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GEOMAGNETIC ANOMALIES ACROSS THE ONSHORE MESOZOIC–TERTIARY SENEGAL BASIN

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ABSTRACT

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Records of the horizontal geomagnetic variation field at nine stations were taken in the onshore Mesozoic–Tertiary Senegal basin (West Africa) across a zone of north–south faults, for periods from 30–1000 s. Simultaneous measurements were made at a reference site situated on the basin about 200 km east of the north–south-trending basin fault so as to calculate the anomalous geomagnetic variation field across this basin. Results show a large anomaly in the horizontal variation fields over the period range which could be caused by channeling of telluric currents in sediments. A second possibility is an induction in conductors of two-or-three-dimensional geometry located in the crust and/or upper mantle. The interpretation is performed by computing the anomalous geomagnetic variation field for two-dimensional conductivity models. The type of model that fits the experimental data involves a body of high conductivity material at only some kilometers from the surface (< 10 km thick). This conducting region extends to nearly 45 km to each side of the north–south trending fault. This crustal conductive layer is asssumed to mark the existence of intrusive bodies in the basement linked to Mesozoic rifting.

INTRODUCTION

The Senegal basin is the largest marginal basin in West Africa. Its onshore part extends to nearly 500 km at the latitude of Dakar (Liger, 1980). Development of the Senegal coastal basin is closely associated with the continental separation of Africa and North America in the Early Mesozoic about 180 Ma ago (Dewey et al., 1973).

In the years 1980–1982, the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) recorded horizontal geomagnetic field variations at nine sites in the onshore Mesozoic–Tertiary Senegal basin in order to look for a possible geomagnetic anomaly associated with the north–south trending basin fault (Fig. 1). Recordings were made simultaneously at a reference site (~ 200 km east of the line of the fault) assumed to be influenced only by the regionally uniform telluric current system. The instrumentation used in this study was designed by the Centre de

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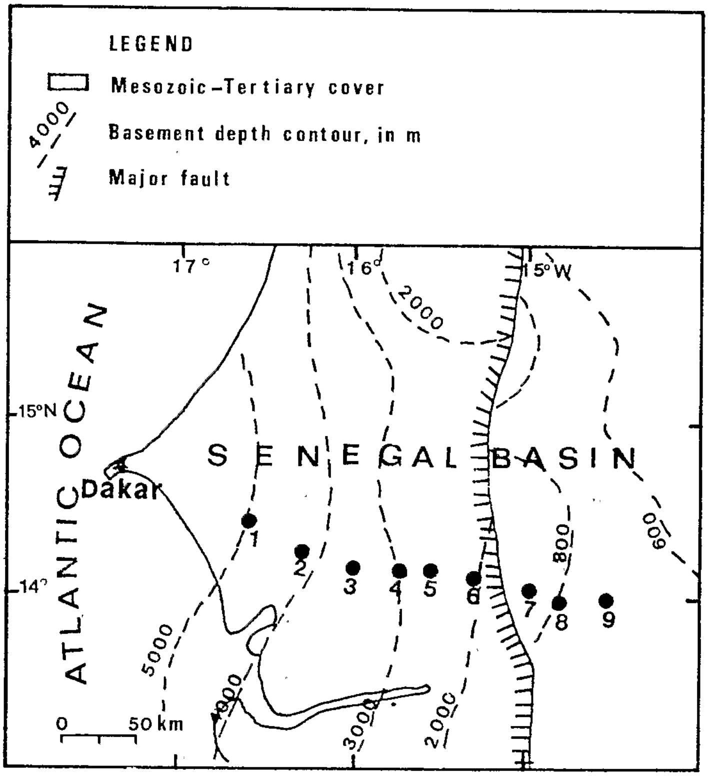

Fig. 1. Schematic map of Mesozoic–Tertiary Senegal basin showing the survey sites numbered from 1 to 9 (filled circles) and their location in relation to the major north–south trending fault.

Recherches Géophysiques in France (Babour and Mosnier, 1977). Magnetic signals were filtered and amplified in the period band ranging from 10 to 1000 s before reaching the graphic recorders.

ANOMALOUS MAGNETIC VARIATIONS

At each site, the observed magnetic field can be considered as the sum of a normal field consisting of the external source field and of its response in a layered medium, and an anomalous field which exists only if the medium has lateral inhomogeneities of conductivity (non-one-dimensional conductivity structure). The anomalous field is entirely internal in origin (Schmucker, 1970). To study the geomagnetic variation field that results from an anomalous conductivity structure, a reference site is located as far as possible from the basin fault. By subtracting the field observed at the reference site from the fields observed at the remaining sites, the anomalous magnetic variations due to the anomalous area can be determined (Babour and Mosnier, 1977). Under the assumption of a uniform source over the study area, information on the frequency dependence of the conductivity anomaly can be gained. The standard procedures for relating the normal and anomalous field variations as a function of frequency were performed using eqn. (1) developed by Schmucker (1970). Cross-spectral analysis is used to find transfer functions that best satisfy:

$$\begin{aligned} H_a &= h_H H_n + h_D D_n \\ D_a &= d_H H_n + d_D D_n \end{aligned} \tag{1}$$

where H_n, D_n, are for the normal field, that is the field in the absence of anomalous conductivity structure; H_a, D_a, are for the field associated with lateral conductivity inhomogeneities. The 2 by 2 matrix is the transfer function.

The amplitude of the horizontal east (D) component increases across the fault, with the result that the amplitude of the D component is about twice that of the reference site. The variations in the horizontal north (H) component appear to be identical across the basin.

DATA ANALYSIS

Using the D component as an example, the modulus of the transfer functions and the phases linking D_a, obtained at each site, to the normal horizontal magnetic field were determined. Profiles of the anomalous D_a component normalized to the reference station are shown in Fig. 2. Four periods in the range 10–1000 s are

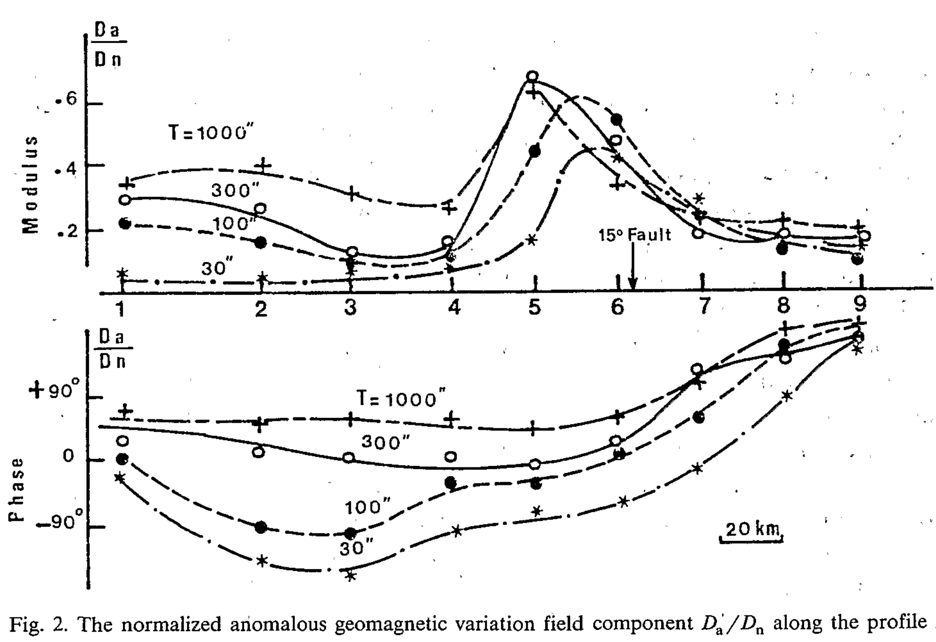

Fig. 2. The normalized anomalous geomagnetic variation field component D_a'/D_n along the profile for periods 30, 100, 300 and 1000 s.

represented. For the period at 30 s, the maximum is situated at site 6. At 100 s, the maximum is situated between sites 6 and 5. For the longer periods, the position of the maximum is situated at site 5. At sites 7, 8 and 9, the amplitude of normalized field D_a/D_n are roughly invariable with the period; for other sites D_a/D_n is small at 30 s (except the site 6) and rises as the period increases. J. Mosnier (pers. commun., 1983) has already revealed some of this effect. He suggests that current flow parallel to the shore is probably an extension of current systems which flow in the ocean when the continent is a conductor. If a north–south current system exists in the Atlantic Ocean, it can invade the Senegal basin. Thus, the origin of the magnetic eastward anomalous geomagnetic variation field across the Senegal basin could be the deflection and the channelling of telluric currents by conductivity contrasts in the zone of north–south faults along longitude 15°W. At 100 s period, the amplitude of D_a/D_n is of 0.52 at site 6 and 0.05 at site 9, a factor of more than 10 and it appears then that site 9 lies on the eastern side of the current concentration and site 6 lies nearer the center. In this case, the maximum depth of the current system is estimated to be about 20 km and therefore the telluric current flows within the crust (Gough, 1973).

INTERPRETATION

As shown in Fig. 2, the anomalous geomagnetic variation field across the basin tends to have larger amplitudes toward the west. At first glance, it appears that telluric currents in the sediments of the Senegal basin might produce this anomaly. At this stage, two-dimensional geomagnetic induction model calculations have been introduced for a more quantitative interpretation (Rijo, 1977). This interpretation was performed by computing the transfer functions for two-dimensional conductivity models. The transfer functions give the modulus of the ratio of anomalous to the normal horizontal magnetic field variations D_a/D_n in the direction perpendicular to the strike of the structure. Previous electrical studies on the Senegal basin (Compagnie Générale de Géophysique, 1956) place useful constraints on the resistivity of the sedimentary section. An initial assumption was that an overburden of resistivity 15 Ωm, 700 m deep, overlaid the whole region. Several models with a sudden thickening of the sedimentary layers west of the north–south trending fault and lateral changes in the sediment conductivity were made to fit the data. This type of sedimentary model was unsuccessful at predicting the observed transfer functions. The successful models giving a reasonable fit to the observed data require conductors in the crust roughly centered at the north–south-trending basin fault. Figure 3 shows a model with a laterally varying conductor in the upper crust against background resistivities of 1000 Ωm and the results of the model compared with the observed data at periods of 100 and 1000 s. The uniqueness of the model cannot be guaranted because of the number of assumptions involved. This model indicates the presence of a relatively conducting crust (20–30 Ωm) at shallow depth. However, significant differences between results of observation and calculation along the profile (sites 3 and 4 at 1000 s period) suggest the possible effects of regional three-dimensional current channelling.

The discovery of such a large volume of conducting material in the upper crust is remarkable. As a case history, it may be compared to the works of Vozoff and Swift (1968) in the North German basin (magneto-telluric sounding) and De Beer et al. (1976) in South West Africa. Other major crustal condutors are mentioned by Gough (1981). The low-resistivity layers are often explained by saline fluids, crustal magma or conductive minerals: graphite, hydrated minerals (Cochrane and Hyndman, 1974; Rooney and Hutton, 1977; Drury and Nibett, 1980).

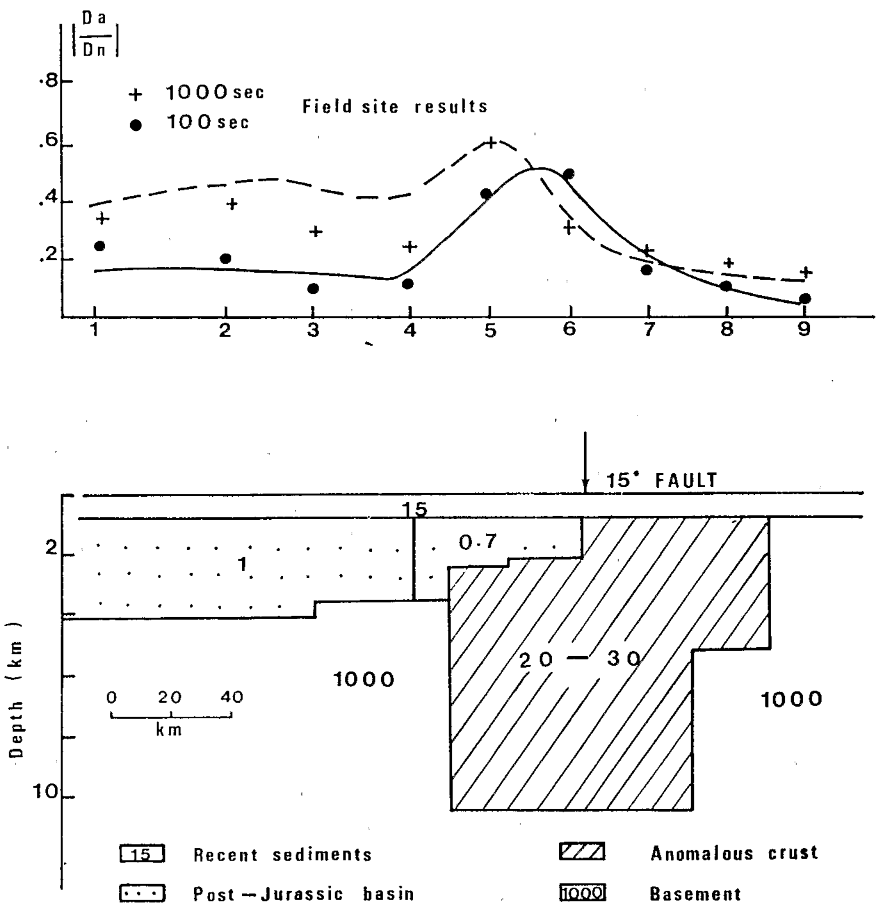

Fig. 3. Two-dimensional model of resistivity distribution beneath east-west profile and computed anomalous geomagnetic variation field component D_a/D_n. Solid and broken lines are the theoretical curves calculated from the two-dimensional model for periods of 100 and 1000 s, respectively. The numbers indicate resistivities in ohm meters.

DISCUSSION AND CONCLUSION

At the present stage of knowledge, very little information is available about the geology and structure of the onshore Mesozoic–Tertiary Senegal basin. Stratigraphic data from deep wells are also very sparse. Because of a lack of data, only typical geological and structural features of the basin will be presented in the following which would justify the presence of a strip of high conductivity material in the eastern portion of the profile. This conductive zone (20–30 Ωm) is roughly centered at the north–south-trending basin fault and appears to extend at a depth of approximately 10 km.

The Senegal basin is filled with more than 7000 m of almost uninterrupted Jurassic to Upper Eocene marine sediments in the Dakar area (De Spengler et al., 1966). In this region, the post-Paleozoic sedimentary cover (Mesozoic and Cenozoic beds) may be about 10,000 m in thickness. The basin sediments become thinner to the east. Furthermore, drillings have indicated a Precambrian or lowest Paleozoic basement (crystalline and metamorphic rocks) that dips westward from a group of north–south striking faults between 15° and 16°W (Castelain, 1965). The basement is no longer reached by electric measurements west of this apparent hinge line (Compagnie Générale de Géophysique, 1956). Basement depth contours under the Senegal basin, though not reliable, are shown in Fig. 1. The area under study is characterized by a large gradient in the gravity field that is probably associated with the intrusion of large volumes of mafic material within the basement complex (Roussel and Liger, 1983).

Numerous rifts developed to form the ocean but many appear to have failed. Onset of rifting in other parts of West Africa was commonly associated with intrusion of Triassic to Liassic magmatic material into fractures (Burke, 1976). Triassic and Early Jurassic dykes have been suggested for the coastal areas of Mauritania (Dillon and Sougy, 1974). Doleritic sills and dykes also occur in Senegal (Maugis, 1955; Hebrard, 1978). However, in the onshore Senegal basin there are no obvious igneous rocks associated with rift tectonics of the Atlantic Ocean opening, but this may be due to the paucity of stratigraphic data in the region. The igneous rocks in Senegal basin have been related to either the Neogene volcanism of the Dakar area or to the Hercynian orogeny. Diapiric structures have been found beneath the continental shelf of southern Senegal which are interpreted to be salt domes. The salt is probably of Triassic age (Aymé, 1965; Templeton, 1971). With regard to present geological and geophysical data, it is not possible to say how the zone displaying anomalous crustal resistivities was formed or what property or material in the zone forms the good conducting layer below the sedimentary basin. No heat flow measurements are available for this region, but the low resistivities at these shallow depths cannot be explained by elevated temperatures. It is likely that Mesozoic rifting and subsidence of the West African margin was accompanied by intrusion of magmatic material into fractures. A possible explanation is that this layer of enhanced electrical conductivity which has been inferred at upper crustal depths is in effect a combination of the fractured wet and highly altered magmatic material and some low-resistivity sedimentary formation. For igneous rocks, 0.2 wt.% of water can increase conductivity by several orders of magnitude at low temperature (Olhoeft, 1981). The present anomaly may reveal a pattern of crustal weakness in this zone. Additional profiles of geomagnetic variations and magnetotelluric soundings are necessary to map the geoelectrical structure of the Senegal basin. Magnetotelluric interpretations will be published in detail elsewhere.

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