HYDROLOGY OF OLKARIA GEOTHERMAL FIELD

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ABSTRACT

Olkaria in Kenya is a large high-temperature liquid-dominated field. It is unusual in that it possesses a vapour-dominated zone sandwiched between two zones of liquid-dominated fluid.

In a re-evaluation of hydrological data, it has been concluded that the field has a primary upflow of boiling chloride water, in a region of the field not yet drilled. Lateral outflows from this upflow region produce the fluid distribution found in the wells drilled to date.

INTRODUCTION

Olkaria field is one of a number of geothermal fields in the Rift Valley of East Africa. Exploration began in the 1950s with the drilling of three shallow wells. Later exploration was carried out under the UNDP programme (Noble & Ojiambo 1975, McNitt 1975). The results of the exploration work have been described in unpublished reports, and by Noble & Ojiambo (1975), McNitt (1977) and Bjørnsson (1978).

Figures 1 and 2 show a map of the field. Surface activity of fumaroles and other steam discharge extends over an area of over 30 km². Geophysical studies indicate an area more than twice this size (Hochstein et al., 1981). The field extends beyond the area of Figure 1. The first two exploration wells, X-1 and X-1, were drilled to depths 500 and 950 m. X-2 encountered temperatures up to 245°C but would sustain only a small flow. X-3 was a very shallow hole that did not penetrate past surface groundwater.

Under the UN programme, OW-1 was drilled as the first deep well in Olkaria. Although sited beside the largest fumarole in the field, a maximum temperature of 126°C was encountered. In addition, a complex pressure structure was found, with upper overpressured aquifers (Noble & Ojiambo 1975, Dench 1980). The second deep well, OW-2, was productive. It reached temperatures of over 280°C and flowed up to 40 t/h of high enthalpyfluid. Subsequent exploration wells were drilled

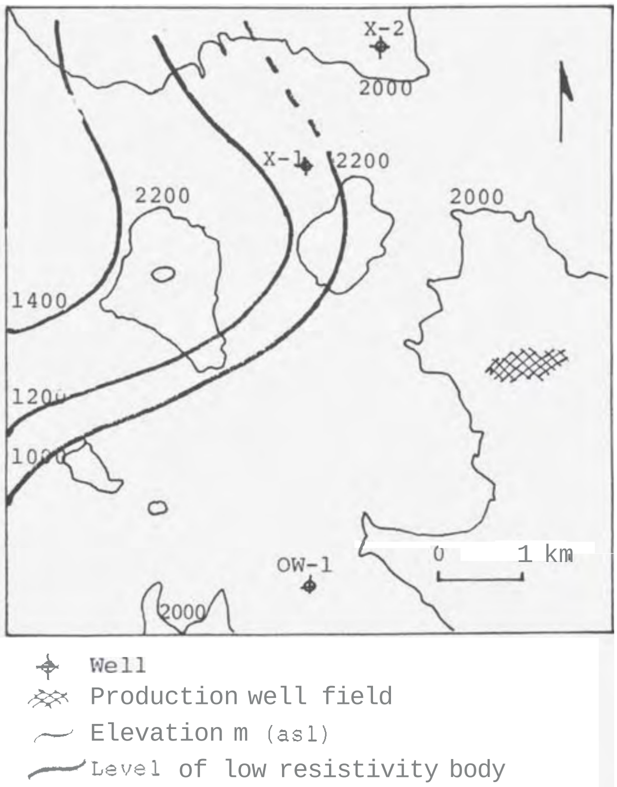
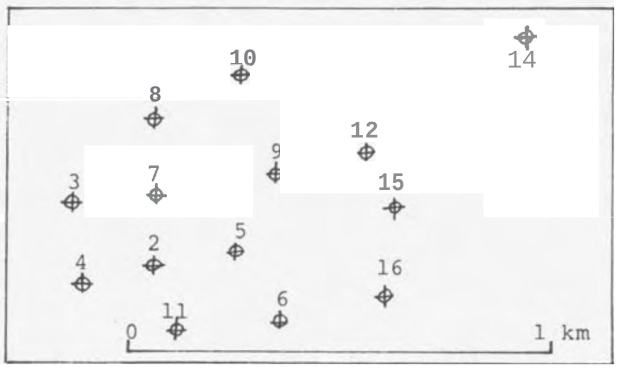


FIGURE 1. OLKARIA FIELD

FIGURE 2. PRODUCTION FIELD



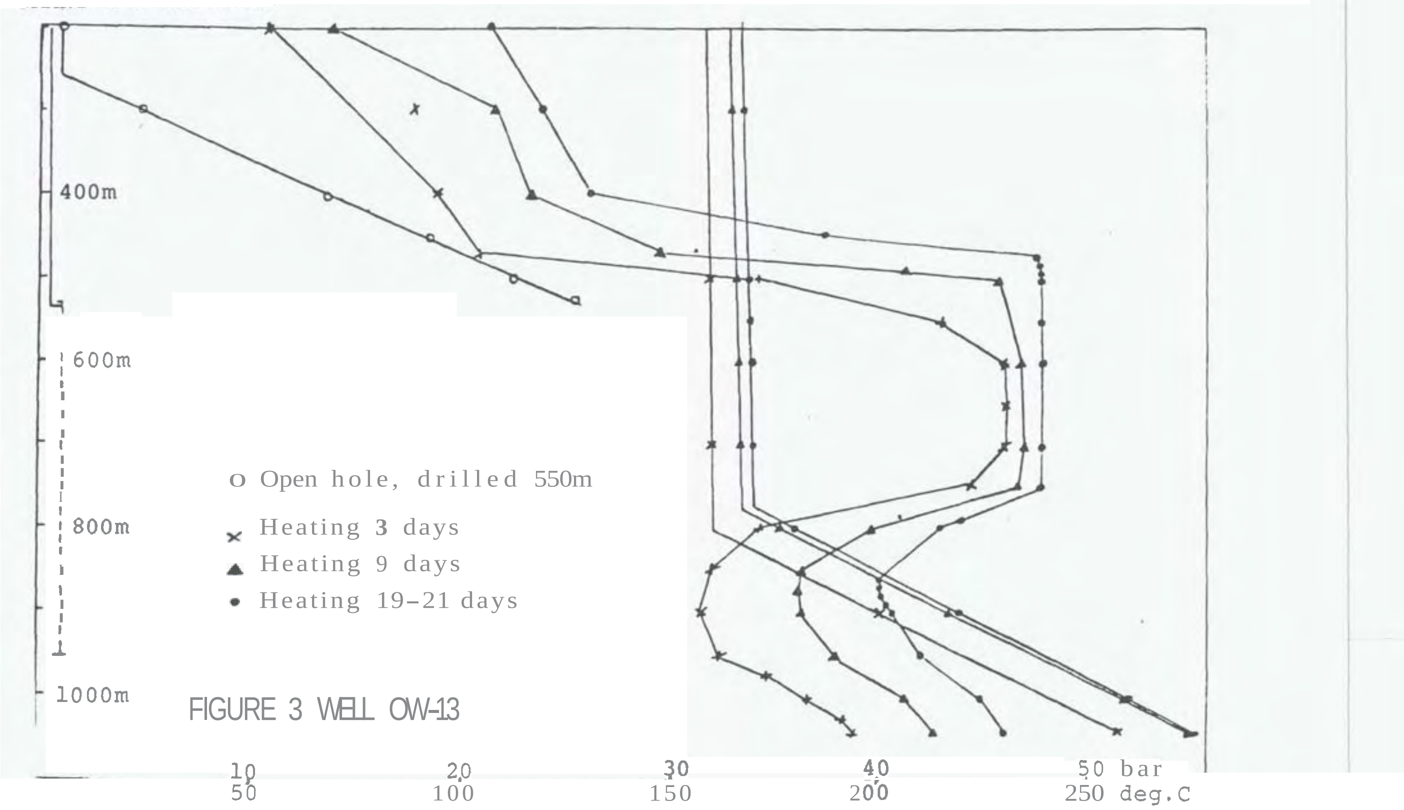


FIGURE 3 WELL OW-13

as stepouts from OW-2, and very similar conditions were found. The wells, except for OW-16, produce an average of about 2 MW electrical equivalent, usually producing a modest flow of high-enthalpy discharge. OW-16 is very similar in pressure and temperature, but produces a flow three times larger than other wells. A 2 x 15 MW power station is under construction, based upon the production well field around OW-2.

In terms of defining a field hydrology, there are essentially four observation points in the field: wells X-1, X-2, OW-1, and the production well field. The production well field is of course much better defined than the other points.

THE PRODUCTION HELL FIELD

INFORMATION DURING DRILLING

In the drilling of some wells a zone of low-pressure steam is encountered close to surface. Where measured, pressures of around 3.5 bg are reported. This pressure is consistent with the indicated fluid supply to the surface steam activity (Mahon, pers.comm.). Beneath this zone a liquid-dominated region is encountered. Pressure and temperature measurements are made during drilling, and casing is set when sufficiently high temperatures have been reached. This places the casing shoe usually near an elevation of 1300 m asl.

COMPLETED WELLS

The casing excludes the shallow low-pressure steam and the liquid-dominated zone beneath it. The measurements in the completed wells, open from 1300 m asl to bottom hole, indicate the presence of a steam zone between 1175 and 1300 m asl, at 35 bar and about 240°C. Beneath this steam zone is a liquid-dominated two-phase zone, in which temperatures rise to above 300°C. The best permeability is usually encountered in the steam zone.

The presence of the steam zone is shown by the stable pressure profile in the wells (Grant 1979). Left shut to recover, most wells adopt a steam cap profile, with steam in the upper part of the hole and pressure up to 35 bar on the wellhead. Beneath this steam column is a column of water in which temperatures show a boiling-point profile. Figure 3 shows measurements in OW-13, in which the steam zone is well marked, when partly drilled, and during heating after completion. The disparity between the shallow and deeper pressures is shown. The steam zone permeability makes itself apparent in the strong heating of the steam column in the well. Deeper temperatures recover more slowly from the effects of drilling and completion testing.

Other downhole profiles have appeared. Some wells have developed internal discharges, with boiling fluid flowing up from the lower zone and being injected into the steam zone. Some wells have poor permeability in the steam zone and do not develop a good wellhead pressure when shut, although shallow and deep pressures confirm the existence of the steam zone. In some wells a temperature inversion persists in the water column in the well, apparently reflecting a genuine inversion in the reservoir.

The steam zone is a striking phenomenon, not reported in any other unexploited liquid-dominated field. The fact that the stable steam cap profile has a water level beneath the major permeable zone shows that it is a steam zone and that the profile is not just caused by accumulation of gas in the casing. Figure 4 shows a combined plot of pressure-depth data for wells in the borefield. Permeability of the Olkaria wells is generally low, so that it is difficult to identify feedpoints and the reservoir pressures at these points. Figure 4 shows instead the stable downhole profiles in wells, over the open interval. The shallow data are measured in wells partly drilled. There is clearly a "step" present in the pressure profile.

The boiling-point conditions beneath the steam zone identify the fluid there as liquid-dominated two-phase. Where inversions are present it isliquid.

WELL PERFORMANCE AND PERMEABILITY

The major feed is usually encountered in the steam zone, with a secondary feed in the liquid-dominated region beneath. Thus well behaviour is controlled by two feeds, supplying fluids of different enthalpy. In addition the upper feed is somewhat overpressured with respect to a hydrostatic gradient to the lower zone. This implies that downhole and discharge measurements can become complex.

On injection, there is sometimes interzonal flow with the steam zone discharging. This is not common, as the moderate permeability implies that at most injection rates all zones will be accepting water. On discharge, cycling is common and severe. The situation in which a vapour zone overlies a liquid-dominated one is particularly prone to cycling (Grant et al. 1979).

Because of the two feeds and the variable fluid that may occupy the wellbore, pressure transient analysis is also more complicated than normally. Ideally, the flow must be allocated between the two zones of the reservoir, and pressure recoveries for both determined. The stable steam cap profile implies that the pressure recovery of the steam zone can be measured at wellhead, and that of the deeper zone by downhole gauge (Pratomo, Grant, unpub. reports). It is also possible to analyse sections of a downhole pressure cycle to determine permeability of the deep zone. Representative values obtained from such analyses give for the steam zone a permeability thickness of 2 darcy-metre, and for feeds in the liquid-dominated zone one-tenth of that, with much variation. In general the wells are slightly stimulated. This and the fairly similar results between wells indicate that the flows of the wells are limited by reservoir permeability.

THE OTHER WELLS

In wells X-1, X-2 and the shallow X-3 a near-surface aquifer was found. Beneath this X-1 and X-2 drilled through a region where blows of dry steam were encountered. Beneath this X-2 reached an aquifer containing liquid water, at or below boiling point.

Pressures during drilling OW-1, and pressures after completion, define a distinct upper and lower aquifer with some intermediate pressures between (Dench 1980, Noble & Ojiambo 1975).

THE FIELD

Figure 5 shows the pressures in these wells together with those from the 'production borefield. It is now possible to construct a coherent model of the field hydrology (Fig. 6). The deep aquifer encountered in X-2 agrees with the highest pressures in the liquid-dominated zone above the steam zone. The field model hypothesizes a primary upflow of boiling chloride water in a region of the field not yet drilled. From this region water can flow laterally, so that chloride water is found both above and beneath the steam zone, but it does not flow directly up through it. The upflow is nearer X-2 than the production field, but is not at X-2. (If it were at X-2, temperatures there would be boiling.) The highest elevation to which chloride water reaches is about 1650 m asl. Above this is the shallow 3.5 bar steam zone, and above that near-surface groundwater. The shallow aquifer in OW-1 is the same groundwater. The deep aquifer in OW-1 is at lower pressure than either X-2 or the production field, and so could be derived by lateral flow from either of these.

The temperature inversions that appear in some of the production field wells, beneath the steam zone, must also be derived by lateral flow. Thus Olkaria is a field in which a primary upflow undergoes substantial modification and phase separation by lateral flow. This contrasts with other more permeable fields in which such large horizontal pressure gradients do not appear.

The steam zone appears in this model as a peripheral feature of the field. It is created by the lateral outflow splitting

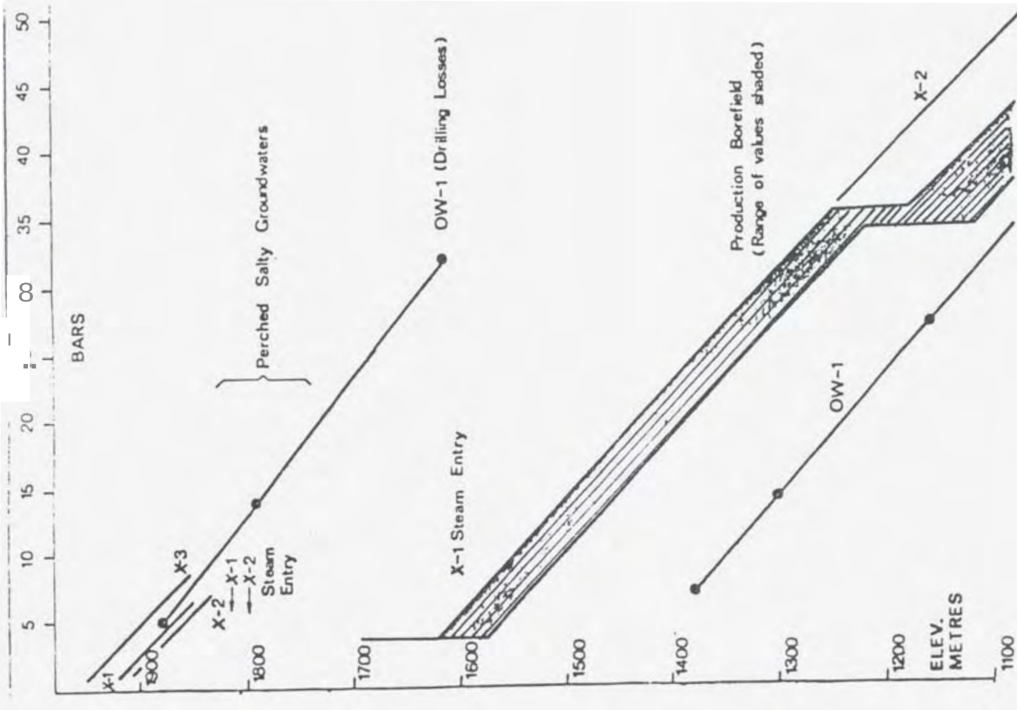


FIGURE 5 PRESSURES IN ALL WELLS

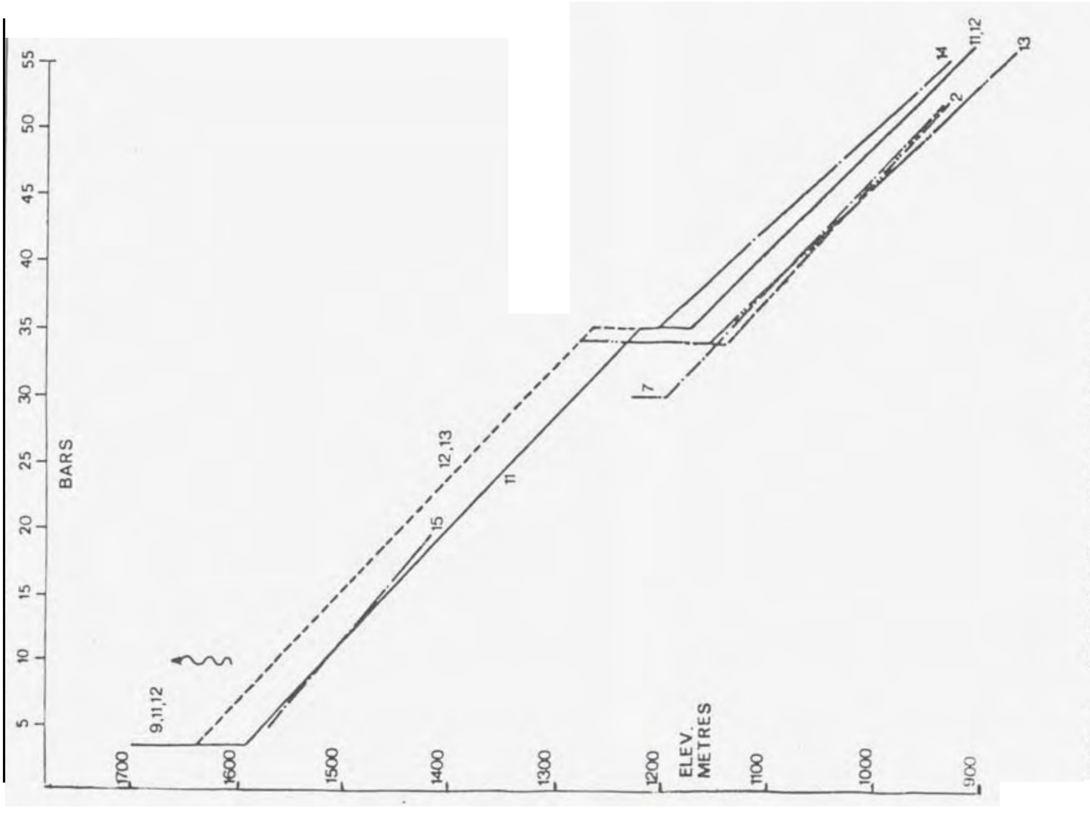


FIGURE 4 PRODUCTION FIELD PRESSURES

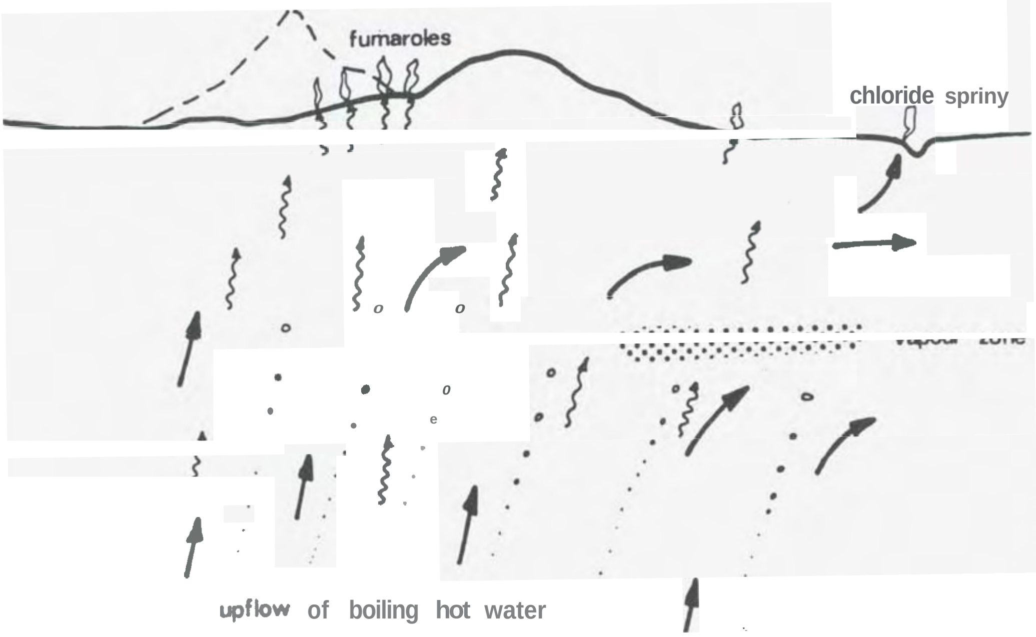


FIGURE 6. CONCEPTUAL MODEL OF THE NATURAL STATE OF OLKARIA GEOTHERMAL FIELD

into two aquifers as it diverges from the main upflow. The surface activity derives immediately from the shallow (3.5 bar) steam zone, in which there is apparently lateral flow of steam. Thus the distribution of such activity does not necessarily correspond to the distribution of a productive reservoir.

Re-interpretation of the resistivity (Hochstein et al., 1981) indicates a coherent low resistivity body to the northwest. This fits very well with the hydrological interpretation of the region of primary upflow. The lateral pressure differences encountered so far indicate moderate to low general permeability, as does the well performance. All these measurements and inference apply only to the outflow structures. With luck, better permeability could be found in the upflow region.

ACKNOWLEDGEMENTS

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