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UTILIZATION OF SLIM HOLES IN GEOTHERMAL RESOURCE EXPLORATION IN JAPAN: Experience of the NEDO Geothermal Development Promotion Survey Project

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ABSTRACT

Since 1980, NEDO has been carrying out geothermal resource preliminary exploration using Japanese government resources. This exploration in various geothermal prospects throughout Japan has involved drilling hundreds of slim holes. The NEDO experience with slim hole drilling may be summarized as follows:

(1) Slim holes have proved useful in characterizing geological structure, subsurface temperature, and distributions of permeability and productivity.

(2) The low cost of slim hole drilling, the portability of the drilling equipment and the small drilling-area requirements help to reduce financial risks and environmental impact.

(3) Disadvantages of slim-hole drilling include the dangers of possible drill pipe failure and blowouts.

INTRODUCTION

In Japan and elsewhere, geothermal resource development usually involves (1) surface exploration surveys and exploration well drilling, (2) drilling of production and reinjection wells, and (3) construction and operation of a geothermal power station. Production and injection wells are normally drilled using "rotary-type" drilling rigs, whereas slim exploration holes are usually drilled by diamond core drilling rigs (usually called "spindle-type" rigs in Japan). During preliminary exploration, subsurface data are sparse, so that numerous exploration holes are needed to properly characterize the resource.

Although the use of slim holes for exploration is much less widespread in the U.S. than in Japan, Lysne and Jacobson (1990) have reported on a 1760 meter hole of final diameter 76 mm in the Valles Caldera, in which the entire hole was cored. Recently Combs and Dunn (1992) have urged the promotion of slim-hole techniques to reduce risks of future exploration projects.

"Spindle-type" rigs have long been used in the Japanese mining industry; in mining, the compactness and portability of the rig are advantageous, and the ability to perform complete coring surveys is very important. Sometimes, however, the relatively low capacity of such rigs (as compared to traditional rotary equipment) has caused operational problems.

The New Energy and Industrial Technology Development Organization (NEDO) has been undertaking the "Geothermal Development Promotion Survey" project using government resources to minimize exploration risks which must be undertaken by private developers and to promote the development of geothermal energy. The project was initiated in 1980 just after the second "Oil Shock"; to date, we have drilled over 200 slim exploration holes in Japan. The project has identified several commercially-viable geothermal resources, in some of which privately-developed power stations are now under construction.

In this paper, the Geothermal Development Promotion Survey project is described, and the experiences (both positive and negative) with slim-hole drilling are outlined.

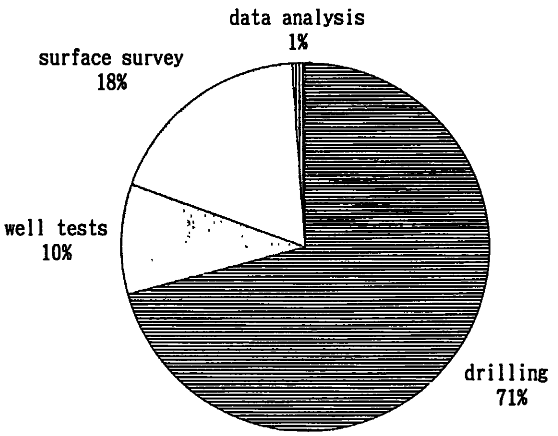
THE GEOTHERMAL DEVELOPMENT PROMOTION SURVEY PROJECT

Typical program and survey costs:

Ordinarily, surveys are carried out over a three-year period and involve areas from 50 to 70 square kilometers in size (which have not previously been explored by private interests) to try to identify regions with both high subsurface temperatures and good permeability. A typical program is outlined in Table 1. Surface surveys include geological and geochemical studies and geophysical exploration surveys, which are used mainly to identify drilling targets and to delineate the hydrothermal zone. Six to nine slim holes (usually from 1000 m to 1800 m deep) are drilled in the area. Sometimes, 400 meter heat-flow holes are also drilled. If any of these

Table 1 TYPICAL PROGRAM IN PROMOTION SURVEY

SUBJECTS	1st YEAR	2nd YEAR	3rd YEAR
1. SURFACE SURVEY			
a) GEOLOGICAL SURVEY			
b) GEOCHEMICAL SURVEY			
c) GEOPHYSICAL EXPLORATION			
2. SLIM HOLE DRILLING			
a) HEAT HOLE (400 m DEPTH)			
b) EXPLORATION WELL (1000 - 1800 m DEPTH)			
INTEGRATED EVALUATION			



(exchange rate 1dollar=120yen)

Fig. 1 TYPICAL INDIVIDUAL AREA SURVEY COSTS (TOTAL COST : $10.7 MILLION)

wells encounter high-temperature permeable fracture zones, discharge tests are performed.

Figure 1 shows typical costs for a NEDO single-area survey (as outlined above). In this case, the total cost of these studies was 1.3 billion yen (about $10.7 million), of which drilling costs account for over 70%.

Project Results:

Since 1980, NEDO has selected two or three new areas for investigation each year. Surveys have already been completed in 36 areas and two studies are presently ongoing. Figure 2 shows the locations of these Promotion Survey areas, as well as the locations of existing geothermal power stations which produce in excess of 10 MWe.

Figure 3 summarizes the survey results in terms of maximum subsurface temperature encountered. Also shown is the number of areas in each temperature classification in which the presence of a geothermal reservoir has been verified by successful discharge testing. About 70% of the areas investigated exhibit subsurface temperatures exceeding 200℃, and wells were successfully discharged in the majority of these areas. Demboya et. al. (1993) describe computed performance forecasts of several slim holes drilled in the Hachijo Island prospect (a volcanic oceanic island south of Tokyo).

In the NEDO program, a total of 22 slim holes in sixteen different exploration areas have been discharge-tested. Most of these tests were limited to about one month duration. Figure 4 illustrates the discharge characteristics (relations among wellhead pressure, flowrate, and enthalpy)

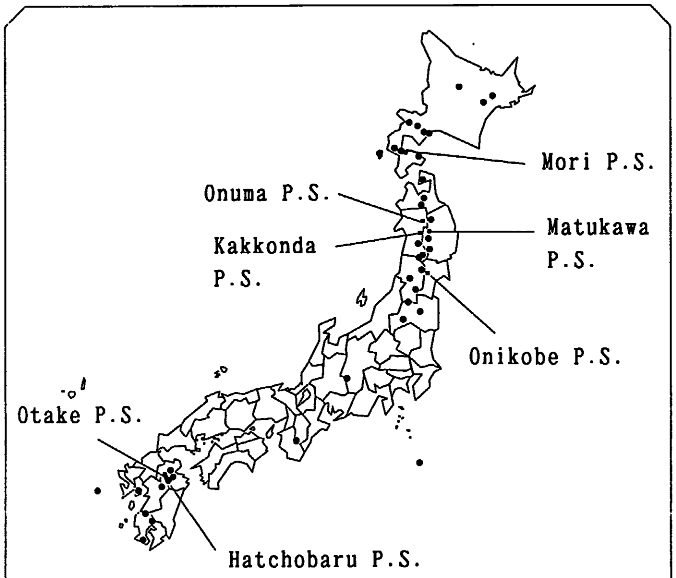


Fig. 2 PROMOTION SURVEY LOCATIONS ("P.S.":GEOTHERMAL POWER PLANT > 10MWe)

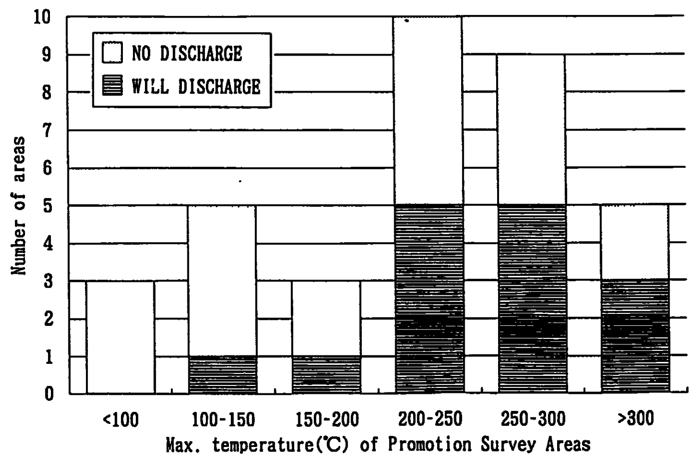


Fig. 3 TEMPERATURE OF FIELDS STUDIED IN PROMOTION SURVEY

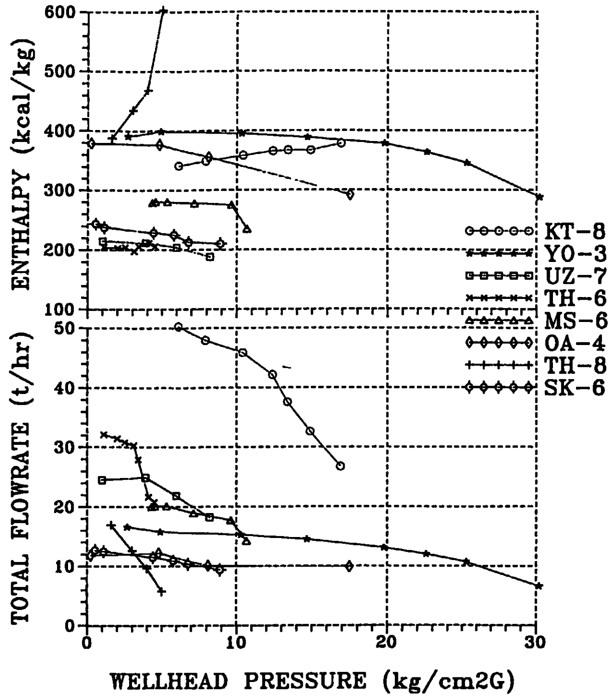


Fig.4 DISCHARGE CHARACTERISTIC TEST IN PROMOTION SURVEY SLIM HOLES

of those of NEDO's various slim holes which have discharged in excess of 10 tons/hour of total fluid and in excess of 200 kcal/kg of enthalpy. In slim holes, it's ordinary less than 30 tons/hour of total fluid and less than 10 kg/cm2G of well head pressure.

In five of the survey areas, private companies are now designing or constructing geothermal power plants.

UTILITY OF SLIM HOLES FOR RESERVOIR EXPLOLATION

Recently, the problem of predicting the production characteristics of future large-diameter production wells based on tests of small-diameter core holes has been discussed by Pritchett (1993) and by Garg and Combs (1993). Mimura et. al. (1991) have discussed the relationship between hole diameter and maximum discharge rate (Figure 5) based on calculations using a wellbore simulator ("WENG"; developed by NEDO). They report that doubling the well diameter results in a six fold increase in discharge rate (with formation temperature, heat transfer coefficient and wellhead pressure fixed).

Production/injection operations in a geothermal field (either during well-tests associated with field development or during later routine field operation) induce pressure transients within the reservoir which are related to the distribution of permeability in the field. Slim holes (which were initially drilled to aid in

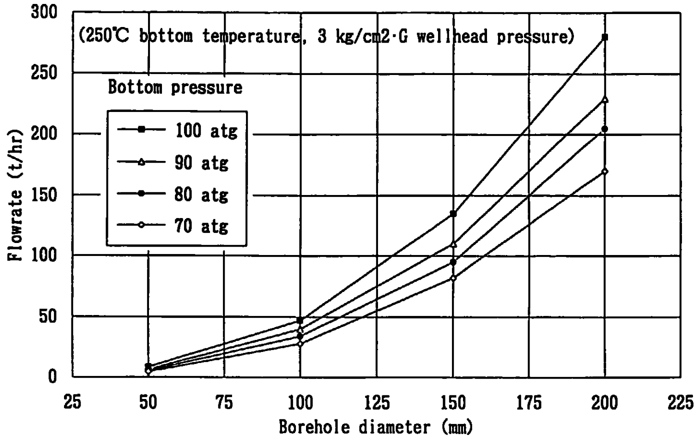


Fig.5 RELATIONSHIP BETWEEN DIAMETER AND MAXIMUM DISCHARGE RATE (after Mimura, et.al., 1991)

early field exploration) have subsequently been utilized as shut-in pressure observation wells during subsequent field development. Useful data have been thereby acquired which has contributed significantly to the characterization of the permeability distributions in the reservoirs involved.

SLIM HOLE DRILLING TECHNOLOGY

Well Design and core drilling:

The casing program of a representative Promotion Survey slim hole (1500 meters deep) is shown in Figure 6. Coring bits in most common use are the "HQ" (98 to 101 mm diameter) and "NQ" (76 to 78 mm) types. The maximum depth achieved so far in NEDO's Promotion Survey project is 1800 meters, but slim holes exceeding 2000 meters depth have been reported by other Japanese operators. In slim holes, the clearance between the casing and

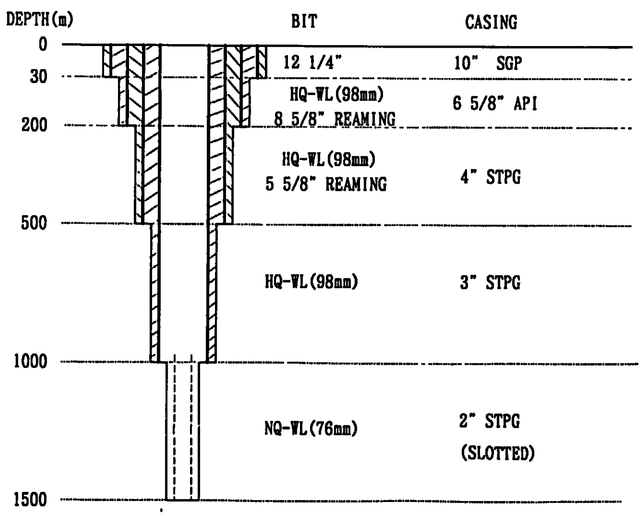


Fig.6 TYPICAL WELL COMPLETION FOR PROMOTION SURVEY SLIM HOLE

the borehole surface is very small (compared to production-size wells). This small clearance can prevent the annulus from being adequately filled with cement slurry during well completion.

Concerning penetration rate, Maki and Kawano (1988) present a statistical study of penetration rates for the HQ- and NQ-size holes drilled by NEDO's Promotion Surveys. Figure 7 shows typical drilling charts which illustrate differences in penetration rate for spindle-type drilling (both with and without coring operations) and conventional rotary drilling. The penetration rate using spindle-type drilling is commonly less than half that attained by rotary drilling.

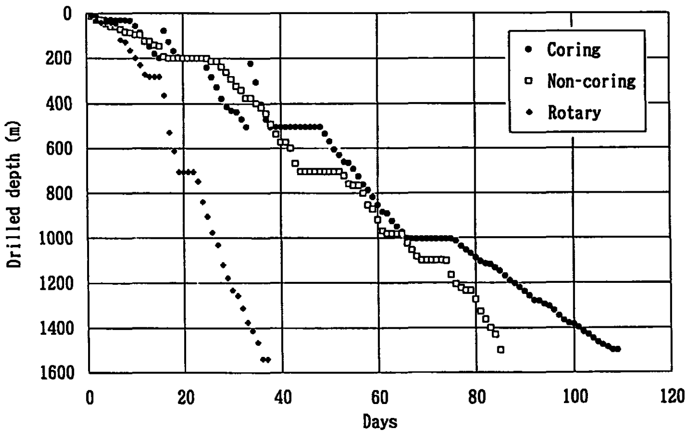


Fig. 7 DRILLING CHART

Portability of Drilling Equipment:

Spindle-type drilling rigs are compact in volume and weight compared to rotary rigs, which facilitates transportation and setup. The drilling pad may also be relatively small and access roads may be narrower; typically, the size of the drilling site and amount of equipment which must be moved for a spindle-type operation are less than half the requirements for a rotary rig. In Japan, geothermal prospects are usually found in heavily forested areas in which roads are poor, sparse, or absent altogether. Clearing and development of drilling sites and roads are often sharply restricted by environmental constraints. Occasionally, it has proved advantageous to transport the drilling equipment to the field by helicopter.

Drilling Costs:

Figure 8 compares our experience with the drilling costs of slim holes using spindle-type rigs with those of production wells using rotary rigs; the slim holes are around half the cost per meter of hole. The slim-hole cost data were obtained from NEDO's Promotion Surveys, whereas the production hole cost data are based both on other NEDO projects and the experience of private developers in Japan. Table 2 shows sample breakdowns of total drilling costs for each technique. Clearly, slim holes offer a substantial cost benefit for preliminary field exploration.

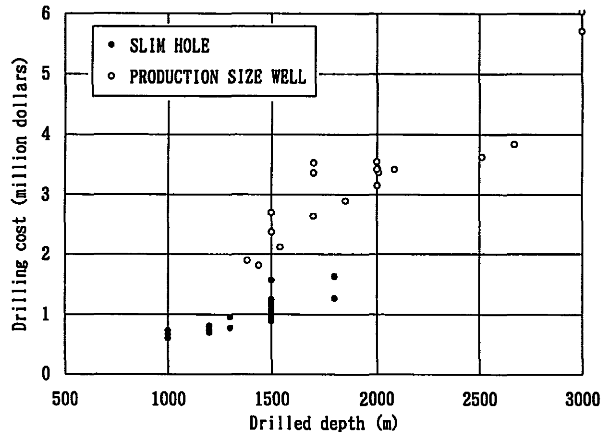


Fig. 8 DRILLING COST OF SLIM HOLES AND PRODUCTION SIZE WELLS

Table 2 BREAKDOWN OF DRILLING COSTS

Items	Spindle-type	Rotary-type
Labor	0.32	0.50
Accomodation	0.08	0.19
Fuel	0.06	0.10
Supplies	0.42	0.99
Rig	0.31	0.49
Transportation	0.13	0.33
Other	0.08	0.27
Total	1.41	2.87

(unit : million dollar)

Operational Drilling Problems:

Drilling problems occasionally occurred in our surveys which arose from the small hole diameter, the low capacity of the drilling equipment, and/or drilling technique. The most serious problems were mainly drill pipe failures and blowouts. As discussed above, there are a number of differences between spindle-type and rotary drilling. The main weaknesses of the slim corehole approach are as follows:

(1) The coring bit diameter is only slightly greater than that of the drill pipe, so that the clearance between the pipe and the rockface is very small.

(2) The drill pipe is thin and its joints are weak, which can result in bending and rupture of the drill pipe.

Sometimes, this results in sticking of the assembly and rupture of the drill pipe.

The blowout accidents are one of the spindle drilling problems and have ever taken place a few times in Promotion Survey. This accident derives from swabbing-effect which occurs when the core barrel and drill pipe are removed can also sometimes promote blowout.

If brittle or unconsolidated formations are anticipated (which can result in sloughing into the borehole) or large circulation losses are expected in a high-temperature zone, it is best to increase the hole diameter and/or shorten intervals of core drilling. To prevent blowout in a high temperature target zone, it is advisable use to rotary drilling.

CONCLUSIONS

Particular results of preliminary exploration using slim holes are as follows:

(1) The costs of drilling a slim hole are typically less than half those of a production-size hole. Thus, slim-hole exploration drilling can significantly reduce risks.
(2) Spindle-type machinery is compact, portable, and easy to set up; slim hole drilling also minimizes environmental impact.
(3) Top-to-bottom coring (available using slim-hole techniques) provides good geological resolution and fracture zone identification which are not possible with conventional production well drilling.
(4) Of the 36 areas for which Promotion Surveys have so far been completed, slim-hole discharge tests have been successfully carried out in 15, confirming the presence of permeability in the target reservoir.
(5) Slim exploration holes can be subsequently used as pressure observation wells to monitor conditions during field development and exploitation.
(6) Under difficult drilling conditions, drill pipe failure and blowouts can present problems using these drilling techniques. If high temperature/pressure reservoirs are identified, larger well diameters should be used and coring should not be attempted.

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