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AN UPDATE OF THE NATURAL STATE NUMERICAL MODEL OF OLKARIA GEOTHERMAL SYSTEM, KENYA

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ABSTRACT

The first field-wide 3-D natural state numerical model of the entire Olkaria geothermal system was developed in 1987 by G. S. Bodvarsson and K. Pruess. The model considered a vertical depth up to 1550 m consisting of a 700 m thick cap rock, 100 m thick steam zone as layer 1, 250 m thick layer 2 and a 500 m thick layer 3. It simulated the geothermal system to be recharged at a total rate of 600 kg/s from two major distinct upflow zones located in Olkaria Northeast and Olkaria West. The upflow in Northeast recharged the system at 250 kg/s of 1290 kJ/kg water and the one in the West at 350 kg/s of 1090 kJ/kg water. The recharge from the two upflow zones mixed near well OW-201 and discharged at 260.5 kg/s to the south and at 175.1 kg/s to the north through OlolButot fault and Olkaria fracture, respectively. Steam loss from the system amounted to 126 kg/s.

The model was updated in 1989 and 1993 but no significant changes were reported. Between 1993 and 2000, 24 additional wells have been drilled and one well (OW-5) deepened in the greater Olkaria geothermal system. While data from some of the new wells have agreed quite well with those calculated by the 1987 model, several other data, especially from the Olkaria Central wells have shown big variations. An attempt has therefore been made to recalibrate the 1987 model with the new data. The same numerical grid has been used, but with some modifications. The grid has been extended horizontally to accommodate the new wells and also vertically to increase the depth to 2550 m. Results indicate a total recharge rate of 1253 kg/s with the upflow in Olkaria West being 298 kg/s of 1560 kJ/kg water around well OW-305, upflow in Olkaria Northeast being 295 kg/s of 1620 kJ/kg water around OW-714 and 500 kg/s of 1650 kJ/kg water around OW-720, upflow in Olkaria East being 105 kg/s of 1620 kJ/kg water around OW-32, upflow in Olkaria Domes being 40 kg/s of 1620 kJ/kg and 15 kg/s of 1350 kJ/kg around well OW-101. The discharge to the south is 811 kg/s and to the north is 147 kg/s. Steam loss from the system amounts to 366 kg/s.

INTRODUCTION

Olkaria geothermal system is located in the East African rift valley to the south of Lake Naivasha and 120 km northwest of Nairobi city. The geothermal system covers an area of more than 120 km^2 and is associated with a volcanic complex situated within the central Kenyan rift.

Exploitation of this resource for the purpose of producing electricity started in 1981 in Olkaria East field when the fast 15 MWe generation unit was put on line with the second and third 15 MWe units in 1982 and 1985, respectively. From 1985 through the 90s, intense surface exploration and deep drilling was done in the neighbouring areas resulting in demarcation of adjacent fields in Olkaria West, Northeast, Central and Domes (Figure 1). A 12 MWe binary plant installed by Ormat Inc. started operation in August 2000 in Olkaria West and a 64 MWe plant is nearing completion in Olkaria Northeast.

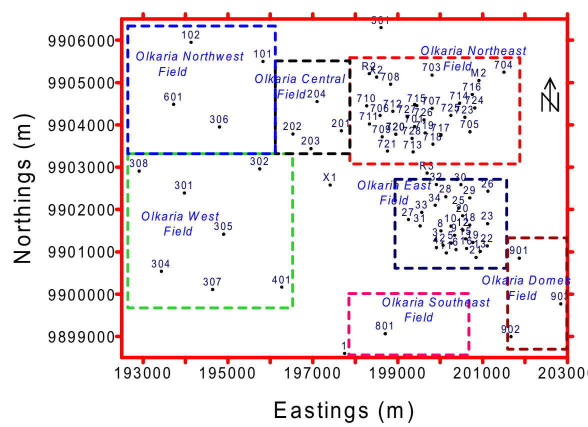

Figure 1. Location of wells and fields in the greater Olkaria geothermal system.

Olkaria geothermal system is liquid dominated and is recharged by hot upflowing fluids from zones in the West, Northeast, East and possibly Domes fields. The upflow zones are associated with the intersection of prominent faults within the geothermal system such as the NE trending Olkaria fault and the NW, NNW trending faults (Figure 2).

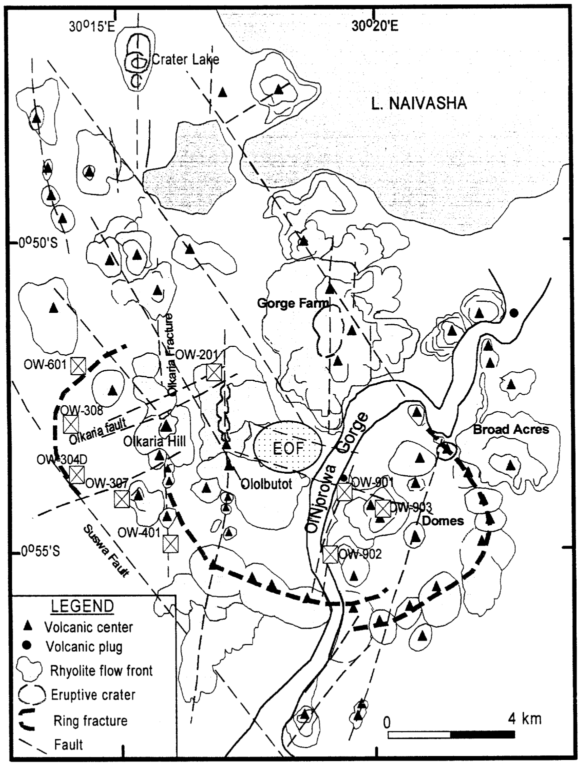

Figure 2. Geological structural map of Olkaria geothermal system

Between the upflow zones in the east and west is a low temperature and pressure zone of Olkaia Central which is associated with the N-S trending Ololbutot fault. Temperatures and pressures in wells drilled in the upflow zones follow the boiling point with depth curve with steam cap forming below the cap rock. Wells in Olkaria Central field have temperature inversions at depth. Subsurface stratigraphy of the wells show that from the surface (which is at an average elevation of 2000 m. a. s. l) to 1400 m. a. s. l, the rocks consist of Quaternary commendites with an extensive cover of pyroclastics. Below these, the rock stratigraphy is essentially horizontal (Muchemi, 1999).

A field-wide 3-Dimensional natural state model was developed in 1987 by Bodvarsson and Pruess (Bodvarsson and Pruess, 1987) and was calibrated against the thermodynamic data obtained from the wells that had been drilled by then. It simulated the geothermal system to be recharged at a total rate of 600 kg/s from two major distinct upflow zones located in Olkaria Northeast and Olkaria West. The upflow in Northeast recharged the system at 250 kg/s of 1290 kJ/kg water and the one in the West at 350 kg/s of 1090 kJ/kg water. The recharge from the two upflow zones mixed near well OW-201 and discharged at 260.5 kg/s to the south and at 175.1 kg/s to the north through Ololbutot fault and Olkaria Fracture, respectively. Steam loss from the system amounted to 126 kg/s. The model was then re-calibrated in 1989 and 1993 to accommodate new data from newly drilled wells, but no significant changes were reported. From 1993 to present, 24 additional wells have been drilled and one well (OW-5) deepened in the greater Olkaria geothermal system. There has been a serious need to update the natural state model to conform with the new findings and also to extend the vertical grid to cover the deeper layers. This paper presents an update done on the old model whereby the thermodynamic data from most of the new wells have been incorporated and the vertical grid extended to cover depths up to 550 m. b. s. l. Simulation runs were done in TOUGH2 V2.0 (Pruess et al., 1999).

MODEL DESCRIPTION

Grid geometry

The grid used is similar to the previous ones but with extension to the west and east so as to accommodate the newly drilled wells in Olkaria Domes and Olkaria West. The model covers an area of about 120 km^2 and is partitioned into 158 grid blocks (Figure 2). Vertically, the model assumes an impermeable cap rock of 700 m thick beneath which underlies a permeable reservoir of 1850 m (Figure 3) that is further partitioned into five layers giving a total of 790 grid blocks (Ofwona, 2003).

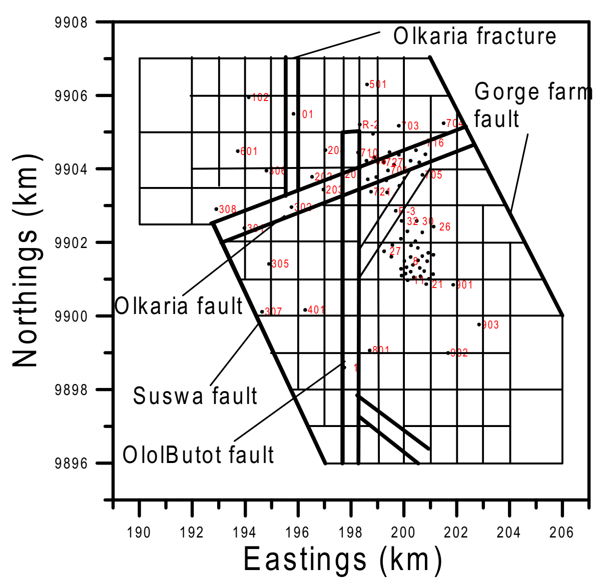

Figure 3. The horizontal grid

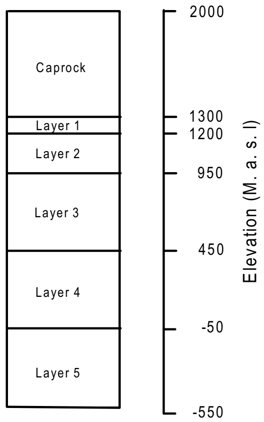

Figure 4. The vertical grid

Boundary conditions

The major hydrogeologic features of the Olkaria system include Olkaria fracture, Olkaria fault, Suswa fault, Gorge farm fault and Ololbutot fault (Figure 2). In the model, the hydrothermal system is recharged by major upflow zones located along the Olkaria fault in the West and Northeast and also smaller upflows in Olkaria East and Domes. The fluids from the upflow zones move along the faults as they undergo conductive cooling as well as cooling by steam loss to the surface and converge in Olkaria Central zone. Major outflow with substantial steam loss and cooling occurs towards the south along Ololbutot fault and towards the north along Olkaria fracture zone. The reservoir is assumed to be bounded in the east and west by no flow boundaries and in the north and south by constant pressure boundaries of 45 bars and 28 bars at 1075 m. a. s. l, respectively. The hot upflows are treated as the source of heat and fluids at the base of the model

Fluid and rock properties

The rock properties used were similar to those used in the 1987 model and changes were made where well tests had shown otherwise and in cases where no information was available, the values used were simply guessed. A rock type with defined rock properties (values of permeability, porosity, density and thermal conductivity) was assigned to each model element. Reservoir fluid was assumed to be pure water and all properties based on steam tables. Table 1 shows the rock properties assigned to the major structures in the geothermal system

Table 1. Rock properties

Rock properties	**Permeabilities, m^2 ($x 10^{-15}$)**		
Density 2650 kg/m^3 Heat capacity 1000 J/kg °C Thermal conductivity 2.0 W/m°C Relative Permeabilities: $k_{rs}(S_s) = (S_s - 0.05)/0.55$ $k_{rw}(S_w) = (S_w - 0.40)/0.60$		Vertical	Horizontal
	Olkaria Fault	230	230 x 230
	Olkaria Fracture	250	250 x 250
	Ololbutot Fault	500	500 x 500

Match to the measured data

The natural state simulation run was done for 10,000 years until a steady state situation agreeing closely with the measured temperatures and pressure values in most parts of the field was found. It was a long trial and error procedure, slightly changing the rock parameters and boundary conditions. Important adjustable parameters in the model were the strength of the upflow (both enthalpy and upflow rate), vertical and horizontal permeabilities and the strength of outflow and steam losses along the prominent hydrogeologic structures. The computed values were compared with the measured or inferred downhole temperature and pressure data.

RESULTS

The results of the simulation are shown graphically for a few selected wells in the Figures 5 – 14. They show graphs detailing pressures and temperatures calculated by the updated model in relation to the measured or inferred formation temperatures and pressures. It is observed that the calculated data matches pretty well with the measured data.

Table 2 and 3 show the flow rates and enthalpies that now define the "best" natural state model. They were obtained after several simulation runs where they were systematically adjusted together with formation permeabilities to obtain better fits between calculated and measured data.

Table 2. Upflow rates and Enthalpies

Upflow Area	**Flow Rate (kg/s)**	**Enthalpy (kJ/kg)**
OW-305	298	1560
OW-714	295	1620
OW-720	500	1650
OW-101	15	1350
OW-32	105	1620
DOMES	40	1620

Table 3. Outflow from the system

Outflow	Flow rate (kg/s)
To the north	147
To the south	811
Steam loss	366

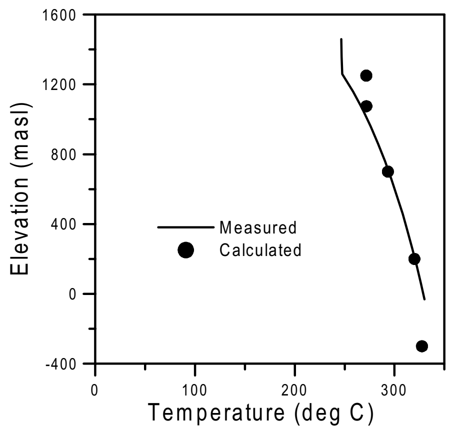

Figure 5. Match to temperature data in well OW-30

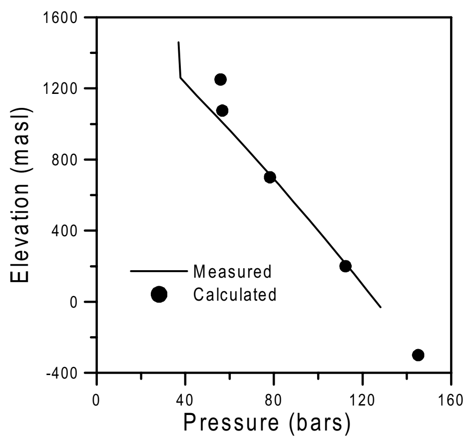

Figure 6. Match to pressure data in well OW-30

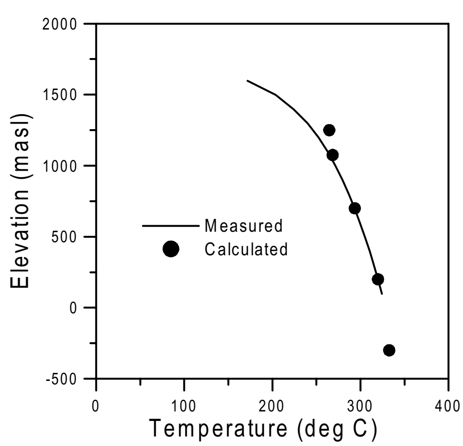

Figure 7. Match to temperature data in well OW-706

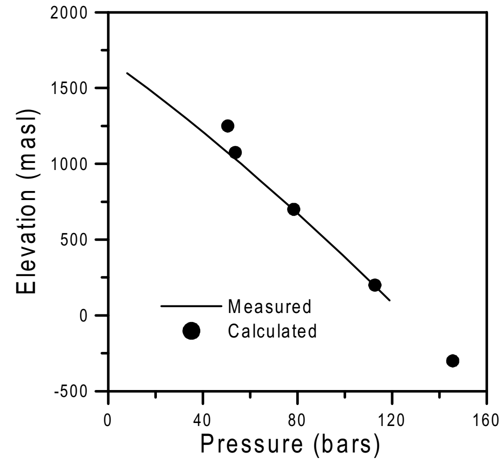

Figure 8. Match to pressure data in well OW-706

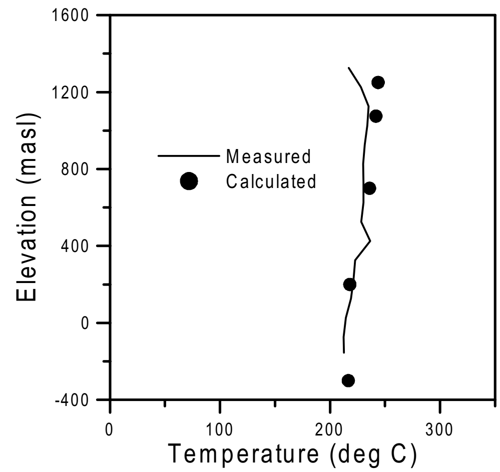

Figure 9. Match to temperature data in well OW-202

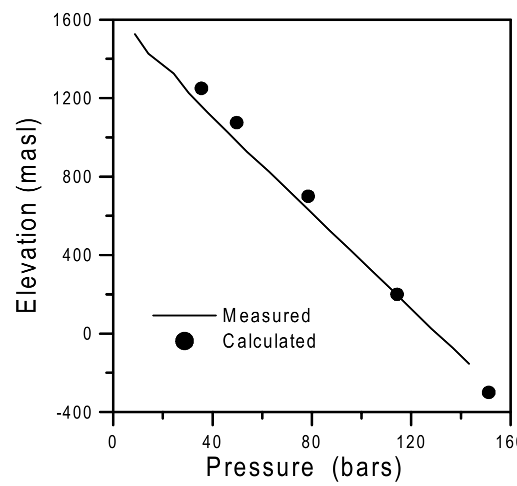

Figure 10. Match to pressure data in well OW-202

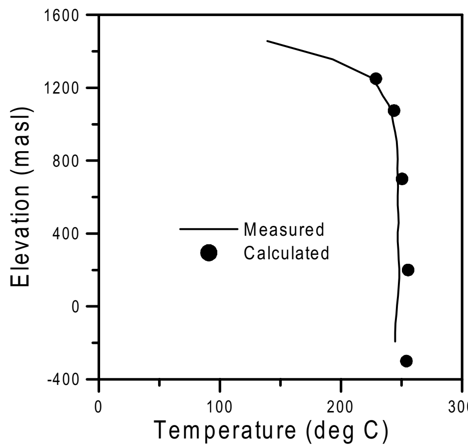

Figure 11. Match to temperature data in well OW-902

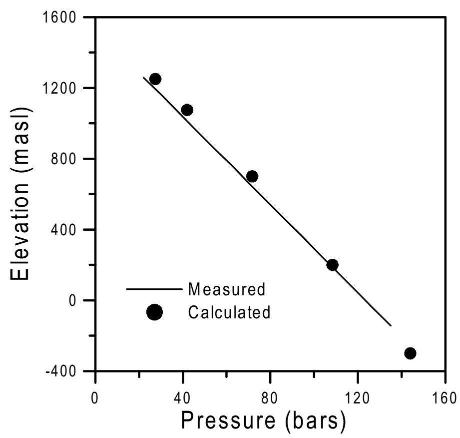

Figure 12. Match to pressure data in well OW-902

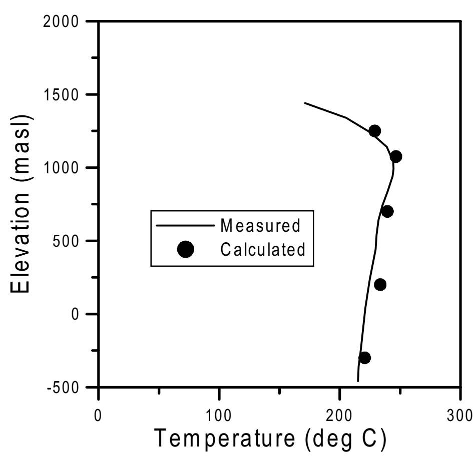

Figure 13. Match to temperature data in well OW-401

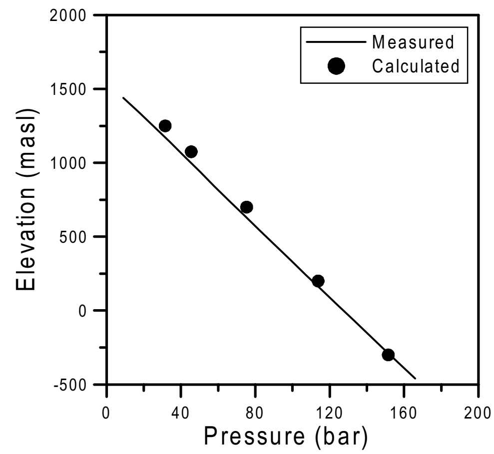

Figure 14. Match to pressure data in well OW-401

CONCLUSIONS

An update to the existing natural state model has been done. The grid has been extended to include the deeper layers as well as horizontally to accommodate Olkaria Domes wells as well as wells in Olkaria West drilled recently. Results show that quite a huge quantity of water is circulating in Olkaria system in the natural state suggesting that the geothermal system could be bigger than previously modeled.

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