AN ADVANCED GEOTHERMAL DRILLING SYSTEM

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ABSTRACT

The historical developments of drilling technology for geothermal resources worldwide have followed similar trends. Local expertise and drilling equipment have been adapted from existing drill rigs used for mining, civil, and water well projects. In ihose areas with hydrocarbon resources, petroleum drilling hardware has been adapted; and in other countries, these units have been imported. This ad hoc approach has provided adequate exploration and production wells. However, the costs of drilling a prospect are high and often are 40 to 60 percent of project resources. Evaluations in the USA indicate that major cost factors are due to lost circulation problems, and to low penetration rates and bit life. In contrast to the incremental improvements in conventional drilling system components, this paper proposes a purpose-developed concept that would solve the above major problems by design. Performance goals of 4 km depth, 400°C, and penetration rates greater than 8 m/h were selected. This advanced geothermal drilling system features: a percussion-hammer drill, a dual-wall or multi-flow path reverse-circulation drillstring, and a versatile drilling fluid subsystem. Results of a preliminary design study are presented.

1. INTRODUCTION

Drilling of geothermal exploration and production wells is a major factor in project costs, and can consume as much as 40 *to* 60 percent of project resources (Benardino et ai. 1986). Therefore, reduction in drilling costs can have a very positive impact on geothermal development. The usual practice in many parts of the worid is to adapt petroleum drilling technology. Improvement of this drilling system has featured incremental advances. However, the problems causing high geothermal driliing costs are inherent in the subsurface conditions and have not yielded to an incremental approach. These major problems are well known (Kelsey and Carson 1987; Baron and Umgemach 1981) and include: low penetration rates in hard fractured rocks, severe ioss of drilling fluid circulation, and high temperatures. While for drilling in shallow, sedimentary basins, it has proven very difficult to provide incremental improvements of that system and reduce costs significantly.

Therefore, the approach taken (Rowley 1994) for this concept study attempts to provide solutions to the major geothermal drilling problems by selection of technologies from existing drilling systems that are directed at solutions of the problems. The choice of a percussion drilling method is proposed as a solution to the low penetration rates. Lost circulation problems of tractured, brittle formations are addressed by choice of a dual-wall, multi-flow path drillstring that uses reverse circulation and largely exempts the borehole-wall-to-drillstring-annulus from use as a drilling fluid flow path. These technologies are wel! developed for shallow drilling in mining, civil engineering, and water well industriks. Therefore. this advanced geothermal drilling system is to be purpose-developed. At each stage ot design, feasibility and analysis should be performed to maximize geothermal drilling solutions and offer features, sub-components, materials, and techniques that reduce significantly the most severe problems shown in Figure 1. The paper records the component options and sets forth the areas needing analyses, refinements and development. Several innovative solutions are introduced in the proposed sub-systems.

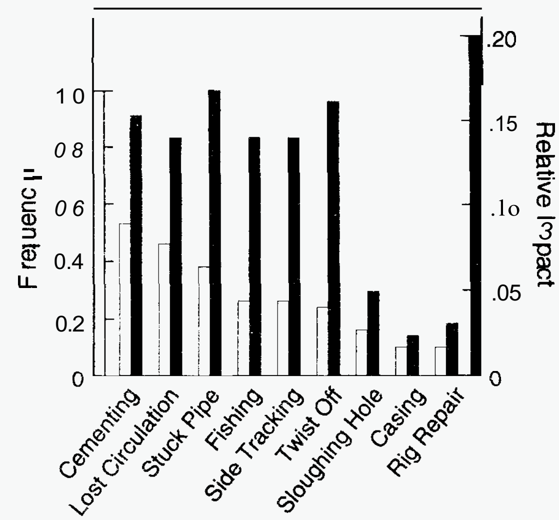

Fig. 1. Major factors reducing the effectiveness of geothermal drilling. Open bars = frequency, closed bars = frequency times days delay

Because this purpose-designed system **is** directed at solution of the geothermal drilling problems, it is necessary to summarize the major problems being targeted. Figures 1 and 2 give a breakdown of driiling problems. Figure 1 indicates that lost circulation and related delays are by far the most severe. The data presented in Figure 2 shows that driiling performance, related to low rate of penetration (ROP) and short bit life are a major source of time required to drill geothermal wells. Shown is a typical time of 71 days needed to drill a 2.5 km deep well (Southon and Dacanay 1994). More than 50% of geothermal production wells are directionally drilled, therefore, any proposed system must also address a lowering of cost of these operations. Figure 3 records the fact that geothermal costs in the USA are generally 2 *to* 4 times those of oil and gas wells.

2. CONCEPT AND DESIGN GOALS

2.1 System Concept

The schematic sketch in Figure 4 illustrates the major components of the proposed advanced geothermal drilling system (AGDS). Major features are:

- A percussion hammer, directional assembly that has downhole force and indexing (rotation) control; the hammer is hydraulically or pneumatically driven.
- A dual-wall, or multi-flow-path drilling fluid flow path providing for reverse circulation and near-isolation of the borehole wall-to-drillstring annulus.
- A versatile drilling fluid supply sub-system for air, nitrogen, water, or foam.

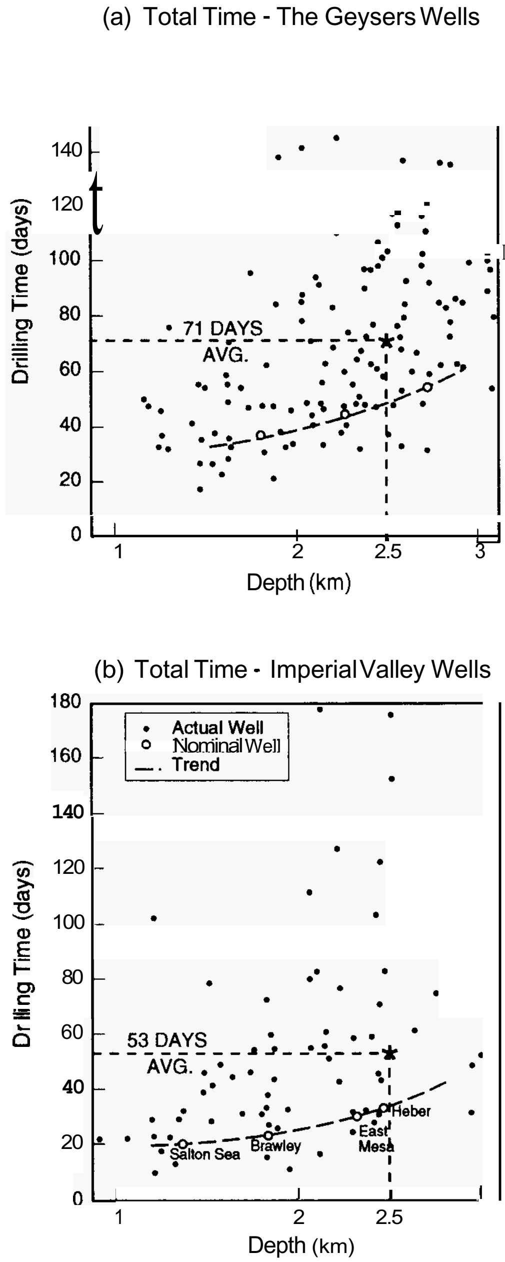

Fig. 2. USA Drilling Times. Data scatter are reduced effectiveness; dashed curves nominal, problem free wells.

2.2 Design Goals

The design concepts are selected to yield solutions to the major geothermal problem areas, and to achieve the following goals:

Performance Improvements

The major increases in ROP and bit life expected are related to the well-established performance of hammer drills in very hard rocks. The following are anticipated results:

- ROP greater than 8 m/h.
- Diamond enhanced tungsten carbide insert cutters for a 200 m bit life.
- Depth capacity to 4 km to tap higher energy fluids, and hot dry rock resources.

Effectiveness Enhancements

Introduction of dual-wall, or multi-flow-path, drilling strings, and the versatile drilling fluid sub-systems should decrease significantly the non-productive time associated with geothermal drilling. These features result in:

- Introduction of reverse circulation to considerably reduce lost circulation problems.
- Essentially isolate the wellbore from the degrading and destabilization effects of the conventional return path for drilling fluids and cuttings.
- Increased ability to control downhole temperatures, and the possibility to provide sensors to monitor downhole drilling conditions.
- Choice of drillstring materials such as corrosion resistant alloys (CRA) to prolong downhole component life significantly.
- Establish 400°C reservoir targets.

Introduction of these features should provide a means of drilling geothermal production wells that can reduce costs and narrow or close the gap between petroleum drilling and oil and gas drilling, Figure 3. An added benefit is the use of larger diameter production holes, up to 31 cm through adoption of the percussion drills, and increase in the economic yield of geothermal production wells.

3. COMPONENT OPTIONS

This section of the report sets forth details of sub-components of the AGDS to illustrate features that are projected to achieve system goals.

3.1 Hammer Percussion Drills

Figure 5 is a schematic sketch of one hammer drill, similar to the design studied by the German ultra-deep scientific drilling project (KTB). The potential for deep, high-temperature hammer drills is summarized by Deutsch et al. (1990). Such drilling tools can be designed with a downhole thruster, Figure 6, similar to those used in slim hole (Murray 1994) and coiled tubing drilling, to control load on the bit. A downhole jet-powered indexing (rotation) sub-system, and a directional navigational sub-system can be included.

Such tools are under development by the petroleum industry. Temperature hardening and long life by use of diamond enhanced TCI cutters (Laursen et al. 1988) will improve bit life.

3.2 Drillstring

The two configurations shown in Figure 7 illustrate design options that are being studied. Figure 7(a) is a string like most reverse circulation drilling systems (Driscoll 1986) and is two concentric pipes, usually fabricated from standard premium casing sizes

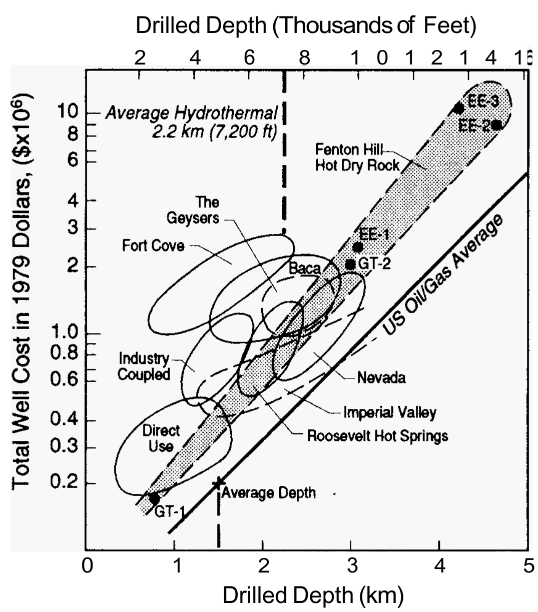

Fig. 3. USA geothermal well costs vs. depth (Kelsey and Carson, 1987).

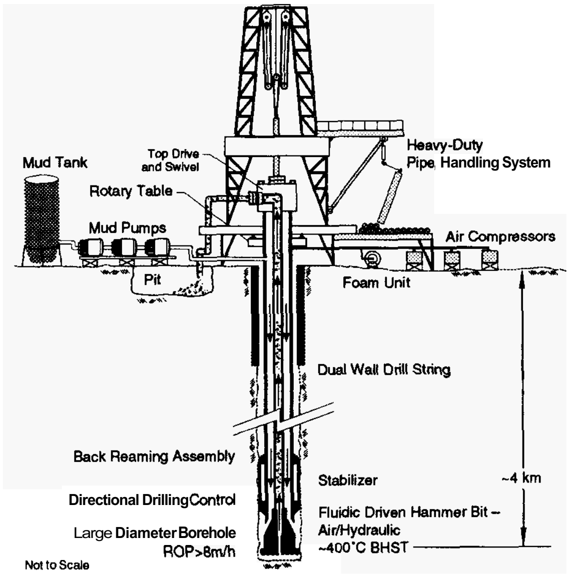

Fig. 4. Proposed advanced geothermal drilling system.

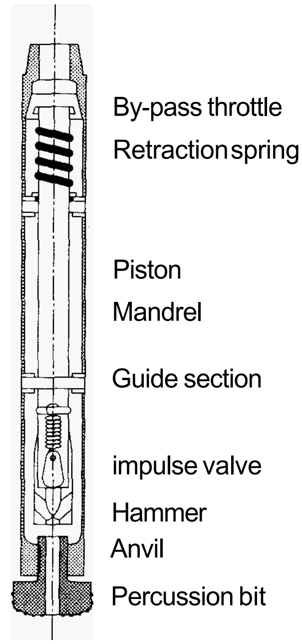

Fig. 5. Percussion-hammer design concept

(Long et al. 1992). The multiple tube drillstring depicted in Figure 7(b) is an advanced concept introduced recently. The two concentric pipes are provided with a set of small diameter tubes within the annulus. This configuration allows reverse circulation, provision of a separate borehole to outer-pipe annulus fluid via one or more of the small diameter tubes, or input flow from the surface and control of fluid chemistry and stability at the borehole wall. One small diameter tube can be used for monitoring sensors, and provide a control of indexing rotation. It will be important to design the drillstrings of high strength steels (Tsukano and Ueno 1991) and to select corrosion resistant alloys (CRA). Lost circulation, reduction and temperature control will enhance drilling effectiveness considerably and recover much of the 65% non-productive time currently experienced.

3.3 Fluid Subsystem

A versatile source of fluids is required (Figure 4) to serve the reverse, multiple flow-path drillstring. Most of that equipment and technology is available from conventional drilling systems; although larger capacity tankage, pumps, compressors, and foaming units will be required. The innovative development considered is a new source of high pressure nitrogen. These diesel powered units are being used in offshore drilling with a large cost saving over the more conventional liquid nitrogen. Such a nitrogen source will provide low corrosion fluid for gas or foam drilling. The reverse circulation mode is well known to provide the best hole cleaning capacity; and offers, by use of hollow hammers or crossover subs above the hammer bit, a cuttings sample directly from the bottom of the hole. In addition, hollow center hammers are best for minimizing plugging of existing fractures with cutting fines.

3.4 Other Components

The rig equipment and derrick structure are a straight-forward design process, once the downhole components are chosen and detailed. It is expected that automation of the drillstring and pipe handling systems will be needed. Also, a computer drilling monitoring and on-board simulation of down hole drilling conditions would be provided. A drillstring load, stress, and fatigue prediction program would be provided (Stahl, 1994).

One component of the system not considered here, but extremely important, (as indicated in Figure 1), is the casing and cementing of geothermal production wells. This element is beyond the scope of this discussion; but must be considered in the drillstring selection and design.

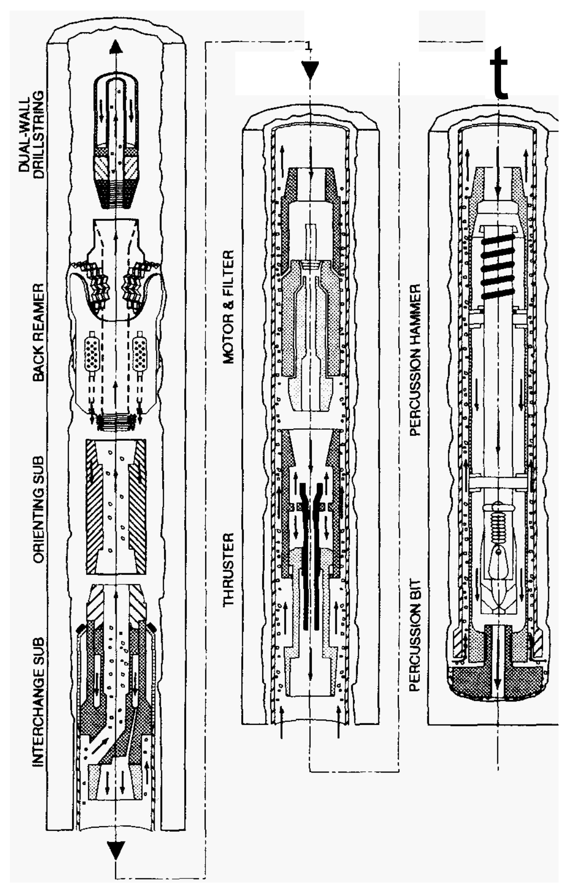

Fig. 6. Directional hammer bottom hole assembly options.

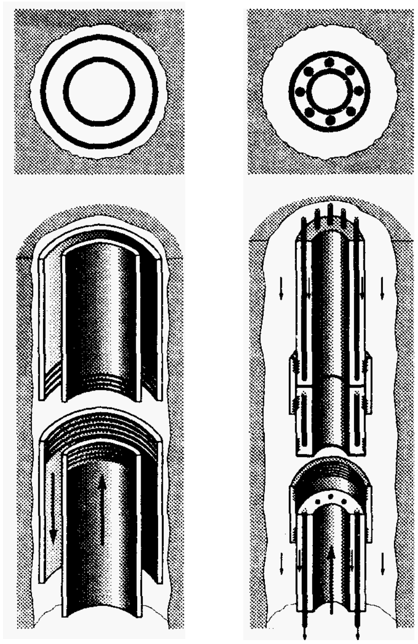

Fig. 7. Reverse circulation drillstring options: (a) Dual-wall, (b) MultiConn.

4. COMPARISONS WITH OTHER DEEP WELL PROJECTS

There are two deep geothermal well projects that afford comparison of production borehole configurations and those that are projected using hammer drilling. Figure 8 illustrates two deep geothermal wellbore configurations, from Larderello, Italy (Vallini 1994), Figure 8(a) and Kakkonda, Japan, Figure 8(b). The large diameters proposed as goals of the AGDS are given in Figure 8(c); with a 31 cm open-hole at TD, as compared to the 22 cm using ccnventional drilling equipment.

5. DISCUSSION

A review of geothermal drilling records and literature reveals that improvements must be made in both avoidance of the severe problems related to lost circulation -- improved effectiveness -- and increased drill bit life and rate of penetration -- increased performance -- if significant cost reductions are to be realized. It follows that a new drilling system concept is needed. A combination of technology transfer -- directional hammer percussion -- and innovative solutions for the drill string designs -- dual wall or multi flow path -- are required. A versatile drilling fluid system using water, mud, air, or nitrogen can resolve both the lost circulation problems and control of downhole temperatures. This discussion has presented the purpose-development concept and illustrated several major component options.

6. CONCLUSIONS

This report presents the first stages of the development of an advanced geothermal drilling system, and sets forth some basic component options and sub-system details. The aim is to reduce costs of routine drilling of large diameter wells to 4 km depths into 400°C reservoirs. A system concept and sub-component details are suggested that should provide built-in solutions to the severe lost circulation problems, and enhance drilling performance. Estimated cost reductions have ranged from 30 to 50%.

Therefore, in concept an advanced geothermal drilling system is proposed that could solve the major geothermal drilling effectiveness problems and enhance performance by use of designed-in features.

Considerably more feasibility and sub-component detail work will be necessary to firmly establish the final design. This is especially true for the directional hammer drilling sub-system, and the reverse circulation, dual-wall or multi-flow path drillstring; both essential to achieve the purpose-developed intent of the design. An informal design team has been formed to continue the design study.

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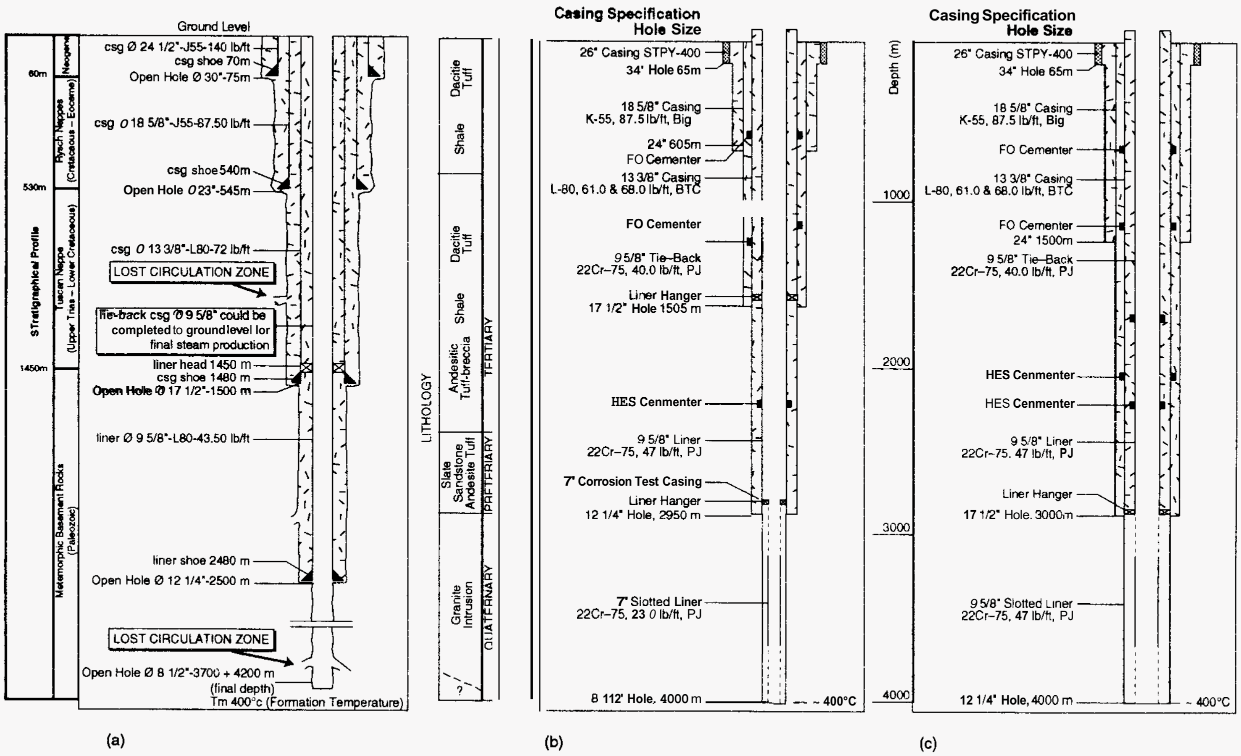

Fig. 8. Comparison of well configurations: (a) Larderello, Italy; (b) Planned, Kakkonda, Japan; and, (c) Potential large diameter completion with advanced system.