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Structure of the southern Senegalo–Mauritanian basin, West Africa, from geoelectrical studies

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Abstract

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The southern part of the Senegalo–Mauritanian basin is geologically featureless, and little is known about the division of the sedimentary sequence and regional geological structure because of the scarcity of deep drillholes. A magnetotelluric survey was, therefore, carried out in an attempt to obtain details concerning the electrical characteristics, thickness and structure of the Mesozoic–Cainozoic Senegalo–Mauritanian basin. From the surface down, the interpretation of magnetotelluric data shows several distinct electrical boundaries. The general trend shows a decrease in near-surface resistivity from east to west. The basin is characterized by water-saturated, unconsolidated, low-resistivity sediments, with a westward-sloping monoclinal style.

The combination of borehole and geological data with a geoelectrical cross-section provides a simplified model of the geological–electrical units of the basin. This shows the distribution of strata above and below the base of the Senonian. Conductive material (10–30 ohm m) at depth in the central part of the profile may represent a northern extension of the Palaeozoic sediments of the Bove sequence, which lies immediately south of the magnetotelluric line. Significant electrical contrasts between the sediments and basement rocks allow mapping of the top of the high-resistivity basement, which is characterized by progressively deeper burial to the west.

Introduction

The Senegalo–Mauritanian (S–M) coastal basin in western Africa is poorly known from its surface geology and little has been inferred about the structure from oil exploration studies. However, the major structural elements could be defined using geophysical data with geological constraints. Magnetotelluric (MT) techniques (Vozoff, 1972) were, therefore, employed in the southern part of the S–M basin in an attempt to identify the principal structural features. Data were recorded at nine sites on a traverse perpendicular to the S–M basin (Fig. 1). From MT measurements in this area a resistivity distribution was obtained using two-dimensional (2-D) model calculations for the sediments (Ritz and Vassal, 1986). The aims of this paper are firstly to establish the electrical characteristics of the major units, and subsequently to translate the resistivity structure into geological terms with the aid of borehole data.

The MT section cuts across the Casamance region of the S–M basin in an approximately E–W direction, from the western flank of the Mauritanides orogenic belt to the coastal plain near the Atlantic (Fig. 1). The Casamance region is bordered on the south by the Palaeozoic Bove basin. The Palaeozoic cover reaches a thickness of about 2000 m in the central Bove region in Guinea (Ponsard, 1984; Villeneuve, 1984). To the east, the area consists of thin sediments of Mesozoic and

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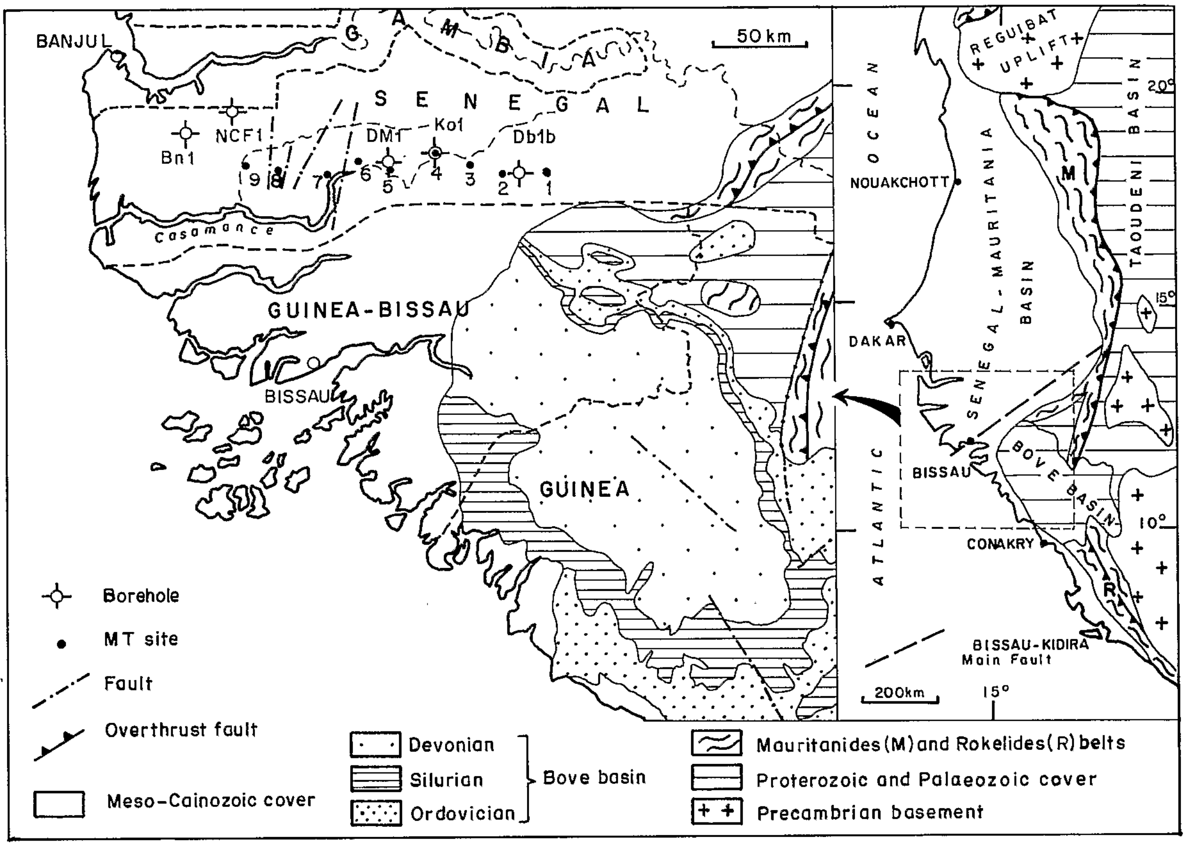

Fig. 1. Geological map of the S–M basin (after Villeneuve, 1984), and MT site locations. Also shown are well locations in survey area.

Cainozoic age overlapping much older sedimentary and metamorphic rocks of Palaeozoic and Precambrian age. In addition, sediments of the Palaeozoic Bove sequence exist in this region (Bellion and Guiraud, 1984) overlying the metamorphic/granitic basement. Moreover, this section is composed mainly of sandstones interbedded with schists. To the west, the post-Palaeozoic sedimentary blanket rapidly thickens seawards and rests upon basement rocks of variable composition. However, the western extension of the basement under the sediment basin is only known within a certain depth range because of the limitations of the geophysical methods used previously in this region. The resistant basement is easily visible to the east (Mathiez and Huot, 1966), but disappeared in the west from a zone between 15° and 15°30′W. West of longitude 16°W, boreholes have reached the lower Cretaceous at about 3000 m, and in the coastal plain near the Atlantic, the post-Palaeozoic cover is likely to reach a thickness of 8000 m or more (Castelain, 1965; De Spengler et al., 1966; Bellion and Guiraud, 1984). This value agrees with recent data from thermal subsidence curves (Latil-Brun and Flicoteaux, 1986). Drilling indicates that the Tertiary and Cretaceous sediments are generally poorly consolidated and porous. Composition is dominantly coarse sandstones, but some clays and carbonate rocks are also encountered. The structure within the Mesozoic–Cainozoic sediments has a dominantly northerly trend, and the main structural trends are southeasterly in the Palaeozoic Bove basin.

Magnetic and gravity interpretations have indicated that the basement and sedimentary cover have been intruded by numerous mafic intrusions (Roussel and Liger, 1983). An E–W-trending positive gravity anomaly centred over Gambia and Casamance is explained by extensive dense intrusives within a thinned crust and may be related to a rift associated with the initial rupture of the Atlantic (Burke, 1976). The structure of the sedimentary units in the survey region is characterized by N–S-trending linear faults due to basement block-faulting or basement flexure (Roussel and Liger, 1983; Bellion and Guiraud, 1984).

Magnetotelluric cross-section

In Fig. 2, a MT cross-section along the traverse across the Casamance region is presented. Three outstanding features are seen in the profile: (1) the sedimentary blanket dips to the west and the depth of the MT basement lies between about 250 m and 5000 m; (2) west of site 6, thick sediments are present, showing a region of extremely good conductivity (east of this site there is an increase in the resistivity with a strong gradient); and (3) the resistivity of the basement is about 100 to 1000 times higher than that of the layer above.

The bulk resistivity of rocks depends on several parameters. For the near-surface rocks, Keller (1971) indicated that the most important factors controlling bulk resistivity are degree of fluid saturation, conductivity of the saturating fluid, and porosity. The interdependence of these different factors, associated with the increase in temperature with depth, indicates that great care is required in any geological interpretation of resistivity structures. However, in completely saturated sediments, variation in the conductivity of the fluid itself becomes the main source of resistivity variation. Results from previous surface and drill-hole studies were used to guide the geological interpretation.

Correlation of resistivity structure with geology

The complexity of the structure in the Casamance region is indicated by significant lateral changes in resistivity, and large uniform layers appear to be rare (Fig. 2). There is a significant change in the character of the resistivity profile from east to west. For example, there is no indication west of site 6 for a layer at depth with values exceeding 10 ohm m. Nevertheless, some continuity can be detected west of site 6, with a highly conductive zone in the resistivity range 0.6–3 ohm m occurring at depths of 1500–4500 m. The resistivity cross-section of Fig. 2 depicts four important layers in the electrical stratigraphy, with a general decrease of resistivity from east to west.

On the basis of borehole data, the uppermost zone corresponds to the post-Turonian formations (i.e. from the basal Senonian base to the present). The resistivity of these formations is low, especially in the western part of the basin. From site 1 to site 6 on the east portion of the profile, the uppermost zone has an electrical resistivity of about 50 ohm m and a thickness of 250–500 m. In this area the water table, which is taken to mark the upper boundary of the saturated zone, generally occurs at depths of less 30 m, and the 50 ohm m material reflects, at least in part, the fully

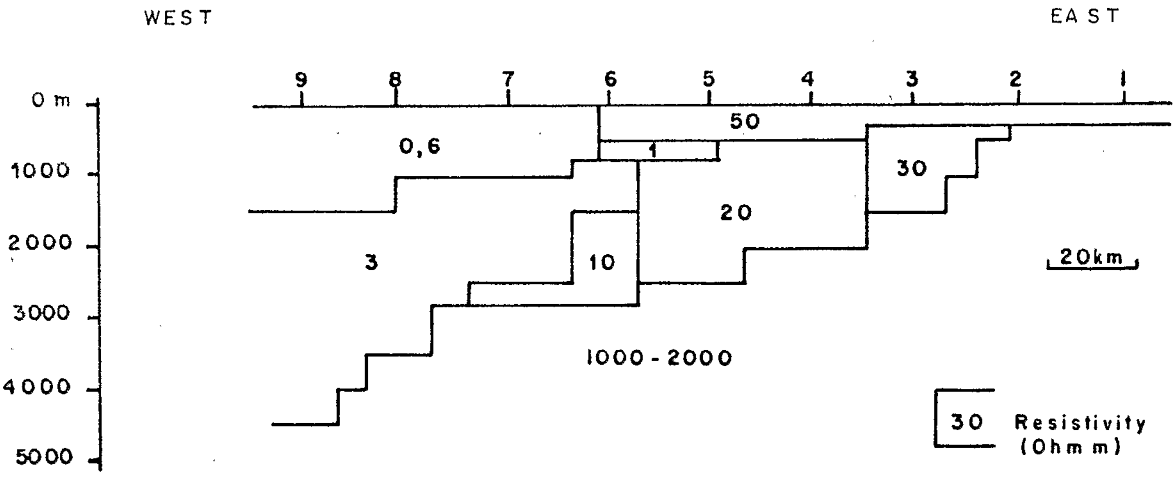

Fig. 2. Geoelectrical cross-section across the southern part of the S–M basin, constructed from MT soundings (after Ritz and Vassal, 1986).

water-saturated state of the sediments. This zone is bordered by a zone of very low resistivity (below 1 ohm m) west of site 6. Saline ground water may cause lower resistivity than expected. The Casamance river (close to the MT line) is saline up to 125–150 km inland (Pages and Debenay, 1986). Owing to high permeability, sea water infiltrates through the western part of the survey area, lowering regional resistivity from the expected 50 ohm m to about 0.6 ohm m. The conductive zone of less than 1 ohm m can be explained by the high electrolyte content of the pore water. An alternative explanation for the very low resistivity of the post-Senonian detected on the west end of the traverse involves a sufficient high porosity of the rock material. The sedimentary sections found in wells in the region (Nord Casamance F1: NC F1, Balantine 1: Bn 1) suggested that the porous section is no more than 1800–2000 m thick. Thus, the depth to the base of porosity nearly corresponds to the base of the assumed post-Senonian formations at site 9. The change in character of the resistivity profile from east to west could then be attributed to variations in salinity or porosity of associated aquifers.

The underlying unit is a low-resistivity one which is correlatable from site 6 to site 9. This unit represents the Mesozoic sediments of the pre-Senonian S–M basin sequence. The resistivity of this sequence increases toward the west from 1 to 3 ohm m. This layer thins from a thickness of some 3 km at site 9 to 700 m just a few kilometers to the east at site 6, and wedges out completely near site 5. This change of thickness is in accord with drilling and geological information. At Diana Malari 1 (DM 1), near site 5, the depth to the freshwater–saltwater interface is only 520 m, the transition is typically abrupt and is marked by a correspondingly abrupt decrease in resistivity. The 1 ohm m material probably represents an intensely altered, porous and saline water-saturated zone extending for a limited distance west of site 5. The 3 ohm m material can be correlated with lower Cretaceous sandstones, which have a substantial clay content that significantly reduces the effective resistivity of the sequence. Boreholes in this region are rare but the Bn 1 well (4106 m) west of site 9 provides evidence for low resistivities, where conductive pre-Senonian sandstones and clays with resistivities as low as 2–4 ohm m were encountered at a depth of about 1800 m.

An important discovery is the relatively conductive layer extending from site 2 to site 7 with resistivity varying progressively from about 30 to 10 ohm m from east to west. Below the surface materials, the thickness of this layer increases from site 2 to site 5, where it reaches a maximum value of about 1700 m. Between sites 6 and 7, there is a marked decrease in thickness of this resistivity unit, and it is in direct contact with conductive sediments of the pre-Senonian S–M basin sequence. The 10–30 ohm m material is regarded as a northern extension of Palaeozoic sediments of the Bove basin. The unit's assumed sedimentary character is based upon borehole information from the Kolda 1 (Ko 1) and Diana Malari 1 (DM 1) wells, which bottomed in sandstones of Palaeozoic age. In particular, the DM 1 well, sited near site 5, intersected approximately 700 m of Bove basin sediments saturated with saline water. In the DM 1 well, the Palaeozoic sequence consists of very fractured hard sandstones (580 m) and black shales (40 m) of Ordovician–Silurian age, and Devonian unfractured sandstones (47 m). Note that the presence of such a layer was not indicated east of site 2 in the Dabo 1 bis (Db 1 bis) well, where altered schists are encountered at a depth of 230 m, and which extends to the bottom of the well at about 253 m. These schists were interpreted as metamorphic basement. The 10–30 ohm m zone at depth below the Mesozoic–Cainozoic S–M basin is suggestive of the existence of a fractured zone with high water content, and lateral changes in resistivity between sites 2 and 7 must then arise from difference in degree of fracture, degree of water content, and/or degree of salinity of the water.

Next in the geoelectrical section is a high-resistivity layer (1000–2000 ohm m) which can be followed across the entire profile. The fact that its resistivity is much greater than the overlying layers, and that the depth to its top (in the west) is considerable, both make it possible that these are basement or near-basement formations. Jurassic deposits, mainly limestones with high resistivities, have been encountered in boreholes in the S–M basin, but they are only known west of 16°30′W, and Triassic sediments have not been reported in the onshore coastal basin. The high-resistivity layer (> 1000 ohm m) that was detected on all the soundings is believed to represent the metamorphic/granitic basement. From east to west, the top of the assumed basement slopes abruptly below the Palaeozoic Bove basin. The depth to basement increases gradually at first, but then rapidly, to reach a maximum depth of 4500 m into the Mesozoic–Cainozoic S–M basin.

Discussion

From the geoelectrical cross-section, the major structural zones of the southern part of the S–M basin can be accurately outlined. In particular, the location and morphology of the Palaeozoic section in the deeper parts of the basin are now known. It was possible to map the top of the conducting Palaeozoic beds and the top of the high-resistivity basement. The main features of the interpretive cross-section (Fig. 2) are in agreement with borehole data as well as with geological conceptions; namely, low resistivities in the post-Senonian, northward extension of Bove basin rocks, and the depth of the basement.

By combining this information and the limited well data with regional geological data, a geological model of the southern part of the S–M basin has been developed (Fig. 3). This shows that the S–M basin is a westward-sloping, open homocline in which the structure is controlled by basement flexures and faults with a more or less staircase profile. The sedimentary section is composed mainly of sandstones and siltstones, which are more argillaceous westwards, with minor intercalations of limestones and clay beds. The lithological units thicken rapidly westwards, much of this occurring across the N–NE-trending faults that characteristically control the major regional patterns of southern Senegal (Fig. 1). The main formations of the basin do not appear to change lithologically across the fault zones, and it is suggested that the floor of the basin was transected by N–NE-trending fractures, which allowed differential subsidence during Cretaceous time. It is evident from the model that subsidence did not affect the basin uniformly, and the zone of abrupt change of thickness (between sites 5 and 6) is

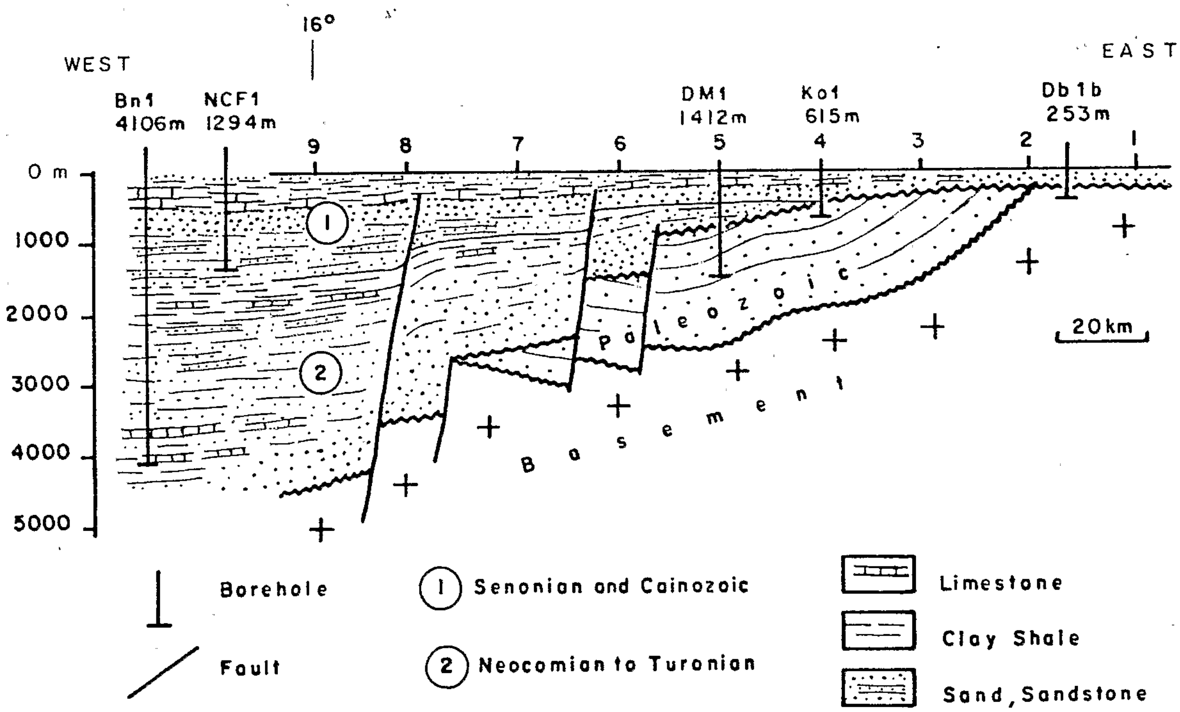

Fig. 3. Interpretative geological model through the southern part of the S–M basin along the MT line.

thought have been a hinge zone separating stable basement to the east from a rapidly subsiding crustal segment to the west.

Sediments of the Palaeozoic Bove basin sequence appear progressively westwards beneath the Mesozoic–Cainozoic S–M basin sequence. The broad geological structure of the Bove basin in this region appears to be controlled by the Bissau–Kidira Pan-African and Hercynian fault zone (Ponsard, 1984; Ritz and Robineau, 1986), thus defining a syncline which is the collapsed prolongation of the structure known in Guinea (Fig. 1). The axial area (between sites 5 and 6) is clearly defined on Figs. 2 and 3. Beyond the assumed hinge zone, an important feature is the gradual westward thinning of the deep-lying Palaeozoic unit which is intersected by vertical faults. This suggests that this zone represents the southwest flank of the Bove syncline. The westward decrease in resistivity of the assumed Palaeozoic unit (Fig. 2) is furthermore suggestive of an enhanced degree of fracture towards the basin margin. This unit apparently no longer exists (or is very thin) beneath the western flank of the MT traverse. It is believed that this region represents the extreme westward extension of the Bove basin. To the west, the S–M basin is characterized by a series of down-dropped basement blocks bounded by faults which cause abrupt breaks in the basement surface.

The geological model constructed from the geoelectrical cross-section, although a simple representation of a complex structure, has provided not only a better understanding of the general geometry of the southern part of the S–M basin but has also led to the discovery of local structures in the sedimentary sequence and in relief of the basement top.

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