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STRUCTURES OF THE WEST AFRICAN CRATON MARGIN ACROSS SOUTHERN MAURITANIA INFERRED FROM A 450-KM GEOELECTRICAL PROFILE

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Abstract. Magnetotelluric (MT) measurements were carried out at 20 sites, extending 450 km across southern Mauritania in order to study lithospheric structures related to the West African craton (WAC) margin. The MT profile starts to the west on the Senegal-Mauritania basin (S-M basin), traverses across the Mauritanides orogenic belt, and terminates on the western border of the WAC (Taoudeni basin). Distortion effects due to local shallow inhomogeneities are present in nearly all of the basin data. In such a situation, the preliminary interpretation of the data was done by using 1D inversions based upon rotationally invariant parameters. Such distortion is not apparent for the belt and craton sites, and 1D inversions were followed by 2D modeling. The models produced reveal a clear crustal subdivision into a resistive upper crust underlain by a two-layer lower crust with two conductors, one at mid-crustal depths (supposed fluid-produced) beneath the S-M basin and the second at the base of the crust beneath the WAC. The 14-km-thick conductive material below the Mauritanides belt is interpreted as large imbricated thrusts representing the deep roots of the Mauritanides nappes. The models also show that significant contrasts in resistivity extend deep in the lithosphere between the cratonic area and the Senegal microplate.

Introduction

Geological (Lécorché et al. 1983; Dia 1984) and geophysical (Briden et al. 1981; Roussel et al. 1984; Ritz and Robineau 1988) observations in Senegal and Mauritania suggested that the western margin of the WAC originated from the accretion of the Senegal microplate against the craton, during a Panafrican suture of a reduced oceanic domain by subduction and continental collision in the Mauritanides belt. Nevertheless, in eastern Senegal (Ritz and Robineau 1986) the Bissau-Kidira Lineament (BKL in Figure 1) modified in a determining way the deep morphology and structure of the belt and probably obliterated the structures observed further north in Mauritania, in the place of the present study (Figure 1), where the oceanization was more important (Dia 1984). In order to obtain a more accurate model of the Mauritanides tectonic zone, and also of the microplate structures beneath the Mesozoic-Cainozoic sediments, MT data were recorded at 20 sites along a 450-km traverse across southern Mauritania (Figure 1). We present here some of the data and preliminary results of 1D and 2D modeling obtained along the traverse.

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Data Analysis and Results

At each site, MT data in the period range 10-10,000 s were analyzed to estimate tensor apparent resistivity values and phases (Vozoff 1972) along 2 principal directions corresponding to the electrical strike of the WA margin (TE mode) and its perpendicular (TM mode). At all sites the resulting MT responses were found to be anisotropic (Figure 2) with skew (Swift 1967) less than 0.3, and we believe that 3D effects from regional structure are small. However, certain of the sites exhibit effects in the apparent resistivity curves which might be described as anomalous. The data for sites 3-10 of the S-M basin show a very pronounced parallel split between the TE and TM amplitude curves. Although it is not apparent from the skew values, one possibility is that this bilateral splitting may be associated with a local near-surface 2D or 3D feature (Ranganayaki 1984). Such distortion (static shift) is seen only on the resistivity data, and the phase data are unaffected. Site 8 (Figure 2) is typical of this bilateral splitting and indicates that a variable amount of static shift is present. Unfortunately, without complete knowledge of the characteristic signs of the heterogeneity or constraints provided by boreholes or other geophysical data, it is difficult to determine the extent of the bilateral displacement of the amplitude curves. It is worthy of note, however, that static shift effects are not apparent from data at sites 1 and 2.

Without the availability of additional constraints, an attempt partly to overcome the problem of local shallow inhomogeneities and avoid the possible erroneous interpretation of MT data is the use of the MT impedance tensor determinant (Ingham 1988; Jones et al. 1988). Examples of apparent resistivities and phases calculated from the determinant of the impedance tensor are shown in Figure 3. Site 2 lies within the deep basin whereas site 8 lies outside. These are several features of interest in these results. For example, the phases at stations within the deep basin, represented here by site 2, are below 45°, whereas the phases outside the deep basin, represented here by site 8, are above 45°. Large phase contrasts associated with sites 2 and 8 indicate the existence of a significant structural change, extending to mid-crustal depths between the two groups of stations of the basin.

Typical MT responses for the other sites on the east, i.e. the Mauritanides belt and the WAC, are shown in Figure 2. Although MT data are anisotropic at these sites, this depends on the range of periods and varies from one zone to the other along the traverse. The most obvious

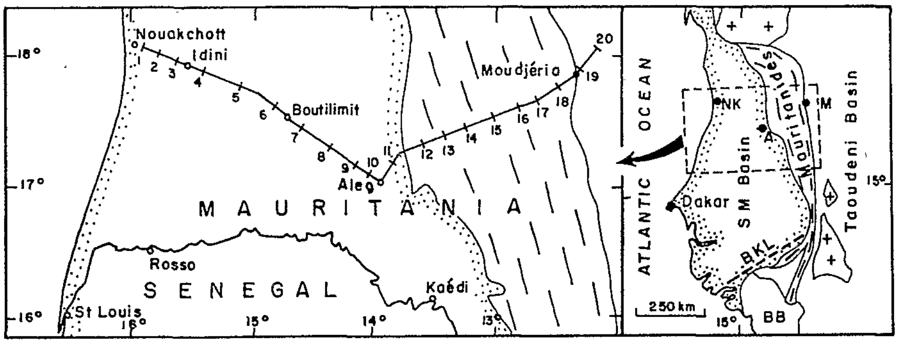

Fig. 1. Main geological units of the West African Craton (WAC) margin with location of magnetotelluric (MT) traverse in Mauritania. 10, MT site number; crosses, WAC; BKL, Bissau-Kidira Lineament; BB, Bove Basin; NK, Nouakchott; A, Aleg; M, Moudjéria.

feature of the data is the large difference in amplitude of the apparent resistivities between stations inside the belt and stations outside the belt (Figure 2). The major resistivity axes are approximately parallel to the NNW-SSE regional geological tectonics trend for the craton sites (sites 17-20), while at Mauritanides sites (sites 11-16) the major axes are nearly perpendicular to the regional trend. At all these sites the behaviour of the MT curves show that distortion effects are not significant. A 2D model could be constructed to fit the data from all of these soundings accurately.

Preliminary Interpretation

Because MT responses are contaminated by the presence of local near-surface inhomogeneities in nearly all of the basin sites, we have concentrated our interpretation on the impedance tensor determinant parameters which may be modeled one-dimensionally according to the procedure of Jupp and Vozoff (1975). Some examples of data fitting and corresponding models are shown in Figures 3 and 4. Models of sites 3-10 are nearly identical and they differ from the models of sites 1 and 2 by the existence of a highly anomalous crustal structure involving a conductive zone of resistivity 10-30 ohm-m at depths that range from 13 km at sites 3 and 4 to 17 km in the eastern part of the basin (sites 8, 9, and 10). Without this intermediate low-resistivity layer at mid-crustal depths, the data cannot be fitted satisfactorily. All of these models contain upper mantle with a resistivity of about 2000 ohm-m succeeded by a drop in resistivity to 50 ohm-m at about 100 km.

A 2D forward modeling program (Wannamaker et al. 1987) was used to model data from sites 11-20 for a line across the belt and its foreland oriented perpendicular to the electrical strike. A 2D section derived from 1D models for each site which fitted the impedance tensor determinant parameters can then be used as the starting 2D model. The 2D modeling procedure and full results will be discussed in a later paper. Figure 4 shows a 2D resistivity model of possible lithospheric structure through the belt and its foreland for east end of traverse of Figure 1. Examples of the fit of the model results to the data of the TE and TM responses at two sites, 15 and 19, are presented in Figure 2. Although we tested many 2D models to determine the sensitivities of the MT responses to the placement of lateral boundaries and to resistivity changes, no simple, unique interpretation has emerged, and it is very difficult to assess the accuracy of the 2D model presented here. However, gravity profile (Lécorché et al. 1983), running close to the MT line for this region of the Mauritanides, has suggested that the base of the crust lies at 22-

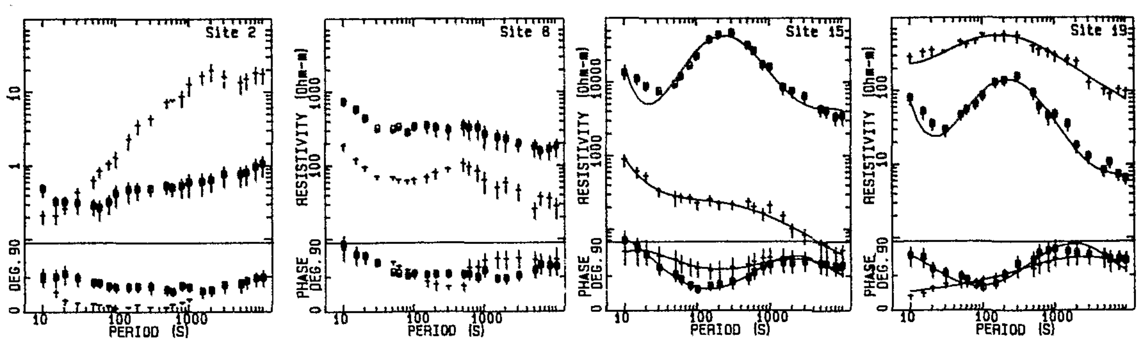

Fig. 2. Magnetotelluric responses from typical sites on the margin of the West African craton. Stations 2 and 8 on the S-M basin. Station 15 inside the Mauritanides belt. Station 19 inside the Taoudeni basin. The tensor resistivity and phases for the TM and TE directions are shown by the dots and crosses, respectively. Uncertainty bars correspond to two standard deviations. Solid and dashed lines through the observed data correspond respectively to the TM and TE directions for the 2D model given in Figure 4.

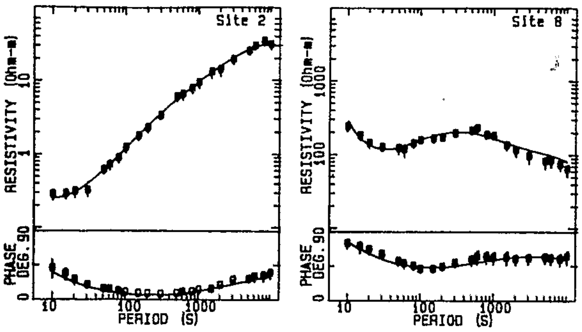

Fig. 3. Apparent resistivities and phases of the determinant of the MT impedance tensor from typical stations on the S-M basin and the corresponding fit for the 1D models of Figure 4. Observed data are shown by the dots and curve is model response.

37 km depth which corresponds well with a boundary in the resistivity model (Figure 4). The electrical model could be compatible with the gravity results.

Discussion of Results and Conclusions

Several outstanding features are observed on the resulting 1D and 2D models (Figure 4), in particular the existence of low-resistivity layers in the crust and uppermost mantle. West of site 3, the sedimentary cover is characterized by a 3 ohm-m material which thickens rapidly seawards. This rather low resistivity reflects the presence of sea-water-invaded rocks. Surface layers are thinner and more resistive eastwards. Sediments are underlain by a resistive layer (1000 ohm-m) found at a depth of about 3600 m under site 1. The uppermost zones extending from site 20 to site 12 varie in resistivity from 80 to 10,000 ohm-m in a dramatic manner. The lower resistivities to the east represent the folded sedimentary cover of the craton (Taoudeni basin) and the more resistive materials to the west correspond to the lithostructural units of the Mauritanides belt. These are underlain by a highly resistive layer (30,000 ohm-m) which may represent a deshydrated (?Archean) metamorphic and granitic basement.

The 1D and 2D models (Figure 4) indicate a three-layer electrical resistivity structure of the crust beneath the WAC margin. There is, however, a significant change in the character of the resistivity profile from west to east. A thin highly conductive layer is shown to exist beneath a large part of the basin with its upper boundary at varying depths, 13-17 km, dipping slightly to the east. This 2-5 km thick mid-crustal conductor (MCC) has resistivities in the 10-30 ohm-m range, in contrast to 1000-2000 ohm-m values in the crust. It appears to end near the Mauritanides belt from where our 2-D model indicates eastwards a highly resistive upper crust typical for cratonic zones (Van Zijl 1977), underlain by a less resistive lower crust (5000 ohm-m). Such MCC are sometimes associated with seismic reflectors (Gough 1986). However, the major feature across the belt and its foreland is the existence of a 15-80 ohm-m material at lower crustal depths. There is an abrupt truncation of the lower crustal conductor (LCC) below the axial part of the belt with a vertical offset of about 10 km between sites 13 and 15. The base of this conductive layer is presumed to be the Moho, via gravity determination (Lécorché et al. 1983). Its westward continuation is questionable because of the obscuring effect of the MCC beneath the S-M basin. Strong arguments exist for relating such

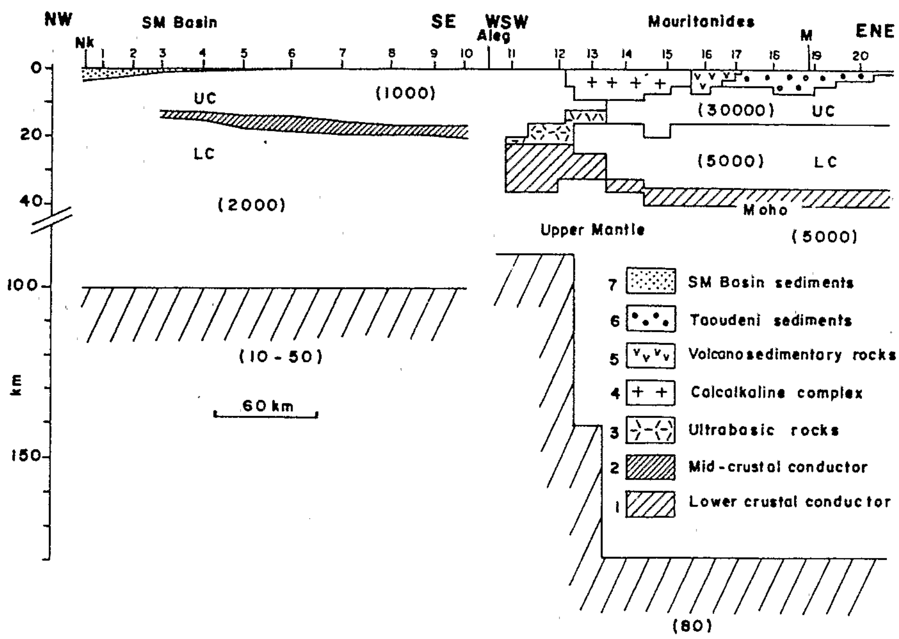

Fig. 4. Two-dimensional geoelectrical model of possible lithospheric structure in southern Mauritania. The 2D model was designed to fit only sites 11-20 and was connected to a simplified 2D section, created from a collation of 1D models based on impedance tensor determinant parameters for the rest of the sites in this presentation. Numbers with brackets give layer resistivity in ohm-m; 1, 15-80 ohm-m; 2, 10-30 ohm-m; 3, 3000 ohm-m; 4, 5000-10,000 ohm-m; 5, 300 ohm-m; 6, 80 ohm-m; 7, 3-30 ohm-m. UC, Upper Crust; LC, Lower Crust; NK, Nouakchott; M, Moudjéria.

conducting zones to the presence of fluids (Shankland and Ander 1983; Kurtz et al. 1986). In this perspective, the mechanism responsible for the MCC could be free water, released by dehydration processes, trapped in interconnected rock pores and fractures, and retained by an impermeable layer above. The base of the crust also contains free water, but in presumed isolated pockets (Jones 1987), hence the resistivity of the LCC is slightly higher.

The repeated orogenesis along the Mauritanides resulted in major changes in the lower crustal environment as evidenced by MT data. First, a moderately resistive (3000 ohm-m) wedge at depths of 14-20 km under sites 11-13 separates two crustal blocks with distinctive electrical properties, the eastern one having a MCC. Dipping west, this wedge approximately correlates with the dense body of a gravity model (Lécorché et al. 1983), interpreted as basic or ultrabasic rocks (Mauritanides gravity high). However, this body is not particularly well resolved because the continuity in resistivity eastwards is obscured by the highly resistive upper crustal rocks. Second, westward rooted thrust zones (Dia 1984) may have provided high-permeability conduits for the concentration of metamorphic fluids (Kerrich et al. 1984) in mylonitic sheared rocks and partially explain the large variations in the thickness and depth to the LCC. Thus where the LCC is depressed, as at sites 14-17, water and other pore fluids are not as extensive as they are at western sites. Third, the orogenic crust clearly thickens eastwards, correlating with the Mauritanides gravity low (Roussel et al. 1984). A major difference in electrical resistivity structure exists beneath the western part of the belt extending deep in the lithosphere. It separates two plates of different electrical properties: the Senegal microplate and the WAC.

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References

Briden, J.C., D.N. Whitcombe, G.W. Stuart, J.D. Fairhead, C. Dorbath, and L. Dorbath, Depth of geological contrast across the West African craton, Nature, 292, 123-128, 1981.

Dia, O., La chaîne panafricaine et hercynienne des Mauritanides face au bassin protérozoïque supérieur à Dévonien de Taoudéni dans le secteur clef de Mejéria (Taganet, sud R.I.M.). Lithostratigraphie et tectonique. Un exemple de tectonoque tangentielle superposée, thèse, 552 pp., Marseille, France, 1984.

Gough, D.I., Seismic reflectors, conductivity, water and stress in the continental crust, Nature, 323, 143-144, 1986.

Ingham, M.R., The use of invariant impedances in magnetotelluric interpretation, Geophys. J., 92, 165-169, 1988.

Jones, A.G., MT and reflection: an essential combination, Geophys. J.R. Astron. Soc., 89, 7-18, 1987.

Jones, A.G., R.D. Kurtz, D.W. Oldenburg, D.E. Boerner, and R. Ellis, Magnetotelluric observations along the Lithoprobe southeastern Canadian Cordilleran transect, Geophys. Res. Lett., 15, 677-680, 1988.

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

Kerrich, R., T.E. La Tour, and L. Willmore, Fluid participation in deep fault zones: evidence from geological, geochemical, and $^{18}O/^{16}O$ relations, J. Geophys. Res., 89, 4331-4343, 1984.

Kurtz, R.D., J.M. DeLaurier, and J.C. Gupta, A magnetotelluric sounding across Vancouver Island detects the subducting Juan de Fuca plate, Nature, 321, 596-599, 1986.

Lécorché, J.P., J. Roussel, J. Sougy, and Z. Guêtat, An interpretation of the geology of the Mauritanides orogenic belt (West Africa) in the light of geophysical data, Geol. Soc. Am. Mem., 158, 131-147, 1983.

Ranganayaki, R.P., An interpretation analysis of magnetotelluric data, Geophysics, 49, 1730-1748, 1984.

Ritz, M. and B. Robineau, Crustal and upper mantle electrical conductivity structures in West Africa: geodynamic implications, Tectonophysics, 124, 115-132, 1986.

Ritz, M. and B. Robineau, Tectonic interpretation of electrical structures beneath the West African craton edge in eastern Senegal, Am. J. Sci., 288, 756-776, 1988.

Roussel, J., J.P. Lecorché, J.F. Ponsard, J. Sougy, and M. Villeneuve, Panafrican to Hercynian deformations in the Mauritanides and tectonic significance of gravity anomaly, Tectonophysics, 109, 41-47, 1984.

Shankland, T.J. and M.E. Ander, Electrical conductivity, temperatures, and fluids in the lower crust, J. Geophys. Res., 88, 9475-9484, 1983.

Swift, C.M.A., A magnetotelluric investigation of an electrical conductivity anomaly in the southwestern United States, Ph.D. thesis, 211 pp., Mass. Inst. of Technol., Cambridge, 1967.

Van Zijl, J.S.V., Electrical studies of the deep crust in various tectonic provinces of southern Africa, in The Earth's Crust, Geophys. Monogr. Ser., vol. 20, edited by J.G. Heacock, pp. 470-500, AGU, Washington D.C., 1977.

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

Wannamaker, P.E., J.A. Stodt, and L. Rijo, A stable finite element solution for two-dimensional magnetotelluric modelling, Geophys. J.R. Astron. Soc., 88, 277-296, 1987.

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