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DRILLING OF TEMPERATURE GRADIENT HOLES WITH AERATED FLUIDS, AND TEMPERATURE SURVEY OF THE ALUTO GEOTHERMAL PROSPECT (S. LAKES DISTRICT, ETHIOPIA)

M.P. HOCHSTEIN[1], P.L. JEPSEN[2], and S.K. COLLIS[2]

[1] Geothermal Institute, University of Auckland

[2] GENZL, P O Box 37-231, Auckland

ABSTRACT

Drilling technique and results of a temperature survey in 50-70m deep holes from the Aluto geothermal prospect are presented. The survey led to the discovery of the Aluto geothermal reservoir (hot water system) beneath the E part of the Aluto Caldera. Use of aerated foam as drilling fluid made it posdible to complete the survey within the short period of 1½ months.

INTRODUCTION

Geothermal resources are widespread throughout the Ethiopian Rift Valley and the Afar Depression. A summary of the better known prospects has been given by Demissie (1980). Mapping and assessment of these resources war started towards the end of 1968 (UNDP report, 1973).

A review of all available data in 1980 rhowed that the Aluto prospect was attractive for deep exploratory drilling (Dench et al., 1980). Exploration data summarized in the 1973 UNDP report, and additional work by the Ethiopian Ministry of Mines, Energy and Water Resources, indicated that a hot water system with minimum equilibrium temperaturer of 180°C occurs between the Aluto volcanic massif and the N shore of Lake Langano (see Fig. 1) where boiling hot springs occur. The approximate location of the deeper reservoir could not be outlined by geophysical methods since low resistivities at depth occur all around and beneath Altuo Volcano (i.e. over an area of more than 200 km^2). To find out where the hot water reservoir was located, drilling of a few deep exploration holes was proposed, and a site for the first deep hole (LA-1 in Fig. 1) was selected (Dench et al., 1980).

Deep exploratory drilling in the Aluto prospect started in 1981 (sponsored by a joint UNDP-EEC aid project). Temperature measurements in the first deep well (LA-1) showed that a lateral outflow of hot water had been intersected at shallow (less than 200m) depths (see Hochstein et al., 1983) and it could be inferred in 1982 that all thermal springs to the S of LA-1 were fed by the same outflow. At the end of 1982, a separate shallow outflw, with boiling point temperatures, was ehcountered by the recond deep well (LA-2, see Fig. 1) beneath the W foothill region of Aluto Volcano. There was therefore great uncertainty whether any high temperature reservoir exists at depth in the Aluto area.

Lateral outflows of thermal fluids, however, are common in geothermal systems which occur beneath steep topographic terrain (Healy and Hochstein, 1973; Harper and Arevalo, 1982). Therefore a decision was made to undertake a quick survey of the shallow temperature structure of the Aluto Volcanic massif to find out whether there war an area with anomalous high temperatures at shallow depths which right define the deeper reservoir.

The temperature survey had to produce immediate results to avoid any longer stand-by time of the big drilling rig, and only 1½ months were available for the survey, which was started in October 1982. Technical details and results of the temperature survey have been published (Hochstein, 1983.) and are summarised in this paper.

Geology and hydrological setting

Aluto Volcano forms a broad volcanic dome (area about 120 km^2), consisting of a sequence of pyroclastics and flows of typical alkaline rift valley volcanics, i.e. alkaline andesites, rhyolites (pantellerites), alkaline basalts. The volcanics around the prospect have been described by Mohr (1971) and Mohr et al. (1980). The Aluto volcanics rest upon Quaternary and Tertiary rift valley basalts which are covered by a layer of recent sediments (lake sediments). A caldera-like depression occurs in the central part of the Aluto Dome (see Fig. 1); this depression and the northern flanks with subdued topography are accessible for 4-wheel drive vehicles. Centres of recent obsidian flows can be found along the caldera rim.

The W part of Aluto Volcano is located over a deep-reaching, en-echelon fracture zone (Wonji Fault belt of Searle and Gouin, 1972; Mohr et al., 1980) of NNE strike; visible faults in the Aluto area strike 015° and about 027°. The dip of joints with similar direction is almost vertical indicating dominant shear movement (Scheidegger, 1982).

The regional groundwater movement is from N to S with a gradient of about 3.5m/km. Assuming that the lateral outflow of hot water is controlled by the direction of the joints and that of the regional groundwater flow, a SSW direction of the outflow intersected by LA-1 is indicated (see Fig. 1), pointing to the E part of the caldera as principal target area for the temperature survey.

HOCHSTEIN et al.

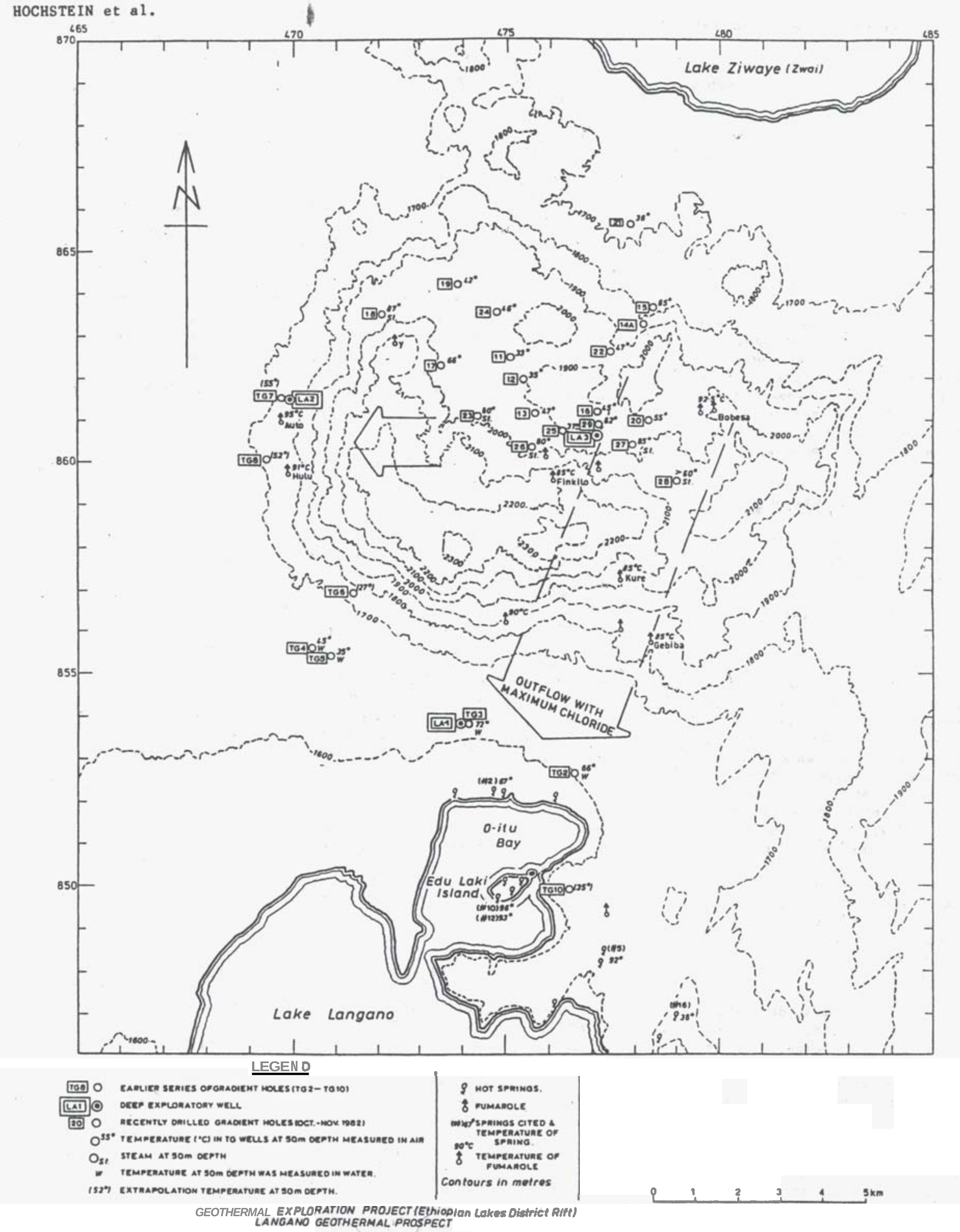

Figure 1: Topographic map of Aluto Volcano showing location of surface manifestations, shallow drillholes (with temperatures at 50m depth) and sites of deep exploration holes (LA-1, 2, 3).

This model, however, does not explain the outflow beneath LA-2, and the survey area was extended to cover the whole caldera and the N slopes of the dome.

The temperature method as an exploration tool

If a geothermal prospect is covered by a thick sequence of impermeable rocks, temperature gradient measurements in holes of intermediate depth (say, 30-100m) can often define the central part of a deeper reservoir. The method has been used successfully, for example in Italy during the exploration of the Monte Amiata Field (Calamai et al., 1970), and also gave good results at Ngawha (New Zealand). However, if the cover rocks are permeable and in the presence of perched aquifers, thermal gradients are usually disturbed by shallow lateral flows of either mixed thermal fluids or colder fluids. In this case, anomalous temperatures at a given reference depth often indicate areas where thermal fluids are rising. Temperature surveys, using intermediate depth drillholes, however, are not a popular geothermal exploration method although they can sometimes, as at Monte Amiata, outline a target area, where other methods have failed.

Drilling of temperature holes on the Aluto Dome

A small, truck-mounted Davey drilling rig was available for drilling the temperature holes in the Aluto caldera. It was equipped with a Gardner-Denver pump, a Davey air compressor ($14 m^3/min$ at 7 bar), and a small soap injection pump. The rig had been used between 1981 and 1982 to drill 8 investigation holes (120-180m depth) in the S and W foothill area of Aluto Dome (TG3 to TG10 in Fig. 1) using mud and water as drilling fluid.

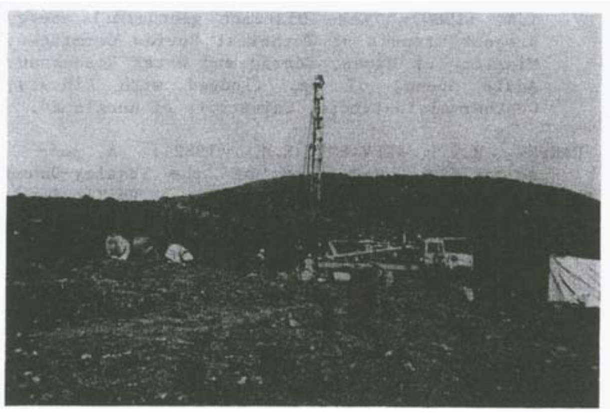

Fig. 2a: Davey rig in operation inside Aluto Caldera.

A track was prepared to get the Davey rig into the caldera. As no water was available in the caldera it had to be transported by a larger oil-field truck from Lake Langano, a distance of over 40 km over poor roads. The first hole inside the caldera (TG11 in Fig. 1) was started with bentonite mud as drilling fluid. After 2 weeks a depth of 80m had been reached, and continuous problems were experienced with loss of circulation. A perched water table occurred below 50m depth, and water was continuously lost in a concealed obsidian flow and a porous pumice layer. It then became obvious that the drilling method had to be changed to enhance the drilling rate.

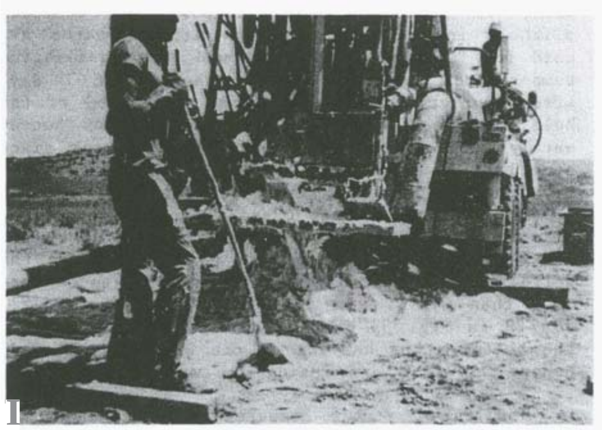

Fig. 2b: Aerated foam and cuttings (pumice) emerging from the top of the TG19 hole.

The strategy was changed to drilling 50 to 70m deep wells with aerated foam as drilling fluid. The method is widely used in drilling deeper wells where water rupply is a problem (production holes in the Olkaria Geothermal Field, Kenya, for example), but to our knowledge it has not been used for shallow holes. Threaded pieces of casing were used as surface pipe and placed at each site before arrival of the drilling rig. An improvised "banjo box" was made up to deflect the foam and cuttings to one side (see Pig. 2b). Significantly less water was required for foam drilling, and less than one tanker load (about $6 m^3$) was sufficient for one well.

The next 18 holes (TG12 to TG28) were drilled within the short time span of 23 days (total depth about 1100m), and stable ground temperature data became available towards the end of November 1982, which allowed a site for the next deep well (LA-3) to be selected.

RESULTS

All holes were drilled with 4-inch bits and cased down to the bottom with 2-inch galvanised steel pipe; the bottom section (6m) was perforated to allow the influx of groundwater or steam. However, groundwater was encountered only in one hole in the lower N foothills (TG21); hence, all temperature measurements had to be made in an air column. A calibrated TRIAC resistance thermometer with digital readout (±0.1°C) was used as sensor, and reproducible temperature readings were obtained in the down-run mode with a standing time of 10 to 15 min. Drilling with aerated foam also disturbs the temperature of the medium around the well; the rocks can be cooled if too much cold water is used but their temperature can also slightly increase if too high air pressures are used for "foaming". Teste showed that equilibrium temperatures (±0.2°C) were reached about 7 days after completion. In the upper part (10m) of the hole these equilibrium temperatures do not necessarily reflect the temperature of the rock since some heat is transported by the casing, a phenomenon which occurs only in cased wells with an air column. Tests in holes cased with non-conductive, plastic pipes showed that differences of up to 2°C can occur in the upper 5m (if no steam enters the well), whereas below 10m depth the differences are lees than 0.5°C. In some wells (TG 18, 23, 27, 28, 29 in Fig. 3) free steam entered the well at the bottom, thus heating up the whole casing and, hence, the air column inside the casing.

Results of stable temperature measurements in the holes are shown in Fig. 3; it vas found that anomalous high temperatures (greater than 50°C at 50m depth) occurred dominantly in the E part of the caldera, where holes drilled at higher ground encountered saturated steam below 30m depth. Subsequent drilling of additional holes in the same area (not shown in Fig. 1) confirmed this. It was therefore concluded that hot water at boiling point occurs in this part of the area at shallow depth (about 150m) and that all steam encountered in the shallow wells derives from evaporation from this surface (including minor steam discharge from small natural vents). Because of restrictions of available pipes for pumping drilling water from Lake Zwai, the third deep well could not be sited in the central part of the target area but had to be shifted towards the W (see location of LA-3).

In January 1983 the third well (LA-3) was spudded in and reached a productive part of the Aluto reservoir between 1750 to 2100m depth (T ≯ 290°C).

SUMMARY

A reconnaissance survey of temperatures at 50-70m depth covering the caldera and the accessible N flanks of the Aluto Dome has shown that anomalously high temperatures and free steam occur beneath the E part of the Aluto Caldera. This area was chosen as the drilling target for the third deep exploratory well (LA-3) which was drilled two months after completion of the temperature survey and which encountered the Aluto geothermal reservoir.

Hot water from the top of the reservoir moves in the form of a lateral outflow to the SSE, following the strike of principal joints, and feeding the thermal springs near Lake Langano, more than 10 km away from the inferred centre of the reservoir; a second, smaller outflow from the reservoir also occurs in a W direction.

ACKNOWLEDGEMENT

Drilling of the shallow holes was undertaken by counterpart (Ethiopian Ministry of Mines, Energy and Water Resources), and the success of the temperature survey, which led to the discovery of the Aluto geothermal reservoir, is mainly due to Ato Berhano and Ato Mulugetta, who were in charge of the DAVEY rig. The senior author also wishes to acknowledge the support of the counterpart manager, Ato Getahun Demissie.

REFERENCES

CALAMAI, A., CATALDI, R., SQUARCI, P., TAFFI, L. (1970): Geology, geophysics and hydrogeology of the Monte Amiata Geothermal Field. Geothermics, spec. issue (1).

DEMISSIE, G. (1980): The geological environment of the Ethiopian hydrothermal areas. Proceedings of the NZ Geothermal Workshop 1980, 167-170, University of Auckland.

DENCH, N.D., HOCHSTEIN, M.P., MAHON, W.A.J., NAIRN, I.A. (1980): Lake District geothermal energy project, report of Technical Review Committee. Ministry of Mines, Energy and Water Resources, Addis Ababa, 67 pp. (lodged with Library, Geothermal Institute, University of Auckland).

HARPER, R.T., AREVALO, E.M. (1982): A geo-scientific evaluation of the Basley-Dauin prospect, Negros Oriental, Philippines. Proceedings of the Pacific Geothermal Conference 1982, 235-240. University of Auckland.

HEALY, J., HOCHSTEIN, M.P. (1973): Horizontal flow in hydrothermal systems. NZ Journal of Hydrology 12, 71-81.

HOCHSTEIN, M.P. (1983): Aluto Geothermal Prospect (Southern Lakes District, Ethiopia). Geothermal Institute Report GIR 008, 43 pp. Geothermal Institute, University of Auckland.

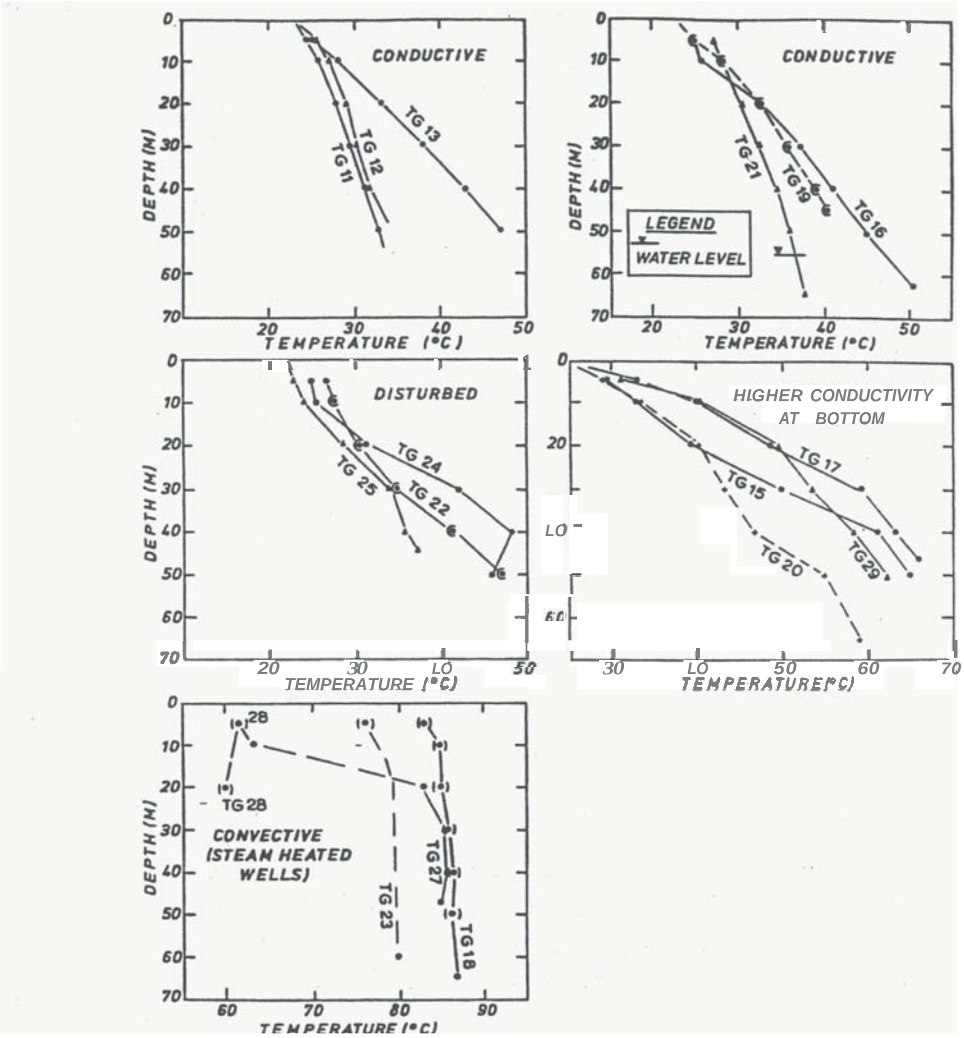

Fig. 3: Stable temperature profiles of shallow drillholes (TG11-TG28) drilled inside Aluto Caldera and over the N slopes of Aluto Dome (for locality of holes, see Pig. 1).

References, (continued)

HOCHSTEIN, M.P., CALDWELL, G, KIFLE, K. (1983): Minimum age of the Aluto geothermal system from fossil temperatures beneath lateral outflows (Southern Laker District, Ethiopia). Proceedings of the NZ Geothermal Workshop 1983, this issue.

MOHR, P.A. (1971): Ethiopian rifts and plateaus; some volcanic and petrochemical differences. Journal of Geophysical Research 76 (8), 1967-1984.

SCHEIDEGGER, A. (1982): Faulting in the central Ethiopian rift. Archiv Met. Geophys. Bioklimatologie, Series A (31), 27-40.

SEARLE, R.C., GOUIN, P. (1972): A gravity survey of the central part of the Ethiopian rift valley. Tectonophysice 15, 41-52.

UNDP Editorial Committee (1973): Geology, geochemistry and hydrology of hot springs in the E Aftrican Rift system within Ethiopia. Technical Report DP/SF/UN/116, UNDP, New York.