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LABORATORY MEASUREMENT OF THE ELECTRICAL RESISTIVITY OF SOME NIGERIAN CRYSTALLINE BASEMENT COMPLEX ROCKS

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ABSTRACT:- *The electrical resistivity of fresh Pre-Cambrian to Upper Cambrian crystalline basement rocks in southwestern Nigeria, hitherto inferred from sounding interpretation, has been determined from laboratory measurements. The rock types consist of granite gneiss, banded gneiss, augen gneiss, biotite granite, charnockite, granodiorite, amphibolite and quartzite. The samples were cut into uniformly thick slices and four non-polarisable silver-silver chloride electrodes set up at the boundary of each specimen. The geometry of the electrode array could take any arbitrary configurations. Electrical contact with the sample is made by injecting the filter tip of the electrode with 0.1 molar KCl solution. The potentials and currents corresponding to the four cyclic permutations on the rock were measured for the five boundary arrays. The specific resistivity of each sample was determined using the Van der Pauw equation. One hundred and two rock samples were considered in the experiment. The resistivities are generally very high, ranging from 1010 to 2.8 * 10^6 ohm-m. The granite gneisses have the lowest resistivities (1.01 * 10^3 to 7.76 * 10^3 ohm-m); they are followed by banded gneiss (2.43 * 10^3 to 6.29 * 10^3 ohm-m); augen gneiss (4.32 * 10^3 to 1.43 * 10^4 ohm-m); biotite granite (8.0 * 10^3 to 6.2 * 10^4 ohm-m); charnockite (2.1 * 10^4 to 1.75 * 10^5 ohm-m); granodiorite (4.0 * 10^4 to 1.1 * 10^5 ohm-m); amphibolite (9.1 * 10^4 to 3.73 * 10^5 ohm-m); and quartzite (5.06 * 10^4 to 2.82 * 10^6 ohm-m). There is a considerable overlap in the resistivity of the various rock types. Moreover, even for different samples from the same rock exposure there may be a wide range of resistivities; these may be attributed to differences in the mineralogical composition. In general, there is a tendency for rocks which are not readily susceptible to chemical weathering (e.g. quartzite) to have high resistivities; conversely, gneisses which are more easily weathered, are characterized by relatively low electrical resistivities.*

INTRODUCTION

The main difficulty in the direct measurement of the electrical resistivity of crystalline basement rocks is in making good electrical contact with the rock outcrop. For this reason, the resistivity is conventionally inferred from the interpretation of sounding data where invariably the bedrock is overlain by regolith, with the attendant loss of resolution due to suppression. The resistivity of the substratum so determined can hardly be precise, especially when the geoelectrical unit directly overlying it has a very low resistivity. In many cases, a somewhat ambiguous and ill-defined „infinite“ resistivity is then assigned to the bedrock (Verma et al., 1980; Beeson and Jones, 1988; Olayinka, 1990; Olorunfemi et al., 1991; Hazell et al., 1992). An alternative approach is to measure the resistivity of the rock in the laboratory.

In the present work, the electrical resistivity of some Pre-Cambrian to Upper Cambrian crystalline basement rock units from southwestern Nigeria, has been measured in the laboratory. The relevant theory is due to Van der Pauw (1958) who derived an analytic expression for the specific electrical resistivity of a material bounded by a simply connected arbitrary shaped closed curve containing no singularities. The expression is in terms of currents and potential differences measured at the boundary of the curve. Four electrodes are used and the rock specimens do not have to take any regular shape, although a uniform thickness must be ensured. Electrical contact is made with the sample by injecting the filter tip of the electrode with 0.1 molar potassium chloride solution.

The resistivity of 102 rock samples comprising quartzites, gneisses, charnockite, amphibolite, biotite granite and granodiorite from 5 locations in southwestern Nigeria, was measured. The results show that, in general, the basement rocks have very high resistivities, ranging from 1.01 * 10^3 to 2.82 * 10^6 ohm-m. The gneisses have the lowest resistivities; followed by banded gneiss; augen gneiss; biotite granite; charnockite; granodiorite; amphibolite; while quartzite has the highest.

EXPERIMENTAL PROCEDURE

Determination of the specific resistivity of samples with arbitrary shapes requires measurement of the potentials and current flows at the boundary of the samples. To carry out this, contacts with the samples must be at the circumference and must have areas that are small compared with the surface area of the sample. This condition is met by the use of special electrochemical electrodes employing silver and chloride ions. Moreover, the sample must have uniform thickness and should not contain any isolated holes. This condition is fulfilled by slicing the sample twice, the first cut being to create a reference surface and the second to complete the slice.

If 1, 2, 3, 4 are small cyclic contacts at the circumference of the arbitrarily shaped uniform thick slice, the following resistances can be defined :

$$R_{12,34} = (V_4 - V_3)/I_{12}$$
$$R_{23,41} = (V_1 - V_4)/I_{23}$$

where V, I denote the potential at and the current through the specified nodes or branches, respectively.

$R_{12,34} = R_{34,12}$ and $R_{23,41} = R_{41,23}$ by the reciprocity relation derivable from Telegen's theorem for a two-port electrical network (Agunloye and Hussain, 1982).

Van der Pauw (1958) has shown that the specific resistivity of a specimen under the above condition is :

$$\rho = \frac{\pi d}{X} \frac{\left[R_{12,34} + R_{23,41}\right] f(\varepsilon)}{2}$$

where X = natural logarithm of 2.0; d = thickness of the sample and f is a function of ε given by

$$\frac{\varepsilon - 1}{\varepsilon + 1} = \frac{f(\varepsilon)}{X} \cosh - 1\left[1/ \; f(\varepsilon)\right]$$

The electrical measuring system (Fig. 1) consists of a current source, current adjuster, selector, data precision model 1350 digital multi-meter and four non-polarisable silver-silver chloride electrodes. A sheet of fine silver mesh, 30 * 20 mm, is cut, with any dirts on its surface removed using emery. A solution of 1 molar HCl is prepared and the silver mesh dropped into it. This is left for seven days after which a proper and permanent coated sheet is obtained. This sheet is rolled up into a cylindrical electrode, 30 mm long and 3 * 10^{-5} square metre cross-sectional area with about 2 to 3 mm of filter paper at the free end. Apart from the fact that the silver-silver chloride electrode obtained this way is very reliable and lasts long, it also helps to minimise the effects of electrode impedance. The only disadvantage is the fairly long time the preparation takes.

A rock sample is cut into uniformly thick slice with the aid of a powerful electrical cutting machine and its thickness measured using a micrometer screw gauge. The electrodes are set up on various positions on the boundary of the sample to represent irregular electrode configurations. They are mounted on the rock by affixing them in holes made in an insulating plate cut in the shape of the sample. The plate is then clamped in such a way that the electrode filter tips rest on the edge of the sample. Electrical contact is made with sample by injecting the filter paper with 0.1 molar KCl solution. The insulating plate thus acts as a socket for the electrodes.

The current source whose output could be varied by a separate current adjuster provides current at two terminals on the selector. This selector ensures that once the electrodes are affixed on the sample the cyclic permutation of electrode function could be made by the use of the selector gear without transferring the contacts on the sample. The voltage-current measurement is done using two digital multimeters of the same type. One multimeter measures current and the other measures the voltage. The potentials and currents corresponding to the four cyclic permutations of positions 1, 2, 3 and 4 on the rock sample are measured for the five boundary arrays. Resistances $R_{12,34}$ and $R_{23,41}$ are calculated and the specific resistivity of each sample determined from the Van der Pauw equation. The only precaution made was to ensure that the preliminary drying and soaking processes allowed reproduction of results.

One hundred and two rock samples were used for this experiment and they comprised various crystalline basement units from southwestern Nigeria. The localities from which the samples were collected are shown in Fig. 2. The rock types include gneisses, quartzite, amphibolite, biotite granite, granodiorite, and charnockite. The results obtained are presented in the following section.

RESULTS

The results indicate a wide overlap in the resistivities of the various rock types (Table 1). This shows that the resistivity of a rock sample is not diagnostic of its lithology. Nonetheless, it is obvious that the gneisses have the lowest resistivities, followed by biotite granite, granodiorite, charnockite, amphibolite and quartzite. The range, mean and standard deviation of the resistivities of the respective rock types are presented in Table 1.

Table 1: Electrical resistivity of crystalline basement rocks from southwestern Nigeria (as determined experimentally)

Rock type	Number of	Range (ohm-m)	Mean (± Std. Dev)	Coeff.
Quartzite	18	$5.06 * 10^4$ to $2.82 * 10^6$	$9.48 (\pm 9.41) * 10^5$	99
Amphibolie	10	$9.10 * 10^4$ to $3.73 * 10^5$	$1.88(\pm 1.10) * 10^5$	59
Granodiorite	10	$4.0 * 10^4$ to $1.10 * 10^5$	$5.87(\pm 2.19) * 10^4$	37
Charnockite	10	$2.1 * 10^4$ to $1.75 * 10^5$	$5.45(\pm 4.44) * 10^4$	81
Biotite granite	30	$8.0 * 10^3$ to $6.20 * 10^4$	$3.20(\pm 1.40) * 10^4$	44
Augen gneiss	8	$4.31 * 10^3$ to $1.43 * 10^4$	$7.35(\pm 3.39) * 10^3$	46
Banded gneiss	8	$2.43 * 10^3$ to $6.29 * 10^4$	$4.37(\pm 1.49) * 10^3$	34
Granite gneiss	8	$1.01 * 10^3$ to $7.79 * 10^3$	$2.52(\pm 2.29) * 10^3$	91

Most of the gneiss samples have resistivities less than 7000 ohm-m while only 8% have resistivities higher than 9000 ohm-m (Fig. 4a). The mean is 4739 ± 3149 ohm-m. The samples with low resistivities (less than 3000 ohm-m) may characterize fractured basement rocks while those with higher values are probably indicative of unfractured bedrock. The biotite granite samples have resistivities ranging between 8020 and 62 000 ohm-m. It may be noted that 40% of these samples have resistivities in the range 20 000 to 30 000 ohm-m (Fig. 4b). The quartzites have the highest resistivities, varying between 50 600 and 2 820 000 ohm-m, although about 77% of those samples have resistivities less than 10^6 ohm-m.

It has been observed that even for the same rock exposure there may be a wide range of resistivities for different samples. An example of this was recorded from Osuntedo where 10 samples of charnockite were collected from different parts of the same outcrop. There is a wide disparity between the lowest (20 900 ohm-m) and the highest (175 000 ohm-m), this being a ratio of 8.37. In particular, the mean resistivity is 54 500 ohm-m while the standard deviation is 44 000 ohm-m, giving a high coefficient of variation of 81%. This is indicative of a high degree of dispersion, which may be attributed to differences in mineralogy at the respective portions of the exposure.

For a given rock type it is to be expected that there will also be variations in resistivity from one locality to another. It has been found out, for instance, that the Ayete quartzite samples have lower mean resistivities (156 000 ± 154 000 ohm-m) than those from Mokola, Ibadan (429 000 ± 273 000 ohm-m) while those from the University of Ibadan Campus have the highest at 2 260 000 ± 395 000 ohm-m. Similarly, the mean resistivities of biotite granite from Idere (29 600 ± 6 000 ohm-m) are lower than those from Tapa (30 200 ± 20 000 ohm-m) and Ayete (36 300 ± 9 600 ohm-m). These variations may also be explained by differences in mineralogy.

DISCUSSION AND CONCLUSIONS

In this paper, a laboratory method has been used to measure the electrical resistivity of fresh samples of arbitrarily shaped samples of fresh crystalline basement rocks from southwestern Nigeria. The results indicate that these rocks have very high resistivities, ranging from about 1000 ohm-m to nearly $3 * 10^6$ ohm-m. This is in agreement with previous work. The granite gneisses samples have the lowest resistivities, followed by banded gneiss, augen gneiss, biotite granite, charnockite, granodiorite, amphibolite and quartzite. In each case, there are large standard deviations of the mean resistivity. One implication of these high resistivities is that the rocks have very low porosity and very low water content.

A comparison of the results with those earlier reported for the resistivity of fresh crystalline basement rocks from parts of Nigeria and other parts of Africa (Table 2) shows a broad agreement with the present work.

There is, in general, some correlation between the electrical resistivity of the various rock types and their susceptibility to chemical weathering. This may have some relationship with the temperature of formation of the constituent minerals. For example, quartzite (comprising largely of quartz) is a low temperature rock; it has a very high resistivity and hence does not weather readily. In most instances, quartzites are overlain by a fairly shallow weathering profile, and stand up prominently as ridges. On the other hand, the gneisses are characterised by lineations which constitute planes of weaknesses and consequently show relatively lower resistivities and weather more readily. Hence, gneisses are often overlain by a very thick weathered mantle (Barker et al., 1992). Although granites contain similar amounts of feldspars and ferromagnesian minerals as gneisses, in the former rock type the minerals are not continuously linked even though the feldspars in the granites may occur in megacrysts (David, 1988). It may be pointed out that granite has a higher resistivity than the gneisses, and is also less susceptible to attack by agents of chemical weathering.

It is envisaged that the experimental data obtained in this research would provide complementary information to those obtained from sounding interpretation and subsequently extended to fractured basement rocks.

Table 2: Resistivity of fresh crystalline basement rocks from parts of Africa (determined from sounding interpretations)

Locality	Lithology	Resistivity (ohm-m)
*Okene, Southwestern Nigeria	granite, granodiorite, migmatite, gneiss and metasediments	>1000
**Kubanni Basin, Zaria, northcentral Nigeria	Biotite granite, gneiss and aplite	>1000
***West Africa (various parts)	amphibolite	>500
	schist	>1000
	granite	>1500
****Victoria Province, Zimbabwe	unfractured bedrock (granite and gneisses)	>3000

Source of data : *Olayinka and Olorunfemi (1992); **Ajayi and Hassan (1990); ***Engalenc (1978); ****Barker at al. (1992).

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