A PRELIMINARY STUDY OF THE VOLCANO-TECTONIC CHARACTERISTICS OF THE OLKARIA REGION (KENYA) USING THE GEOMAGNETIC DEPTH SOUNDING METHOD.

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A B S T R A C T

Olkaria is seated at the centre of the Kenya rift valley. The region underwent intense faulting and volcanism during the formation of the rift (Miocene-Quaternary). A geophysical research, using the Geomagnetic Depth Sounding (GDS) method in the period range 0.01-10000 s, was undertaken in Olkaria to determine the volcano-tectonic characteristics of the region and the relative geothermal field. The study included computation and mapping of induction arrows at 30 sites. Preliminary interpretation of the real induction arrows showed that their corresponding azimuth increases with period anti-clockwise from north and it is about 20-40°W, 230-240°W, 325°W in the period bands 0.02-0.05, 5-50, 200-2500 s respectively. The results relating the shorter period band data were interpreted in terms of local geoelectric anomalies while the results relating the longer period band data were interpreted in terms of geoelectric anomalies associated with regional volcano-tectonic features.

ΜΕΛΕΤΗ ΤΩΝ ΗΦΑΙΣΤΕΙΟ-ΤΕΚΤΟΝΙΚΩΝ ΧΑΡΑΚΤΗΡΙΣΤΙΚΩΝ ΤΗΣ ΠΕΡΙΟΧΗΣ ΟΛΚΑΡΙΑ (KENYA) ΜΕ ΤΗ ΜΕΘΟΔΟ GEOMAGNETIC DEPTH SOUNDING (GDS)

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Π Ε Ρ Ι Λ Η Ψ Η

Η περιοχή Ολκάρια βρίσκεται στο κέντρο του Κενυάτικου τεκτονικού βυθίσματος. Η περιοχή υπέστη έντονο τεκτονισμό και ηφαιστειότητα κατά τη διάρκεια της δημιουργίας του βυθίσματος (Μειόκαινο-Πλειστόκαινο). Στα 1989, το Πανεπιστήμιο του Εδιμβούργου σε συνεργασία με τη Kenyan Power Company διενήργησε στην Ολκάρια έρευνα με την μέθοδο GDS. Σκοπός της έρευνας ήταν η μελέτη των ηφαιστειο-τεκτονικών χαρακτηριστικών της περιοχής και του ομώνυμου γεωθερμικού πεδίου. Εγινε υπολογισμός και χαρτογράφηση επαγωγικών ανυσμάτων Parkinson για κάθε θέση διασκόπησης και για εύρος περιόδων 0.01-10000 s. Παρατηρήθηκε προσανατολισμός των ανυσμάτων αυτών κατά συγκεκριμένη διεύθυνση, διαφορετική κάθε φορά, για 3 φάσματα περιόδων (0.02-0.05, 5-50, 200-2500 s). Τα αποτελέσματα ερμηνεύτηκαν λαμβάνοντας υπόψη τοπικές γεωηλεκρικές ανωμαλίες για το πρώτο φάσμα, ανωμαλίες δε συνδεόμενες με την ηφαιστειο-τεκτονική κατάσταση της ευρύτερης περιοχής για τα άλλα δύο φάσματα.

INTRODUCTION

Olkaria is located (Fig.1) on the central part of the Kenya rift valley, 80 km NW of Nairobi and 10 km SW of Lake Naivasha. The area extends over approximately 500 km2 and is situated at 1700-2300 m above the sea level. Since the Miocene, during the formation of the rift, the region underwent extensinve volcanism and intense faulting. Volcanism and faulting are responsible for the high enthalpy geothermal field of Olkaria.

Olkaria East is being exploited during the last 8-9 years and more than 20 productive wells supply with hot fluids and steam the local geothermal power station. The current plans of the Kenya Power Company (KPC) are associated with the geophysical mapping of the Olkaria West and North potential fields and the detection of a possible heat source. These were the objectives of a recent geophysical research.

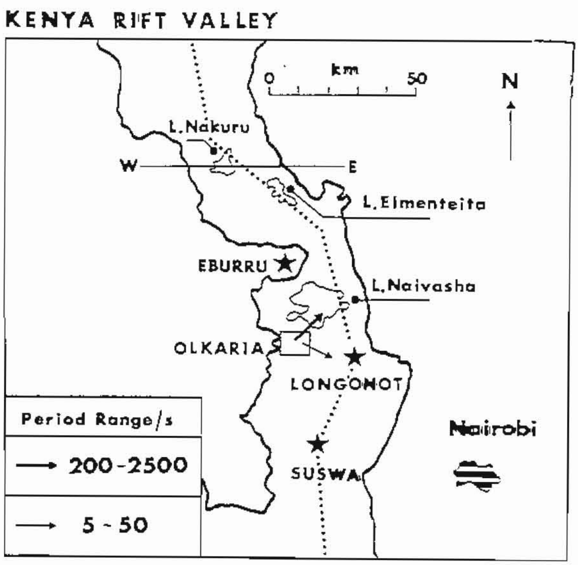

Fig.1. The Kenya rift valley (dotted line: central axis of the rift; black stars: volcanic centres; solid line: profile of geotectonic model of Henry et al. (1990); black arrows: real induction arrows (magnitudes and azimuths averaged over two period ranges)).

The geophysical investigation included application of the MagnetoTelluric (MT) and GDS methods in the period range 0.01-10000 s which was undertaken during 1989 by the University of Edinburgh, in collaboration with KPC. In the present paper, the GDS data are analysed and interpreted in order to provide some preliminary results concerning the volcano-tectonic features of Olkaria region. In particular, the real part of induction arrows is mapped for 30 sites in the period bands 0.02-0.05, 5-50, 200-2500 s respectively. A proposal for further work is finally presented.

GEOLOGY AND TECTONICS OF OLKARIA

The formation of the Kenya rift valley has been explained in several ways, as a result of crustal streching and thinning (Girdler et al., 1969) and as a zone of crustal rupture and injection of igneous rocks (McKenzie et al., 1970). It is now accepted that the Kenya rift results from an extensional stress system (Baker and Wohlenberg, 1971; Henry et al., 1990).

The geotectonic evolution of the Kenya rift was subdivided into four stages by Baker and Wohlenberg (1971). During the first two stages (Lower Miocene-Middle Pliocene), the Kenya rift passed through a period of broad crustal flexing and local faulting accompanied by voluminous flood phonolite eruptions, basaltic and trachytic volcanism. During the third stage (Upper Pliocene-Middle Pleistocene) massive eruptions of trachytic ignimbrites occured along the central part of the trough in the Naivasha sector, accompanied by several phases of graben faulting. During the last stage (Late Quaternary), trachyte, basalt-trachyte and phonolite volcanic centres built up axially in the floor of the graben, such as those of Eburru, Olkaria, Longonot and Suswa (Fig.1).

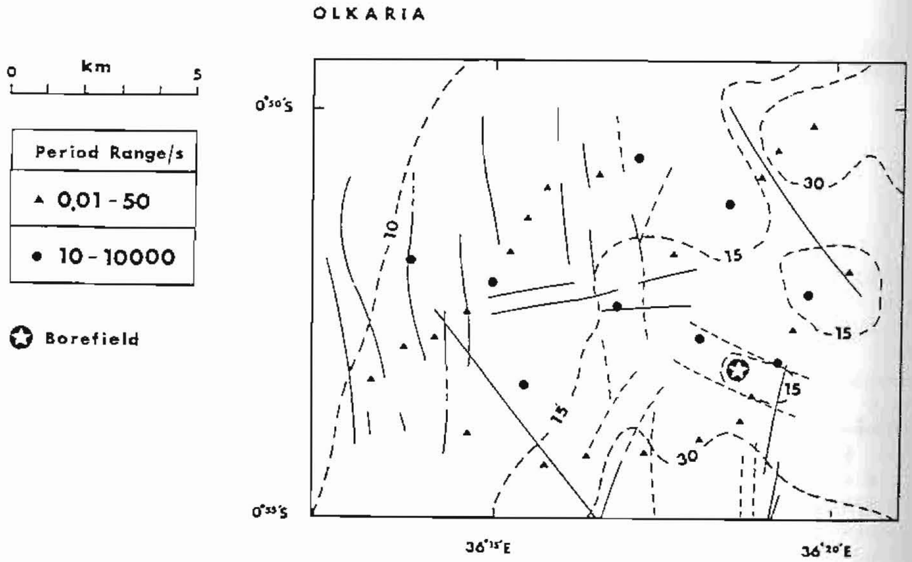

Fig.2. Olkaria geothermal field (solid lines: normal faults; dashed lines: hypothetical extension of existing faults; dashed contour lines: Niblett-Bostick (Jones, 1983) resistivites at 1 km depth; black solid dots and triangles: GDS site locations).

Olkaria is one of the most important volcanic centres. Petrological data indicate that the products of the eruptions are predominantly alkali volcanics of rhyolite to trachyte composition together with calc-alkaline basalts and rarely dacites. Normal faulting occurs mainly in N-S, ENE-WSW directions, but also in NW-SE directions (Fig.2). The N-S structures are associated with the dominant trend of the rift floor faulting, while the ENE-WSW trending is related to the Olkaria fault zone. The major NW-SE structures in Olkaria, are the Ol Olbutot fault and the Suswa lineament. The geological stratigraphy in Olkaria concerns a series of quaternary pyroclastics, tuffs and volcanic ash overlying a composite pile of subaerial volcanic lavas and associated pyroclastic rocks of rhyolitic, trachytic and basaltic compositions about 2000 m thick. The intense faulting and volcanism in the region enabled the formation of a high enthalpy geothermal field.

GEOPHYSICAL INVESTIGATIONS IN OLKARIA

For more than eight decades the Kenya rift valley has attracted the interest of Earth scientists. Most of the geophysical surveys which have been undertaken have been concerned with the understanding of the nature and mechanism of rifting. The proposed geotectonic models for the rift are based on the results from gravity (Girdler et al., 1969; Searle, 1970; Khan and Mansfield, 1971; Baker and Wohlenberg, 1971), seismic refraction (Griffiths, 1971; Henry et al., 1990) seismological (Savage and Long, 1985), GDS and MT (Banks and Ottey, 1974; Beamish, 1977; Banks and Beamish, 1979; Rooney and Hutton, 1977; Rooney, 1977; Hutton et al., 1989; Galanopoulos, 1989) studies. The most recent accepted geotectonic model is that one presented by Henry et al. (1990) as a vertical section across the rift at the region of Lake Nakuru (Fig.3).

During the last two decades many geophysical investigations employing several methods such as, D.C. resistivity (Bhogal, 1980; Mwangi and Bromley, 1986), gravity (Swain and Khan, 1977), aeromagnetics (Van Dijck, 1986), seismic refraction (Henry et al., 1990), MT and GDS have been undertaken in the Olkaria region. In 1989 an MT survey has been carried out by Geotermica Italiana over an area east of Olkaria and close to Longonot volcano (Mwangi, 1989, private communication) while during the same year MT and GDS measurements were conducted in Olkaria by the University of Edinburgh (Hutton et al., 1989; Galanopoulos, 1989). Interpretation of the D.C resistivity, gravity and aeromagnetic data has provided the integrated geophysical model shown in Fig.4.

DATA COLLECTION AND ANALYSIS

The GDS measurements in Olkaria were carried out within the time period 1/2/89-15/3/89. Thirty SPAM Mk II (Dawes, 1984) soundings in the range 0.01-50 s were conducted along 4 approximately linear profiles (Fig.2). Three of these had a NE-SW direction while the fourth one was crossing the other three in a WNW-ESE direction. At 9 of these sites (Fig.2), a broader period range (10-10000 s) was used. Three simultaneously operating systems incorporating three component EDA fluxgate magnetometers and NERC Geologgers (Valiant, 1977) were used for recording signals in the longer period range 10-10000 s. The three magnetic components were measured in the N-S, E-W and vertical directions.

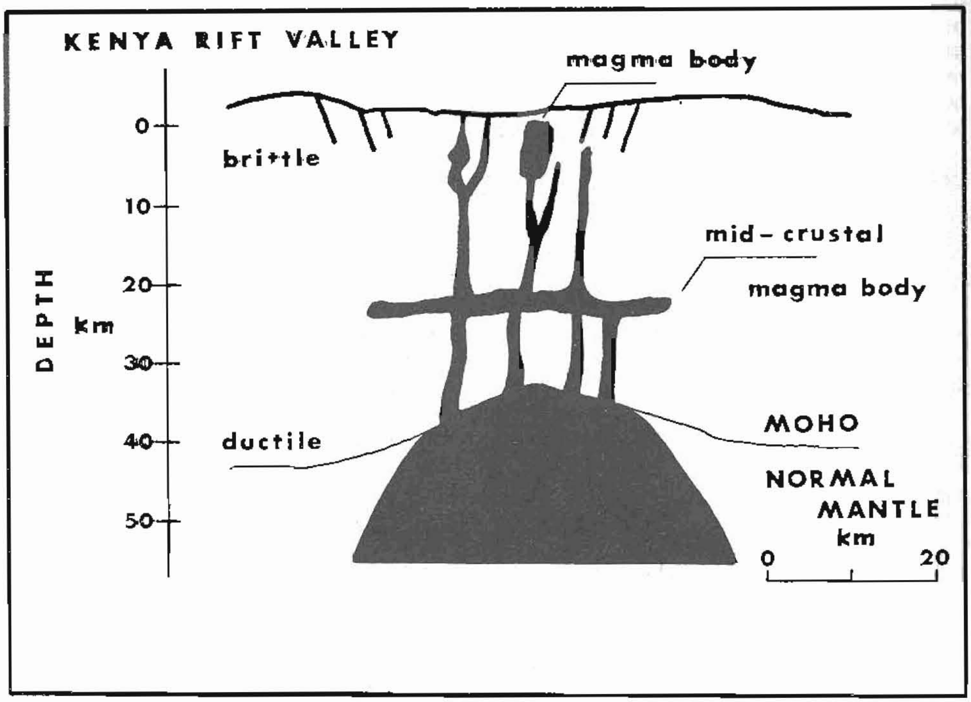

Fig.3. A geotectonic model for the Kenya rift valley. (After Henry et al., 1990).

For the shorter period range, time series windows having 256 digitised values and satisfying preset acceptance criteria (Galanopoulos, 1989) were recorded for the three magnetic components and written to data cartridges. The sampling rates varied according to the SPAM Mk II sub-band period range. A prefixed sampling rate of 10 s was used for the longer period observations for which the three orthogonal magnetic field components were recorded digitally on magnetic tape cassettes. The GDS data were reprocessed on the mainframe computer system of the Univeristy of Edinburgh, using the same acceptance criteria. For the longer period range the data processing additionally included time series window selection, also comprising 256 digitised values.

Computations of the magnetic transfer functions (Schmucker, 1970) in the period range 0.01-10000 s enabled estimation of the magnitude and azimuth of induction arrows for this period range to be made. Such arrows reversed in direction, are helpful in delineating lateral variations in resistivity structure as they point in the direction of concentration of induced current flow and their amplitudes are functions of the distance from the resistivity contrast and of the contrast magnitude itself (Patra and Mallick, 1980). For example, large real induction arrows are expected to indicate large or deep-seated conductors. In this case, Fig.5 shows the real induction arrows for three period bands.

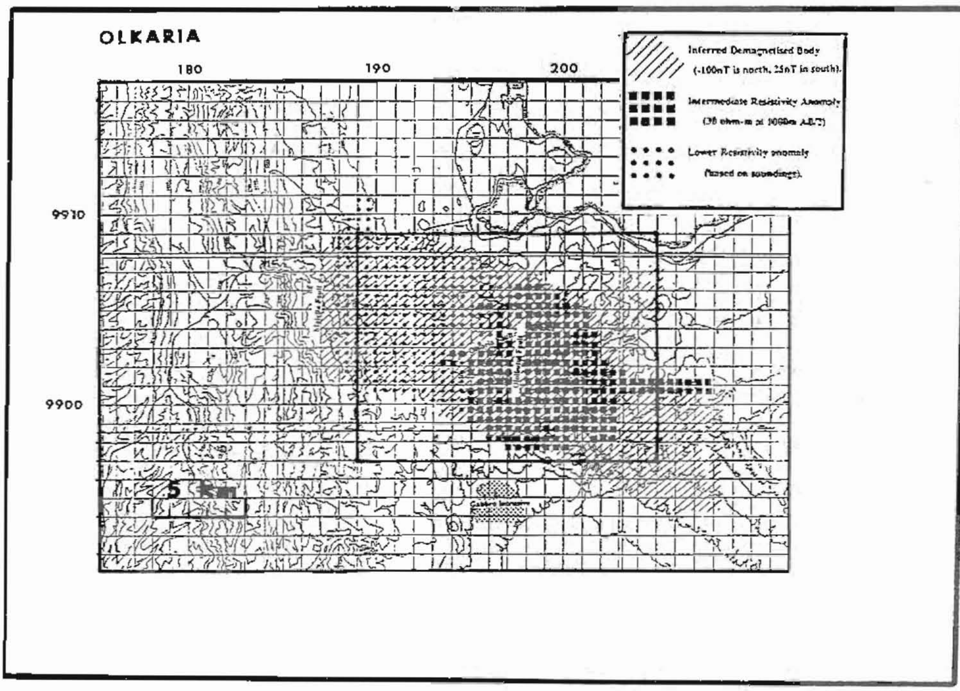

Fig.4. An integrated geophysical model for Olkaria (After Mwangi and Bromley, 1986).

The main features of the illustrated map may be summarised as follows-(a). At most of the GDS sites, the magnitude of the arrows icreases with period, (b) At all the GDS sites, the azimuth of the arrows increases with period anti-clockwise from north and it is about 20-40°W, 230-240°W, 325°W in the period bands 0.02-0.05, 5-50, 200-2500 s respectively.

It is only for the lowest period band (0.02-0.05 s) that lateral variations in resistivity can be inferred for the study region. In this case, the real induction arrows point towards a more conducting region in the northwest, which is compatible with the resistivity map (Fig.2) of Olkaria (Hutton et al., 1989) and the integrated geophysical model (Fig.4) of Olkaria (Mwangi and Bromley, 1986). For the longer period bands interpretation is only possible in a more regional setting. The arrows in the period range 5-50 s show a more or less uniform azimuth of about 230-240°W but with amplitudes increasing in that direction. This pattern together with increased amplitude relative to that of the lowest periods implies that a major resistivity contrast exists to the SE of the present study area (Fig.1). This feature needs further study to determine if it is associated with the Longonot volcano or with magma ascension from the asthenosphere to the crust, at depths of 20-30 km along the axis of the rift (Henry et al., 1990). The uniformity in amplitude and direction of the arrows of the longest period band is directly compatible with the results (Fig.6) of Rooney and Hutton (1977) and Beamish (1977) and implies a large concentration of induced current flow to the NE of Olkaria (Fig.1). This feature too, merits further study to resolve if it is related to the rift as a whole relative to the resistive zones on its flanks or to a southward continuation of the Banks and Ottey (1974) low resistivity zone (20 Ohm.m) east of the Kenya rift valley.

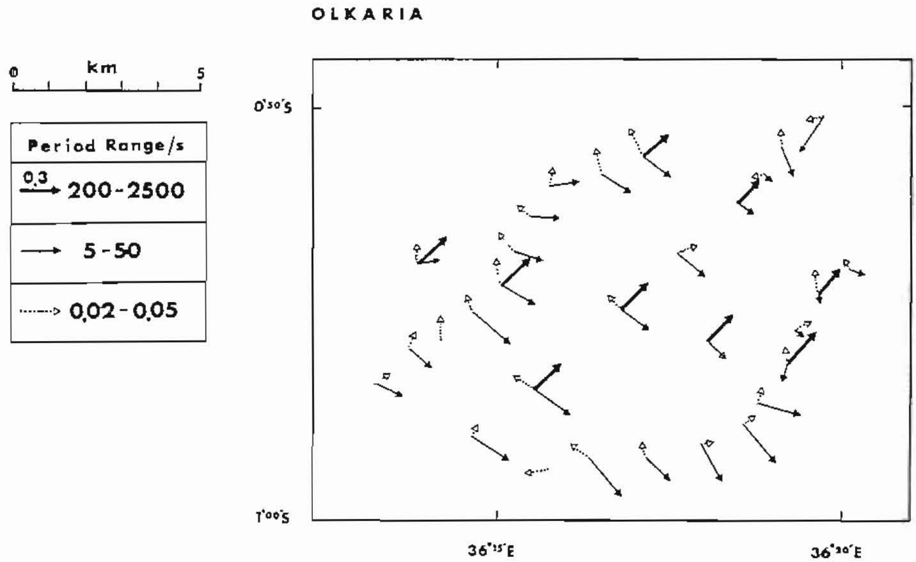

Fig.5. Real induction arrows. Magnitudes and azimuths averaged over three period ranges.

CONCLUSIONS

The following stand as general conclusions for the Olkaria geothermal region and the Kenya rift valley.

(a) The real induction arrows of the lowest period band (0.02-0.05 s) point towards a more conducting region (<10 Ohm.m) in the northwest which has been identified by Hutton et al. (1989) as the Olkaria West potential field.

(b) The real induction arrows of the longer period bands (5-10000 s) have been related to regional features concerning the volcano-tectonic settings of the rift.

This paper provides a preliminary account of aspects of the GDS data analysis and interpretation. Athough the results of this paper correlate with those of Banks and Ottey (1974), Beamish (1977), Rooney and Hutton (1977) and support the geotectonic model of Henry et al. (1990), further consideration is needed, including two or three dimensional data modelling to study in a more detailed way, the Olkaria region and the Kenya rift valley at the Olkaria latitude. Two dimensional modelling of the GDS data is currently carried out and is expected to provide additional information for the local and regional tectonic settings.

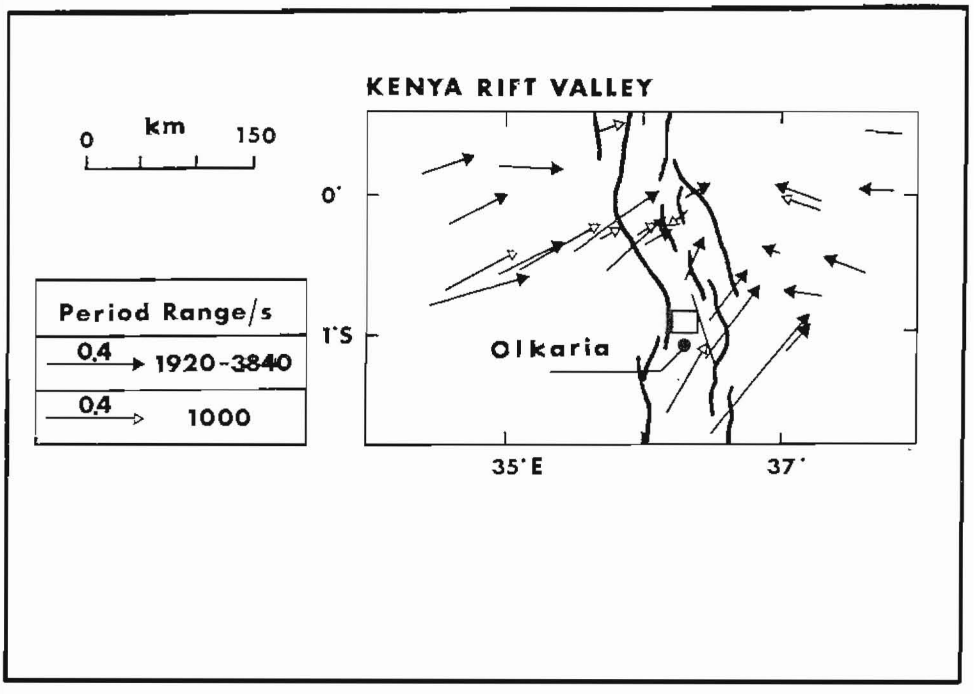

Fig. 6. Maximum response arrows across and along the Kenya rift valley. Magnitudes and azimuths averaged over two period ranges (black arrows: after Beamish (1977); white arrows: after Rooney and Hutton (1977))

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