ITALIAN EXPERIENCE AND PROBLEMS IN DEEP GEOTHERMAL DRILLING

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1. INTRODUCTION

Geothermal activity in Italy is now directed partly at exploring new areas and partly at recovering fluids with better thermodynamic characteristics from the traditional geothermal areas. For the latter reason the Tuscan geothermal areas are now the subject of a deep drilling program which is aimed at individuating, below the reservoir exploited at present, geological horizons whose lithological characteristics are such as to guarantee the presence of hydrothermal circuits.

A seismic survey of the Larderello area indicated a deep reflecting horizon that varies between 3500 and 7000 m depth. At the moment, however, "deep research and exploration" is used in reference to wells that are 3000-5000 m deep. The objectives set for these wells are:

1) to verify whether, at technically feasible depths, there are permeable horizons capable of forming a second reservoir of industrially exploitable endogenous fluids;
2) to improve the hydrogeological model of the field for a more rational exploitation of the resource;
3) to evaluate the geothermal potential in terms of "resource" and "reserve," to a depth of 5 km;
4) to study the possibility of recharging the field artificially by injecting water to great depths.

These objectives are attainable if the deep wells can guarantee:

- exploration of the deep horizons with wide diameters capable of providing significant data on their productive capacity;
- isolation of any reservoirs encountered in shallower horizons.

The stratigraphic sequence expected in these wells in the Larderello zone is, approximately:

from 0 - 500 m: cover formations, comprising Neogenic sediments and flysch facies allochthonous complexes of a mainly clayey-carbonate composition.

from 500 - 1000 m: complex forming the so-called "first reservoir," consisting of limestones and the Mesozoic Anhydritic Series. These are highly fractured formations.

below 1000 m: Triassic-Paleozoic schistose-quartzitic basement, made up of schists, quartzites, micaschists, amphibolites and gneisses. These rocks are also rather fractured.

In view of the objectives of the program and the geological situation in the area, the technical profile of these deep wells is usually that shown in Fig. 1. That is, the cover formations are lined with an 18"5/8 casing; the first reservoir is isolated with the 13"3/8 casing to 1500 m; the first part of the schistose-quartzitic basement is lined with a 9"5/8 casing to 3000 m. The last stretch of the bore remains uncased, with a diameter of 8"3/8. Depending on well conditions a 7" liner can be inserted in the last sector of the bore and joined to the 9"5/8 casing with a hanger.

2. RIG MACHINERY AND EQUIPMENT

Special machinery and equipment had to be used for these wells.

For the drilling in the Larderello area, the first rig was electric-driven so as to take advantage of the electricity produced by Larderello's own power-plants. The drilling rig, whose nominal drill capacity is 5000 m, consists of the following main elements (Fig. 2).

- 142 foot cantilever mast with a Gross Nominal Capacity of 1.025.000 lbs and storage capacity of 5000 m for 5" diam. D.P.; the tilt-up sub-structure is 7.60 m high with a set-back capacity of 227 tons and 363 ton casing capacity;

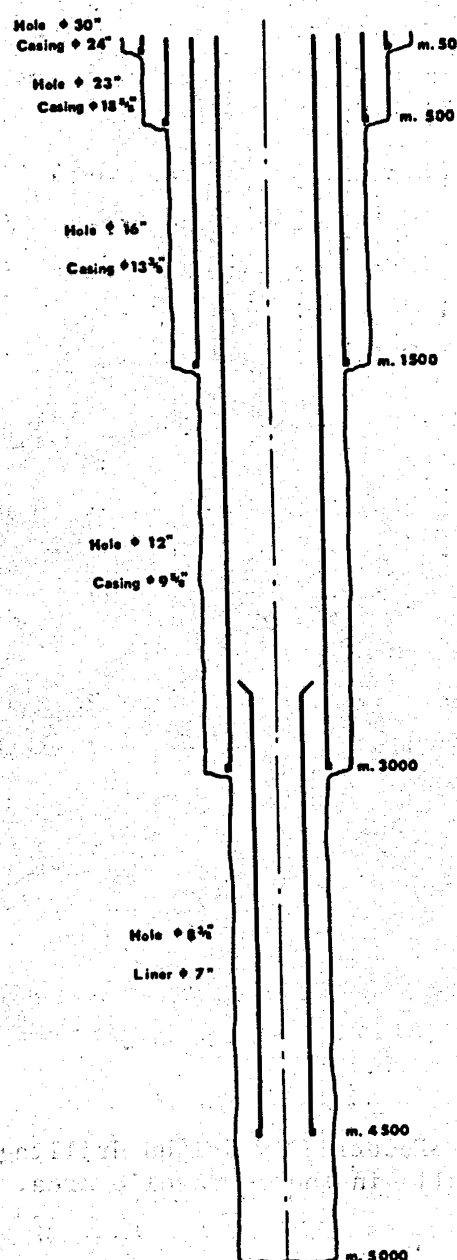

Fig. 1. Typical technical profile of the Larderello deep wells. These are used at Larderello to explore the layers between 3000 and 5000 m.

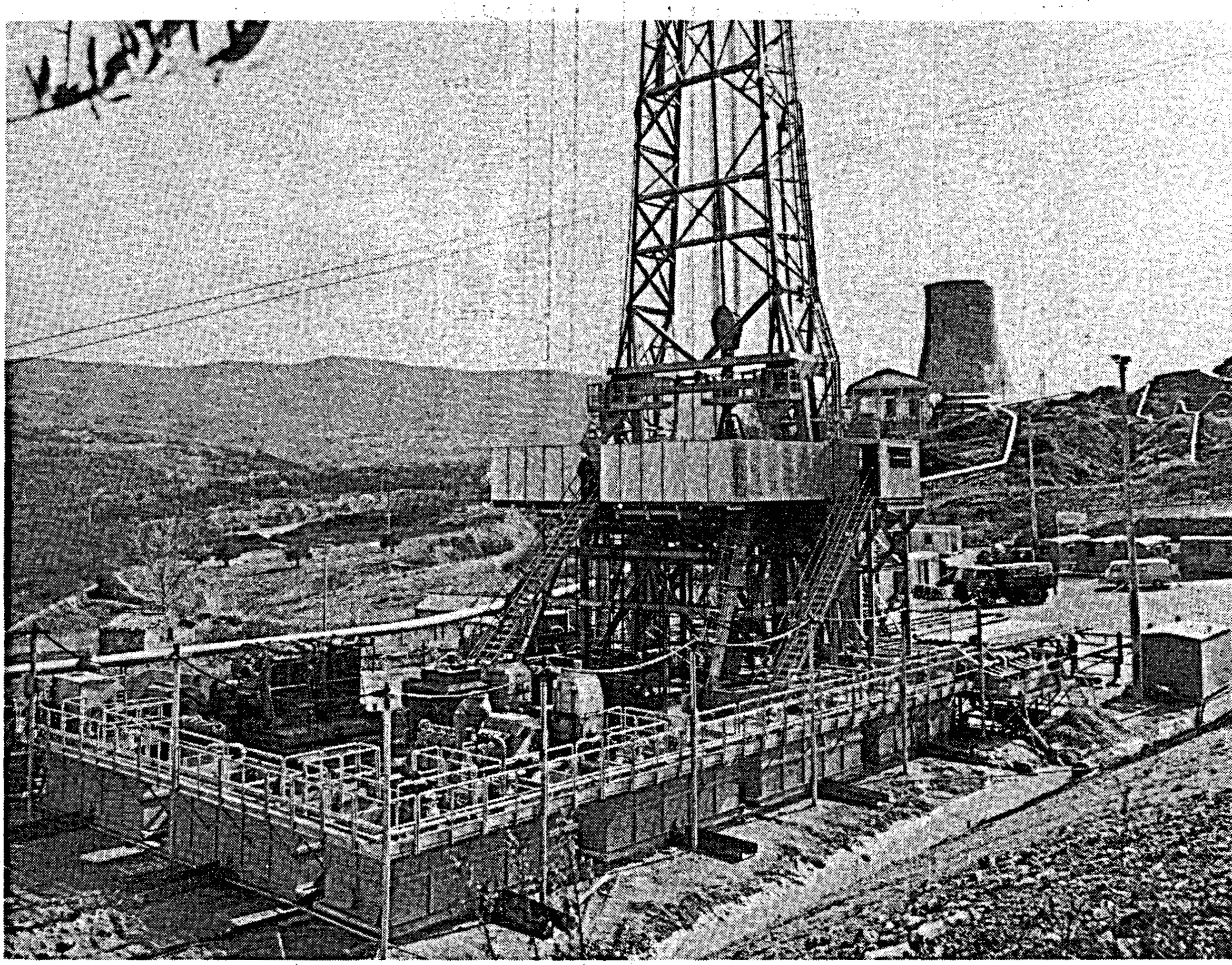

Fig. 2a. View of electrically driven drilling rig used for deep geothermal wells in the Larderello area. Capacity is 5000 m.

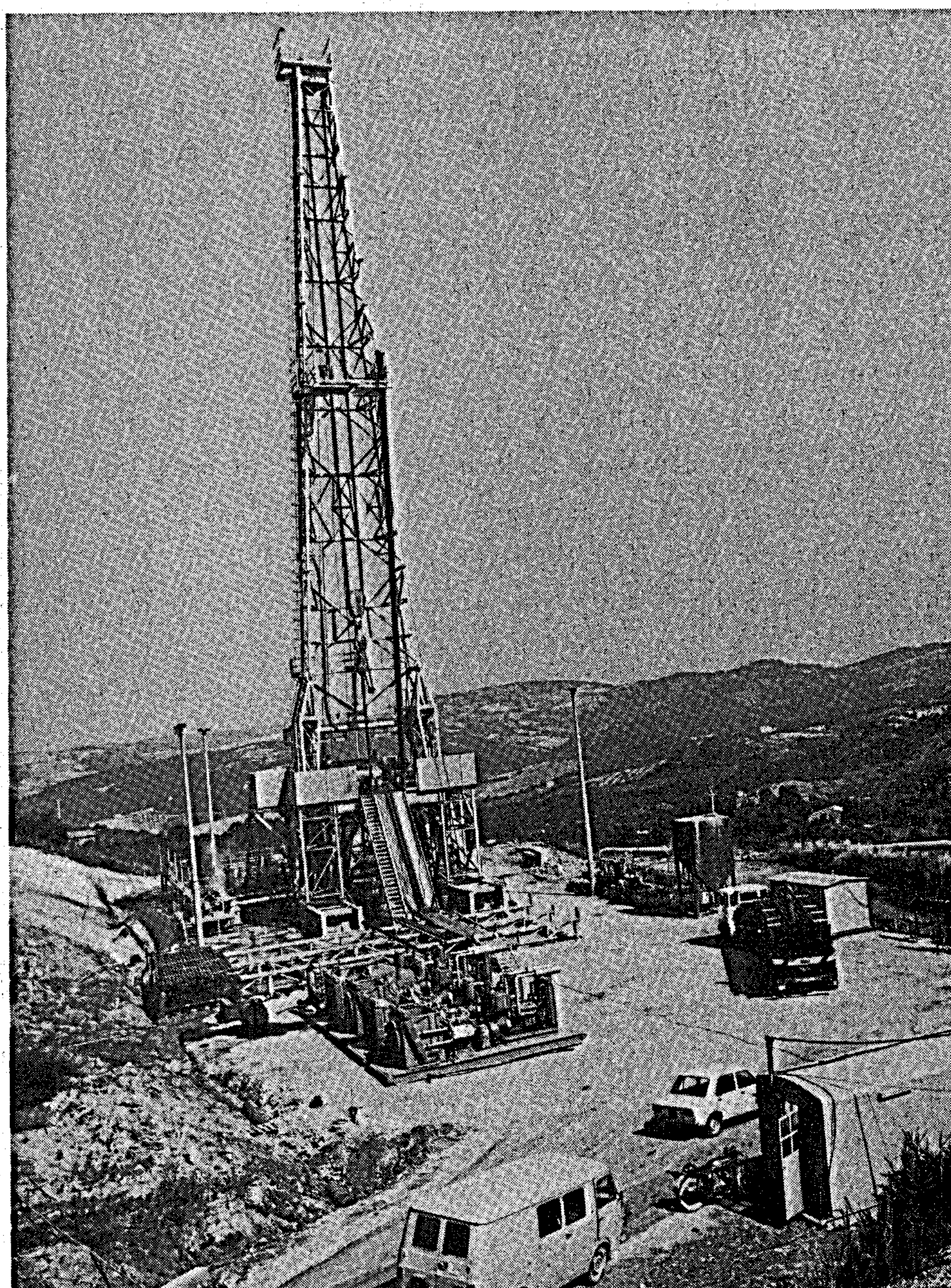

Fig. 2b. Another view of drilling rig as in Fig. 2a.

- drawwork driven by two coaxial d.c. electric compound engines, of 600 H.P. each at 1100 revs/min;
- two triplex 7" x 9", 1000 H.P. mud pumps, with maximum discharge pressure of 5300 psi. One of the triplex pumps is driven by two 600 H.P. d.c. electric engines, 1100 revs/min, and the other by two 600 H.P. compound diesel engines. Mechanical operation was provided to guarantee continuity of the circulation system during eventual breakdown in the electricity supply;
- electrical feeding system comprising a three-phase, triple-winding transtormer of about 2000 KVA, fed by a 16 KV line.

The main facilities (drawwork, rotary table and electric pump) are fed by the secondary circuit, with an output of 1850 KVA at 570 V, after static conversion of the current from alternate to direct through a system of controlled diodes (thyristors).

The tertiary circuit of 150 KVA at 380 V feeds the other minor facilities and auxiliary equipment.

The drilling yard is fitted with an air-drilling plant, ready for use in deep geothermal wells. This plant consists of four parts:

1) compressed air production from four two-stage 10"1/4 x 7" x 6" compressors, with an effective capacity of about 22 Nmc/min each and maximum delivery pressure of 18 kg/cm^2; a booster is also provided for raising the pressure to 106 kg/cm^2;
2) stand-pipe containing the instrumentation for measuring and recording the flow-rate, pressure and temperature of the air;
3) discharge line with dust separators, silencer and air-water separator;
4) system for dosing chemical additives, injecting foaming agents and corrosion inhibitors.

The well-head was specially designed for geothermal drilling (Fig. 3) and consists of API 3000 valves and spool capable of operating at a working pressure of up to 192 kg/cm^2 at 232^{o}C. Beyond the kill-line are two 10" lateral flow lines for high fluid flow-rates

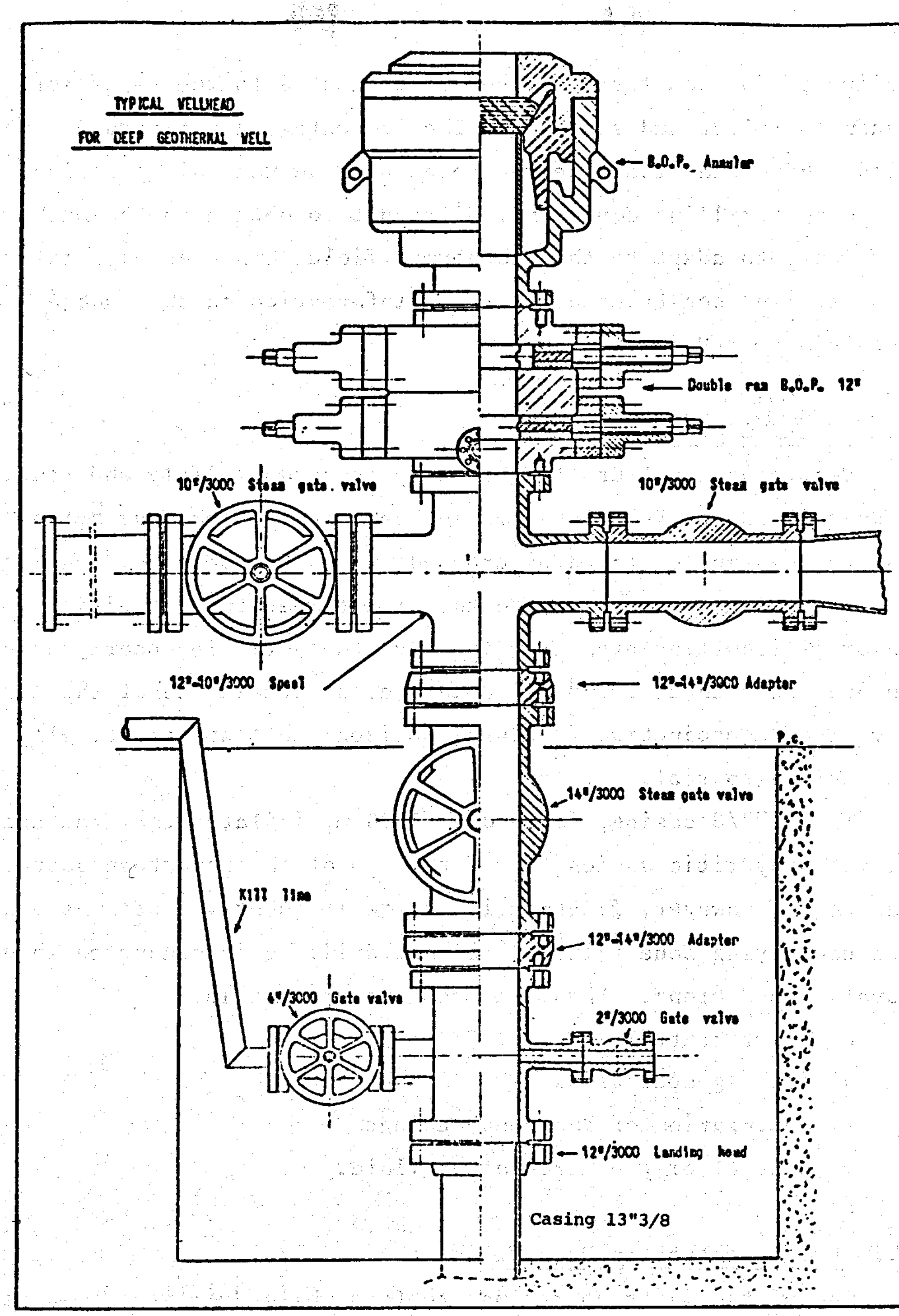

Fig. 3. Typical wellhead for deep geothermal wells.

during production tests; these are connected to the separator, measuring plant and silencer. The preventers are fitted on the well-head, which can also take the rotating-head when air-drilling.

Other drilling equipment, difficult to obtain on the market or difficult to adapt to the geothermal field, has been especially designed and constructed. Further information on this subject can be obtained from Ref. 1.

3. DRILLING PRACTICE

Deep geothermal drilling usually proceeds swiftly and routinely down to 3000 m. Beyond this point certain problems may arise, either due to the type of terrains crossed, which may be hard, unhomogeneous or of complex attitude, or to the high temperature conditions. The major difficulties stem from the fact that drilling nearly always has to proceed without return circulation, a consequence of the large number of unproductive fractured horizons that are practically impossible to seal.

The 13"3/8 casing, lowered at 1500 m, isolates the fractured zones of the anhydritic series and of the top of the schistose-quartzitic basement. However, fracturation quite frequently continues down into the underlying zone (Fig. 4) so that drilling is conducted in very adverse conditions. The main problems are met in:

- drift control
- fishing operations
- cementation of the deep casings
- control of the circulation fluid.

3.1 Drift Control in Deep Wells

One of the major operating problems while drilling these wells is controlling their drift, as they are extremely prone to deviation and the formation of terrible dog-legs.

The geological formations are responsible for this phenomenon. The terrains of the schistose-quartzitic basement vary in lithotype from schists to quartzites and gneiss. These rocks have undergone

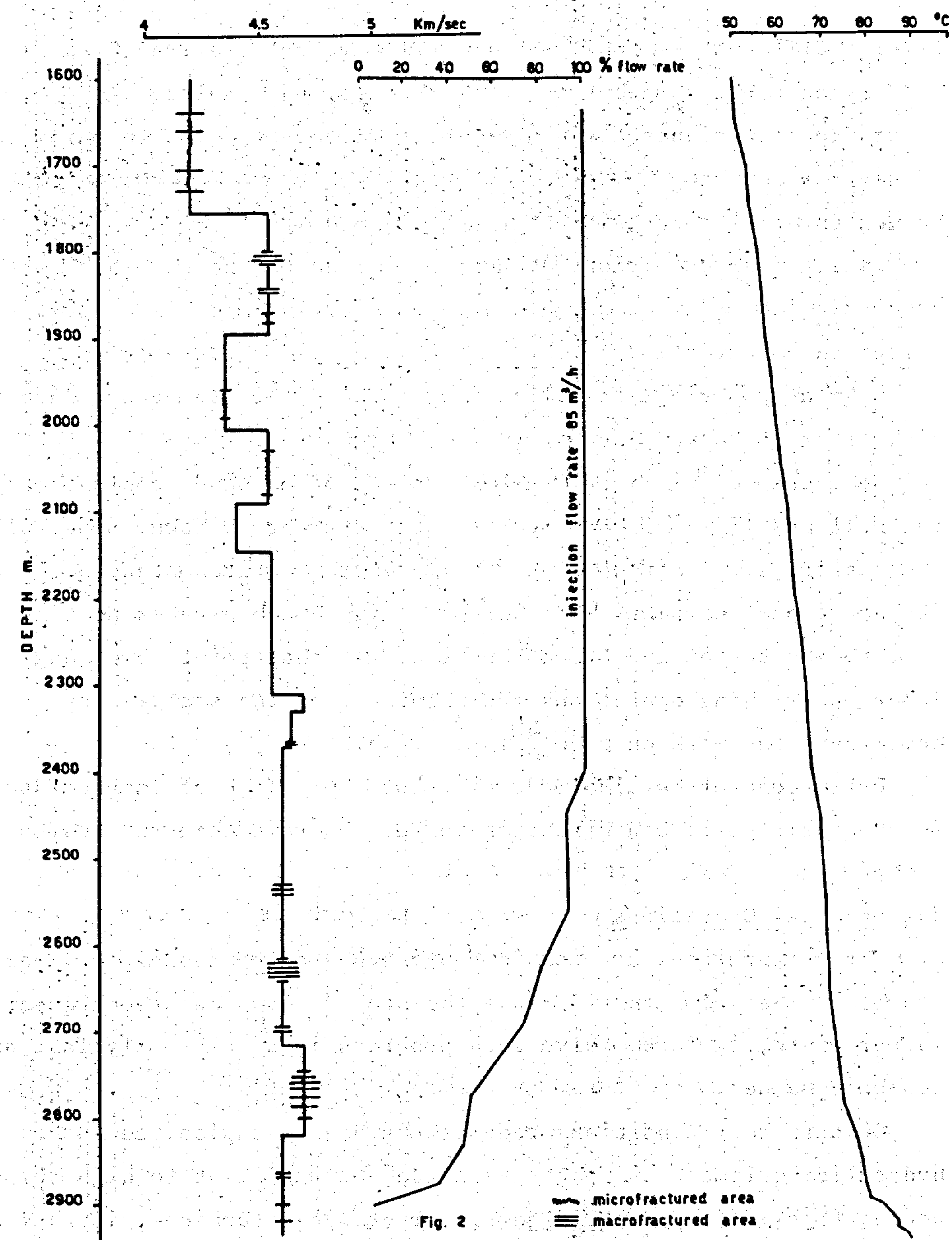

Fig. 4. Diagram 1: Sonic log of the layers forming the exploited reservoir. Diagram 2: Injectivity log of the layers forming the exploited reservoir (injected flow - rate: 85 m^3/hr). Diagram 3: Temperature log run during the injection test of diagram 2. Note the extent of the fractured zones that are so difficult to isolate.

several different tectonic events that have created fractures, filled to varying degrees with secondary minerals, and faults. The stratification planes are consequently tilted by a few to a few tens of degrees. A sample of these rocks taken from a core was shown to have a uniaxial compressive strength of 800 kg/cm^2.

Under these conditions even a small load on the rock bit in attempting to drill at a reasonable rate of 1-2 m/h has a negative effect on bore verticality.

Only a very rigid stabilization of the drill-stem can reduce the risk of drift and doglegs.

An extremely rigid drill-stem, on the other hand, could endanger the well itself should some part of the stem break down, especially when water is the circulation fluid. In these circumstances the water is such a poor carrier that the debris in the bore takes no time to fall to the bottom and block the fish. At that point some long, laborious fishing operations are required, as the stabilizers complicate the work on cleaning the fish.

Drift control is also made difficult by a lack of instrumentation for measuring tilt and direction in very extreme temperatures.

3.2 Fishing Operations

These operations are considerably hindered by the high temperatures in the wells that exclude the use of classical techniques; the latter would, in fact, solve such problems in a relatively fast and economic manner.

Certain well conditions require the use of explosives and hydraulic equipment, or parts that are not resistant to high temperatures (back-off, hydraulic jars, bumper subs, turbines, impression block, etc.). In these circumstances one must fall back on more simplified and less efficient mechanical devices or, for example, undertake time-consuming, hazardous unscrewing of the pipes within the bore, using a left-hand drill-string.

When, as sometimes happens, it is no longer economically worthwhile recovering a fish, the side-track technique is used to unblock the well. However, the high temperature conditions may preclude the traditional system for this technique, which consists of a support cement plug and turbine with bent sub. Our alternative in this type of operation, used at a depth of 4028 m and with an in-hole temperature of about 380°C, was to design and construct a special permanent whipstock (Fig. 5), diameter 7"3/4. This was lowered into a 8"3/8 diam. open-hole, fitted with a stalk of seven 7" casings, so as to join the equipment to the underlying 3"1/2 pipes of the fish. The whipstock was blocked by pumping barite bentonitic mud of 1800 gr/l density. After the mud had set, with the help of the high temperatures, the deviation was successfully brought to completion.

Technical measures of this type are frequently resorted to when the specialized market is unable to provide the necessary equipment and material for geothermal drilling.

3.3 Cementation of Deep Casings

Cementation of the casings in deep geothermal wells is one of the most complicated drilling operations. Intense rock fracturation causes serious problems in filling the annulus, added to which are the temperatures that affect the behaviour of the slurry.

Various methods have been developed for attaining the good cementation required in deep wells only partly filled with water as a result of circulation losses.

The first step is to cement the casing from the bottom up to the fracture, injecting large quantities of partly thixotropic slurry of low density from the bottom upwards. A duplex casing shoe is used, for operating with a stinger and drill-pipe.

The second stage can be approached in various ways. The annular space from the fracture to the surface can be filled by placing a full opening multistage cementer above the fracture, isolating the latter with an external casing packer. Where there is more than one fracture this operation can be repeated, perhaps even shooting into the casing to create injection holes for the slurry; the top of the previous cementation is individuated beforehand by means of a log. The slurry

Fig. 5. Whipstock made in Larderello for side track operation in a deep geothermal well.

used for these operations must be specially prepared each time, adding silica flour, retarders, filtrate reducers and lightening materials as necessary.

In place of the external casing packer one could inject an extremely clogging mixture through the full opening multistage cement (sodium silicate in brine environment); this mixture will temporarily plug the fracture and keep the slurry within the overlying annulus.

In other situations the second step will consist of injecting down into the empty annulus, in various stages if necessary. The slurry in this case is preceded by a given thixotropic volume spacer which, due to the load loss from pumping this mixture, slows the slurry down and creates a more uniform distribution.

3.4 Control of the Circulation Fluids

As an alternative of drilling with water and no return circulation in the schistose-quartzitic formations of the basement we have sometimes conducted tests with air as circulation fluid. The advantage in this case is the avoidance of the problem of finding the immense quantities of water (up to 100 m^3/h) needed during drilling without return circulation.

However, the well must be very dry for drilling with air only. The circulation system could be assisted by a contribution of dry steam. The steam flow-rate must, at all events, be rather small, or problems will arise during extraction and insertion of the drill-stem.

We have very rarely encountered optimum conditions for air-drilling in the deep geothermal well. The intensely fractured formations cause a reduction in the rising velocity of the air, thus reducing the system's flow capacity. On other occasions a very small quantity of water or wet steam may come from the fractured formations. In such cases the debris produced by the bit is not removed fast enough and accumulates at well-bottom in a slushy phase, preventing the bit from cutting into the virgin rock. The foam agents used in such high temperature environments are not always able to solve this problem.

When a total loss of circulation occurs in routine drilling with mud or water a certain hydrostatic level stabilizes in the well. This must be removed before air-drilling is begun. When this water is being removed, however, there is sometimes a strong and continuous flow of water from the surrounding formations, so that the operation cannot be completed immediately. Drilling must then continue with the air-water circulation system, regulated to varying ratios.

The well conditions, however, are not always suited to drilling with lightened fluid, especially as regards depth, diameter, elevation of the hydrostatic level and the fracturation system. In order to use this fluid, its density must be reduced until the level reaches the surface. So much air must be injected to attain this that, instead of having one lighter fluid only, we produce two dynamically unstable phases (water and air) that may lead to a loss of the air phase along the fracturations and even to uncontrolled blow-outs. For example, we conducted a test at about 3200 m in an 8"3/8 well with a hydrostatic level at about 2300 m and flow of water. Despite the jet subs placed in critical points along the drill-stem, the circulation fluid was not homogeneous enough to make drilling a success.

Where mud drilling is possible or advisable the fluids used must have a rheological stability and filtration characteristics that guarantee optimum operating conditions in high temperature environments.

The muds that have proved successful in prolonged working conditions of up to 200°C have a bentonitic base dosed with a synthetic resin and chromolignite. The resistance can be improved, especially for higher temperatures, by adding products such as a synergesic blend of selected polymers.

Good results up to 250°C were obtained with bentonitic and asbestos-based mud, activated with chromolignite and polycrylates, with or without the polymeric products, and with synthetic resin and caustic soda.

A similar success was also attained with the sepiolite and bentonite-based muds, using a small amount of the bentonite and the same additives mentioned above, although they do tend to develop rather strong gels in static, high temperature conditions.

Finally, oil or a colloidal suspension of sized asphaltic solids in water or in diesel-oil can further improve stability, even in higher temperatures than those described above.

The efficiency of the above mud systems can, of course, be improved by attending to a few practical matters, such as replacing any water lost by evaporation, cooling the fluid in special towers, stirring the fluids continually in tanks fitted with electric agitators and guns.

4. CONCLUSIONS

The deep exploration program for the Larderello area is now in its first stage of development. The activity carried out so far has presented us with new problems in terms of operating methods and equipment.

It became immediately clear that the first priority was to devise an adequate technology for deep drilling, with the result that this is now one of the objectives of the deep drilling program itself. The solution to the problems outlined above lies in the construction of equipment and instruments designed specifically for the geothermal field.

Particular attention is paid in this respect to perfecting the methods and materials for controlling drift, for a more extensive use of air as a circulation fluid and for alleviating any eventual fishing operations.

The casings and drill-pipes of the geothermal wells are subjected to extreme mechanical stress and corrosion. The studies and research being undertaken in this sector should contribute greatly to the success of the deep exploration.

It is clear from what we have just said that the work times and costs involved in this first phase cannot be held representative. However, there is no doubt that this type of research is a heavy financial commitment. At the moment the unit cost ratio between traditional geothermal wells and the deep bores in the Larderello area is 1:1.4.

Nevertheless, the objective remains that of optimizing the technical aspects of drilling and minimizing as much as possible the difference between these two factors.

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