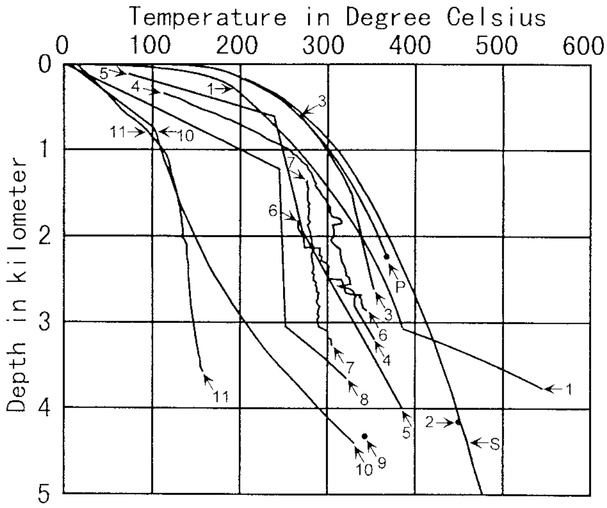

Fig. 2. Published temperature-depth profiles of deep geothermal wells in the world

P: A boiling point depth curve of pure water and its critical point; S: A boiling point depth curve of 10 wt % NaCl in water (Fournier, 1987)

1: WD-1a, Kakkonda, Japan (Muraoka et al., 1998); 2: Monte Amiata, Italy (Bertini et al., 1995); 3: Bulalo, Philippines (Otte et al., 1990); 4: State2-14, Salton Sea, USA (Ross and Forsgren, 1992); 5: Larderello, Italy (Otte et al., 1990); 6: Northwest Geysers, USA (Walters et al., 1992); 7: Relatively central Geysers, USA (Walters et al., 1992); 8: The Geysers, USA (Otte et al., 1990); 9: M-205, Cerro Prieto, Mexico (Mario et al., 1997); 10: GT-2, Fenton Hill, USA (Burns and Potter, 1995); 11: GPK-1, Soultz, France (Baria et al., 1995). The details of references cited here are left out due to space limitation.

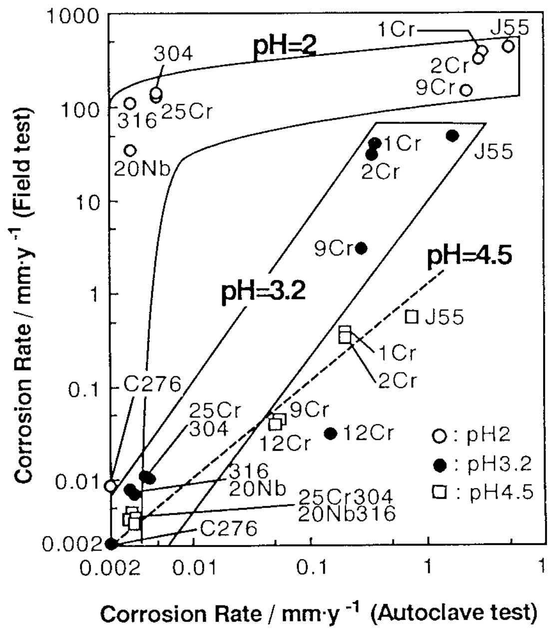

Fig. 4. Comparison of corrosion rates in flowing two-phase fluid tests with static autoclave tests at 137°C
Flow velocity in field test: 70-100 m/s

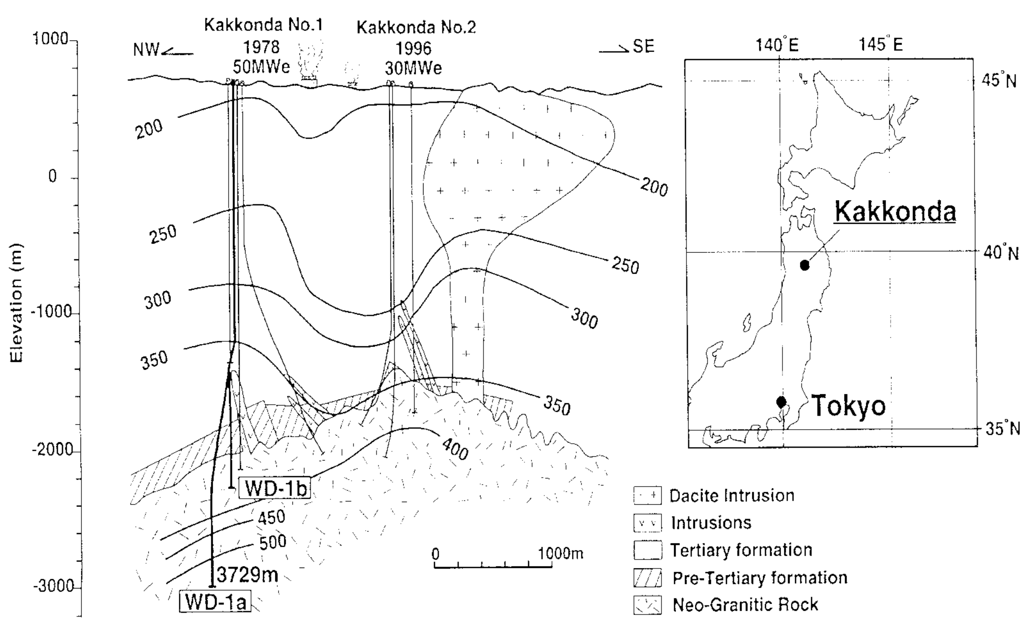

Fig. 5. Location and cross-section of the Kakkonda geothermal field, northern Japan