NIEDERSÄCHSISCHE STAATS- UND
UNIVERSITÄTSBIBLIOTHEK GÖTTINGEN

Werk

Jahr: 1984
Kollektion: fid.geo
Signatur: 8 Z NAT 2148:55
Digitalisiert: Niedersächsische Staats- und Universitätsbibliothek Göttingen
Werk Id: PPN1015067948_0055
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948_0055

LOG Id: LOG_0035
LOG Titel: A high conductivity anomaly on the West African craton (Mali)
LOG Typ: article

Übergeordnetes Werk

Werk Id: PPN1015067948
PURL: http://resolver.sub.uni-goettingen.de/purl?PPN1015067948
OPAC: http://opac.sub.uni-goettingen.de/DB=1/PPN?PPN=1015067948

Terms and Conditions

The Goettingen State and University Library provides access to digitized documents strictly for noncommercial educational, research and private purposes and makes no warranty with regard to their use for other purposes. Some of our collections are protected by copyright. Publication and/or broadcast in any form (including electronic) requires prior written permission from the Goettingen State- and University Library.
Each copy of any part of this document must contain there Terms and Conditions. With the usage of the library's online system to access or download a digitized document you accept the Terms and Conditions.
Reproductions of material on the web site may not be made for or donated to other repositories, nor may be further reproduced without written permission from the Goettingen State- and University Library.

For reproduction requests and permissions, please contact us. If citing materials, please give proper attribution of the source.

Contact

Niedersächsische Staats- und Universitätsbibliothek Göttingen
Georg-August-Universität Göttingen
Platz der Göttinger Sieben 1
37073 Göttingen
Germany
Email: gdz@sub.uni-goettingen.de

J Geophys (1984) 55:182–184

Journal of Geophysics

Short communication

A high conductivity anomaly on the West African craton (Mali)

M. Ritz

Office de la Recherche Scientifique et Technique Outre-Mer, Boîte Postale n° 1386, Dakar, Sénégal

Key words: Magnetotelluric – Mali – West African craton – Electrical conductivity – Crust

Introduction

The geophysical section of Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) in Senegal has been conducting magnetotelluric (MT) soundings for several years on the West African craton and on its eastern and western borders. Up to the present, the interpretation of the data throughout Senegal, Upper Volta and Niger has shown characteristic models of platforms and continental shields with the first conductive layer situated in the upper mantle at a depth of 80–130 km (Ritz, 1982). On the Canadian shield, Kurtz and Garland (1976) find a conductive layer at a depth of 170 km. Tammemagi and Lilley (1973) place their conductive layer at a depth of 230 km on the Australian shield and, on the Kaapvaal craton, Van Zijl (1977) describes the presence of a conductive layer in the upper mantle at a depth of 90 km. However, an increasing number of soundings suggests regions of high conductivity at depths ranging from 10 to 40 km so that a tectonic province without this conductive zone is beginning to be considered an anomaly. Thus, in the southeastern section of the Canadian shield, MT soundings conducted by Dowling (1970) establish a conductive zone at a depth of 8–15 km. Geomagnetic depth soundings (GDS) made in the western section of the American platform also show conductive zones in the crust (Camfield et al., 1971). Van Zijl (1977) finds a conductive layer at a depth of approximately 35 km on the Rhodesian and Kaapvaal cratons. The absence of a conductive layer in the crust of the West African craton in Senegal, Upper Volta and Niger can be regarded as irregular (Ritz, 1983). We have, therefore, conducted an MT sounding in the centre of the West African craton at Bafo (latitude 13° 25′, longitude 6° 16′ W) in the southwestern part of the Segou basin, Mali (Fig. 1). The equipment used has been described in a previous article (Ritz, 1982).

A synthetic geological and geophysical picture

From the geological point of view, most of Mali belongs to the West African craton, which was definitively stabilized during the Eburnean orogeny (1,850 ± 250 m.y.). Birrimian rocks are by far the most plentiful in the Precambrian basement. Elsewhere the basement is concealed by a more recent sedimentary cover. Sedimentary rocks consist of series of the Infracambrian age, of the "Continental terminal", a limnic and fluvial formation of Tertiary age and Quaternary dunes (Dars, 1961). The fundamental tectonic structure of the studied area can be assimilated to a large synclinal structure (Reichelt, 1972). However, the geological information about the Segou basin is poorly known. The basin is characterized by Palaeozoic sandstones and Infracambrian sediments which rest on a Birrimian basement comprising highly metamorphosed sedimentary rocks and different intrusive rocks (Dars, 1961).

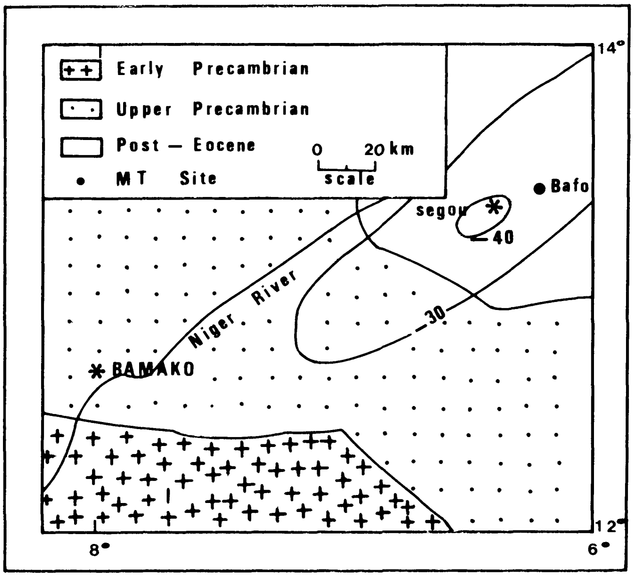

Fig. 1. Generalized geological and Bouguer gravity map of the Segou area. Gravity contours in milligal

The Bouguer gravity anomaly (Fig. 1) shows that the Segou basin is dominated by a major east-northeast trending negative anomaly. It is centred in the vicinity of the MT site (Bafo), and is as much as 40 mgal in magnitude. This axial minimum coincides with a large "lineament band", Bamako-Segou (Simon et al., 1982). The Bouguer anomaly along a NW – SE profile is shown in Fig. 2. This "low" is most probably due to the thick sedimentary deposit in the basin. A single density contrast of 0.26 g/cm^3 was used for the basement in a model employed in the computa-

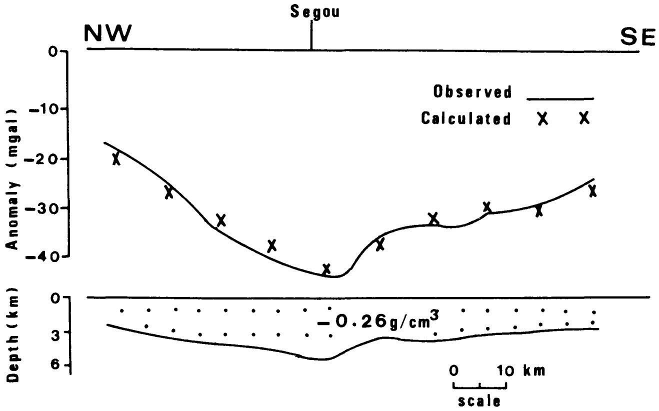

Fig. 2. Observed Bouguer anomaly and schematic interpretational model along a NW-SE profile

tion of depth to the basement (Rechenmann, 1957). The result showed that with a single density contrast there is a close fit between the observed and computed gravity anomaly profile. The gravity anomaly indicates sediments 5 km thick in the deepest part of the basin (Fig. 2).

Results

The variations of the electric and magnetic fields have been measured in the period range extending from 6 to 2,000 s at Bafo. The analysis techniques are those described by Vozoff (1972) and will not be discussed here. Generally, two apparent resistivity curves (and phases) resulted for a site, due to the effects of inhomogeneous structures. The apparent resistivities and the phases in the directions of the principal axes of anisotropy, the direction of the major axis of anisotropy and the preferential direction of the flow of the telluric currents as a function of period are shown in Fig. 3a–c. The data between 6 and 100 s on both major and minor curves are nearly the same. The apparent resistivity curves display increasing anisotropy with increasing period. It should be mentioned that the minor curve has important error bars for periods longer than 100 s (not presented). It can be seen that the major axis of anisotropy is orientated north-south at Bafo. The separation between apparent resistivities in the principal directions for periods longer than 100 s is an indication of two- or three-dimensional structures. We assume that the apparent anisotropy detected at Bafo is caused by a conductivity inhomogeneity. The problem is to decide which of the two curves best represents the electrical conductivity structure under Bafo. Studies made on the behaviour of the MT fields in the presence of two-dimensional inhomogeneities show that for sites on or off a buried conductor, the maximum apparent resistivity curve is more representative (Patrick and Bostick, 1969). As a result, on the conductive side, this curve will tend to overestimate the resistivity. However the maximum curve is more accurate for a one-dimensional interpretation.

As a first step, major data from Bafo were inverted to a resistivity-depth function by applying the Bostick transform (Bostick, 1976; Goldberg and Rotstein, 1982). This method is an inversion technique applied to the observed data which yields a smoothed variation of the resistivity with depth directly. The result of this transformation is presented in Fig. 3d. The major data were also fitted to layered models according to a linearized, least squares inversion modelling scheme (Jupp and Vozoff, 1975). A low resistivity layer is found, whose upper surface is between 4.5 and 6.5 km in depth and which is about 6 km thick. There is a transition to a highly conductive layer at a depth of 48–60 km (Fig. 3d). Although the model gives results which correspond to the field results, there is a high degree of nonuniqueness of the selected model, since we only considered the MT response at a single site.

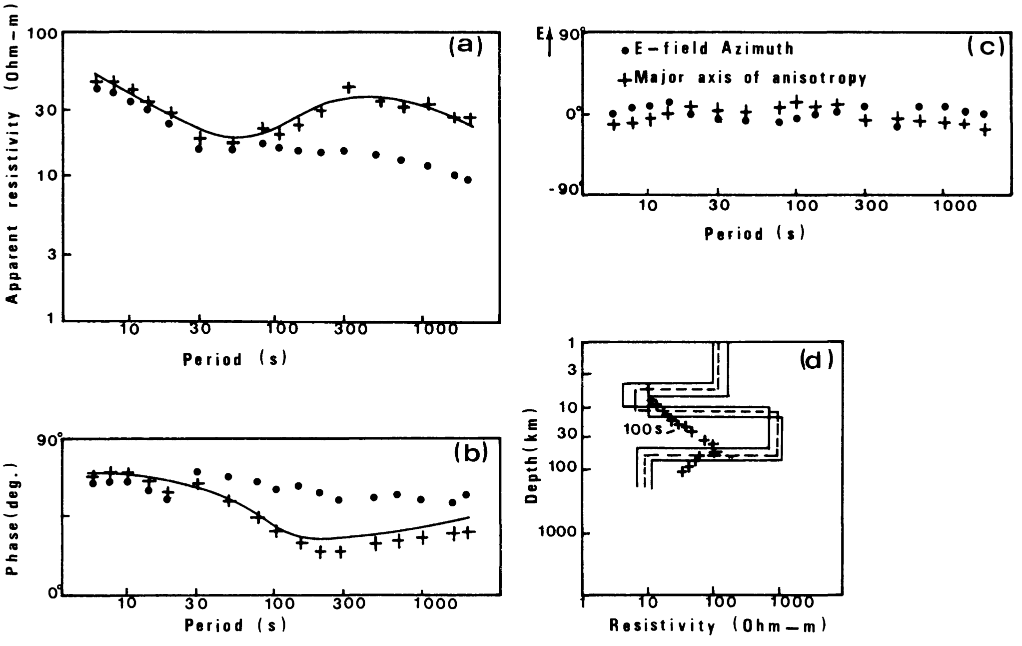

Fig. 3. Rotated major (*crosses*) and minor (*dots*) magnetotelluric responses for Bafo (**a** and **b**). *Solid curves* on the major data represent theoretical curves calculated from 1-D model. **c** The directions of the major axis of the impedance tensor and the angles of polarization of the telluric current. **d** One-dimensional model for Bafo, the *dashed line* represents the best-fitting 4-layer model and the *solid lines* the bounds of acceptable models. A depth-resistivity diagram (Bostick, 1976) is presented, marked by *crosses*

The conductive zone found between 5 and 10 km in the upper crust is rather unexpected. Gravity surveys indicated sediments 3–5 km thick in this area, underlain by a crystalline basement. To a first approximation, it appears that the basement is fractured and if the fractured zone is filled with water, it will form a low resistivity zone.

Discussion

The explanation usually given for the existence of layers of low resitivity in the crust is based on hydration processes, with or without partial melting. A temperature of more than 700° C is needed for partial melting of water-saturated rocks at lower crustal levels (Hyndman and Hyndman, 1968). In the case of hydrated basalts, melting could begin at 800°–900° C; the resistivity is then in the region of 10 ohm-m (Volarovitch and Parkhomenko, 1976; Pham Van Ngoc et al., 1980). Since the conductive zone begins at a depth of about 5 km, a geothermal gradient of approximately 160° C/km would be required if partial melting were responsible for the conductive layer at this depth. Such a temperature gradient should create hot springs, but this does not seem to have been noted in this region. Such high temperature gradients are to be found in rift zones (Iceland: Beblo and Björnsson, 1980; Afar: Berktold et al., 1974; Kenya: Rooney and Hutton, 1977). Unfortunately, in this region no measurement of heat flow has been obtained. The only measurements of heat flow made on the West African craton are those by Chapman and Pollack (1974) in Niger. They found values that were very low, and lower than the continental average (18–22 mWm^{-2}). On the other hand, temperature in the range of 800° C at the level of the conductive zone in the crust may appear exaggerated in a stable shield region. The conductive zone in the crust could then be attributed to the hydration process of Hyndman and Hyndman (1968).

Anomalously high conductivity near the top of the crust can also be connected with the presence of well-conducting minerals, like sulphide and graphite. Such zones have been found in crystalline shields at depths of 5–8 km (Dowling, 1970; Lilley and Tammemagi, 1972; Sternberg and Clay, 1977; Adam et al., 1982). The presence of graphite in rocks leads to a considerable increase in the conductivity which can reach a resistivity of the order of 10 ohm-m (Kotvun, 1976).

It appears, however, that definite conclusions seem to be still premature or largely speculative because of the lack of other geophysical and geological findings in the region. More detailed results may be reached in the future by additional MT soundings.

References

Adam, A., Kaikkonen, P., Hjelt, S.E., Pajunpää, K., Szarka, L., Verö, J., Wallner, A.: Magnetotelluric and audiomagnetotelluric measurements in Finland. Tectonophysics **90**, 77–90, 1982

Beblo, M., Björnsson, A.: Magnetotelluric investigation of the lower crust and upper mantle beneath Iceland. J. Geophys. **45**, 1–16, 1980

Berktold, A., Haak, V., Angenheister, G.: Magnetotelluric measurements in the Afar area. Inter-Union Commission on Geodynamics, Scientific Report n° 14, pp. 67–68, 1974

Bostick, F.X.: A simple and almost exact method of MT analysis. Workshop on electrical methods in geothermal exploration, Snowbird, Utah, 1976

Camfield, P.A., Gough, D.I., Porath, H.: Magnetotelluric array studies in the North-Western United States and South-Western Canada, Geophys. J.R. Astron. Soc. **22**, 201–221, 1971

Chapman, D.S., Pollack, H.N.: "Cold spot" in West Africa: anchoring the African plate. Nature **250**, 477–478, 1974

Dars, R.: Les formations sédimentaires et les dolérites du Soudan occidental (Afrique de l'ouest). Mémoire B.R.G.M. n° 12, 1961

Dowling, F.L.: Magnetotelluric measurements across the Wisconsin Arch. J. Geophys. Res. **75**, 2683–2698, 1970

Goldberg, S., Rotstein, Y.: A simple form of presentation of magnetotelluric data using the Bostick transform. Geophys. Prospecting **30**, 211–216, 1982

Hyndman, R.D., Hyndman, D.W.: Water saturation and high electrical conductivity in the lower continental crust. Earth Planet. Sci. Lett. **4**, 427–432, 1968

Jupp, D.L.B., Vozoff, K.: Stable iterative methods for the inversion of geophysical data. Geophys. J.R. Astron. Soc. **42**, 957–976, 1975

Kovtun, A.A.: Induction studies in stable shield and platform areas. Acta Geodaet., Geophys. Montanist. Acad. Sci. Hung. 333–346, 1976

Kurtz, R.D., Garland, G.D.: Magnetotelluric measurements in Eastern Canada. Geophys. J.R. Astron. Soc. **45**, 321–347, 1976

Lilley, F.W.M., Tammemagi, H.J.: Magnetotelluric and geomagnetic depth sounding method compared. Nature **240**, 184–187, 1972

Patrick, F.W., Bostick, F.X.: Magnetotelluric modelling techniques. Report n° 59, Electronic Research Center, University of Texas, Austin, 1969

Pham Van Ngoc, Boyer, D., Le Mouël, J.L., Courtillot, V.: Propriétés électriques de la croûte et du manteau supérieur du rift d'Asal (Djibouti) d'après les sondages magnétotelluriques profonds. Bull. Soc. Géol. France **5**, 863–871, 1980

Rechenmann, J.: Mesures gravimétriques et magnétiques en Afrique Occidentale. Rapport interne. Centre Géophysique ORSTOM de MBour, 1957

Reichelt, R.: Géologie du Gourma (Boucle du Niger). Mémoire B.R.G.M. n° 53, 1972

Ritz, M.: Etude régionale magnétotellurique des structures de la conductivité électrique sur la bordure occidentale du craton ouest africain en République du Sénégal. Can. J. Earth Sci. **19**, 1408–1416, 1982

Ritz, M.: The distribution of electric conductivity on the eastern border of the West African craton (Republic of Niger). Geophys. J.R. Astron. Soc. **73**, 475–488, 1983

Rooney, D., Hutton, V.R.S.: A magnetotelluric and magnetovariational study of the Gregory Rift Valley, Kenya. Geophys. J.R. Astron. Soc. **51**, 91–119, 1977

Simon, B., Brisset, A., Roussel, J., Sougy, J.: Confrontation de la télédétection (analyse numérique et analogique, téléinterprétation à petite échelle) avec la cartographie géologique classique et les données gravimétriques du Mali sud occidental (Afrique de l'ouest). Bull. Soc. Géol. France **1**, 13–22, 1982

Sternberg, B.K., Clay, C.S.: Flambeau anomaly: a high conductivity anomaly in the southern extension of the Canadian shield. In: The Earth's crust, Geophys. Monograph Series, AGU, 20, pp 501–530, 1977

Tammemagi, H.Y., Lilley, F.E.M.: A magnetotelluric traverse in Southern Australia. Geophys. J.R. Astron. Soc. **31**, 533–545, 1973

Van Zijl, J.S.V.: Electrical studies of the deep crust in various tectonic provinces of Southern Africa. In: The Earth's crust, Geophys. Monograph Series, AGU, 20, pp 470–500, 1977

Volarovitch, M.P., Parkhomenko, E.I.: Electrical properties of rocks at high temperatures and pressures. In: Geoelectric and geothermal studies, Adam ed: pp 319–369, KAPG Geophys. Monogr. 1976

Vozoff, K.: The magnetotelluric method in the exploration of sedimentary basins. Geophysics **37**, 98–141, 1972

Received December 1, 1983; Revised May 2, 1984
Accepted June 15, 1984