ELECTRICAL PROPERTIES OF SOME GHANAIAN METAMORPHIC ROCKS

Aboagye Menyeh
BSc MSc
Department of Physics,
University of Science & Technology,Kumasi,Ghana

T.N. Ahwireng
BSc
Department of Pysics,
University of Science & Technology, Kumasi,Ghana

K.E.N. Tsidzi
BSc MSc PhD
Department of Geological Engineering
Institute of Mining & Mineral Engineering(IMME)
University of Science & Technology, Kumasi,Ghana

ABSTRACT

The temperature dependence of electrical resistivity of three Ghanaian metamorphic rocks has been investigated between room temperature (300K) and 570K. The resistivity values were measured for samples prepared in directions parallel and perpendicular to the rock foliation. The resistivity behaviour was found to be highly anisotropic and the anisotropic coefficients were found to be between 3.0 and 7.0. All the rocks showed a transition at a characteristic temperature where the resistivity became a maximum beyond which it decayed exponentially. The activation energy calculated for some temperature ranges was found to be of the order of 1eV (10^{-19}J) which is typical of semiconductor behaviour within these regions.

Keywords: resistivity,f oliation, anisotropy, activation enegy

INTRODUCTION

The increasing rate of extraction of economic minerals, underground water and fossil fuels (crude oil and natural gas) has made the role of Geophysics very important in our world today. A detailed interpretation of geophysical data for mineral deposits or for oil and gas accumulation requires not only a sound knowledge of the local geology but also knowledge of the physical properties of the rocks. For example in the location of gravel deposits, water bearing rocks as well as some mineral deposits, information about the resistivity of these targets is very important. Similarly, in locating oil resevoir rocks, it is essential to correlate seismic data with physical properties such as density, porosity and the permeability of the formations. Due to the fact that there is no catalogue of data on physical properties of Ghanaian rocks, Earth Scientists working in this country have relied solely on data obtained elsewhere as quoted in textbooks of Geophysic and Engineering Geology. This practice is most unfortunate and needs to be rectified since physical properties of rocks depend on a large extent on local conditions such as weathering and serious erors mazy be encountered when reliance is placed on these textbook values. The Physics Department in collaboration with the Geological Engineering Department of the Institute of Mining and Mineral Engineering (IMME) of the UST is currently undertaking a research into the physical properties of Ghanaian rocks and minerals with the ultimate objective of preparing a catalogue of data on these properties.

This work summarizess the results of an experimental study of the electrical resistivity of three Ghanaian metamorphic rocks, taking into account the temperature dependence of resistivity.

TEST SAMPLES

The samples studied were homeblende garnet gneiss of the Dahomeyan formation obtained from the Shai Hills, a potential area for rock aggregates in the Greater Accra Region; two phyllites, one from the Birimian formation at Nsuta (a rich manganese mining town) and the other from the Tarkwaian formation at Tarkwa (a gold mining town). The gneiss and phyllites are respectively weakly foliated following the scheme of classification proposed by Tsidzi[1]. The phyllites are differentiated on the basis of colour and mineralogy; Nsuta phyllite is grey and tuffaceous while the Tarkwa phyllite is green and chloritic.

ELECTRICAL RESISTIVITY OF ROCKS

If a solid conductor carries current with parallel lines of flow over a cross sectional area A, then its resistivity is defined by the relation (RA/L)where R is the resistance measured between the two parallel surfaces separated by a distance L. The resistivity of rocks generally is an extremely variable property, ranging from about $10^{-6}\Omega$m to about $10^{12}\Omega$m[2]. It depends on a number of factors such as the type of rock material including the fabric, the amount and nature of pore fluids, pressure and temperature. The flow of electricial current in most rocks is largely by electrolytic (ionic) conduction at lower temperatures which takes place in the pore fluids and also through the mineral grains. Consequently the quantity of water and the nature and amount of the dissolved salts play the most important part.

The electrical resistivity of rocks depends strongly on temperature according to the relation $\rho = \rho_0 \exp(E/kT)$ which is obeyed by semiconductors; ρ_0 is the resistivity at 273K, E is the activation energy for the ions contributing to current flow at absolute temperature T. Most rocks behave as semiconductors at high temperatures with activation energies of a few electron volts [3]. Rocks may also show anisotropic behaviour in their electrical conductivity [3]. Anisotropy is most significant and predominant in rocks such as shales, schists, gneisses, phyllites and slates which are generally more conductive along the discontinuities than perpendicular to them.

EXPERIMENTAL

The rocks under investigation were carefully studied to identify their directions of foliation. They were cut to the desired dimensions (after preliminary study) of about 0.05m x 0.02 x 0.06m. For each rock type, samples were cut, one having its largest face parallel to the direction of the foliation.

The two-electrode method of resistivity measurement was used to determine the resistance across the sample. In this method the electrodes are located symmetrically with respect to each other on opposite sides of the sample. One electrode, the high voltage electrode is connected to the current supply while the other is connected to the measuring meter. An R-C-L Bridge, (Type PM301) was used to measure the effective resistance of the rock sample connected in parallel with a suitable standard resistor. The parallel connection was to reduce the resistance registered by the bridge for accurate measurements. A number of preliminary tests were carried out to determine the reliability of the techniques for resistance measurement. The stability of the set up was also tested over a period of a few hours while the accuracy of the bridge was also tested by calibrating with standard resistances over a wide range of resistance values. The uncertainty in the resistance measurements was ±0.1%. Aluminium foils were used to ensure sufficient electrical contacts between the rock sample and connecting wires. After room temperature measurements, the samples were heated gradually by an electrothermal bunsen and the effective resistance measured at some recorded temperatures by placing a mercury-in-glass thermometer jkust in contact with the midpoint of the sample. Knowing the effective value of the parallel arrangement and the standard resistor, the resistance of the rock sample was calculated from which the resistivity was obtained.

RESULTS AND DISCUSSION

The room temperature resistivity for the samples parallel and perpendicular to the foliation and the anisotropic coefficient (λ) as defned by Parasnis [3] are given in Table 1 which data are useful in the interpretation of electrical resistivity data in geophysical prospecting. The resistivity values which are of the order of $10^6\Omega m$ are within the range of resistivity values for rocks[4]. The tuffaceous phyllite from Nsuta has a higher resistivity in both the perpendicular and parallel direction than the Tarkwa chloritic phyllite justifying the assertion that physical properties of rocks depend on minor differences in rock type. The anisotropic nature of resistivity of some rocks is also evident in the table, that is, electrical conductivity is much easier in the foliation direction than in direction perpendicular to it.

Temperature dependence of resistivity between 300K (27°C) and 573K (300°C) for the samples is given in figures 2.1 - 2.6. These include the resistivity in the direction parallel and perpendicular to foliation. All the rocks show transitions at certain characteristic temperatures where resistivity becomes maximum. These transitions are given in Table 2. Beyond the transition temperatures, there is a decay of resistivity with increasing temperature. However, the exponential relation $\rho = \rho_0 \exp(E/kT)$ has been fit to some temperature ranges and not the entire range of temperature between the transition temperatures and the maximum temperature since this range did not show a good fit to the relation. Thus assuming semiconductor behaviour to hold in these temperature ranges, the energy gap, or the activation energy has been calculated for the samples and this is given in Table 3. the activation energy of the order of 1eV(10^{-19} J) agree with the order of magnitude for typical semiconducting materials. Thus beyond their transition temperatures, conduction may be predominantly due to charge carriers as a result of rapid decrease in resistivity. The charge carriers in the valence band acquire enough thermal energy to move into the conduction band to contribute more to the conduction process. Practically the resistivity of the rocks at low temperature initially shows little variation presumably the resistivity depending much on the porosity and the nature of the electrolyte filling the pores. It is possible therefore that electrolytic conduction predominates at temperatures below the transition temperature. The common occurrence of a transition in the resistivity behaviour could also be explained on the basis of a phase transformation taking place, for example, quartz inverts to other polymorphs after heating beyond 546K (273°C). The loss of fluid filling the pores, during the heating process might be an important contributing factor to this phase transformations.

Table 1: Room temperature (300K) resistivities of three Ghanaian metamorphic rocks, in current directions perpendicular and parallel to the rock foliation

SAMPLE	$\rho_\perp/10^6\Omega m$	$\rho_{\parallel}/10^6\Omega m$	$\rho_\perp/\rho_{\parallel}$	$\lambda = (\rho_\perp/\rho_{\parallel})^{1/2}$
Hornblende garnet gneiss	6.88	0.47	14.77	3.84
Nsuta Phyllite	68.68	4.23	16.25	4.03
Tarkwa Phyllite	4.72	0.09	50.90	7.13

TABLE 2: Observed transitions in resistivity of three Ghanaian metamorphic rocks in current directions perpendicular and parallel to the rock foliation, with corresponding transition temperature

SAMPLE	$\rho_\perp/10^7\Omega m$	$T_\perp/K$	$\rho_{\parallel}/10^7\Omega m$	$T_{\parallel}/K$
Hornblende garnet gneiss	2.77	423	2.20	438
Nsuta Phyllite	4.15	470	2.49	409
Tarkwa Phyllite	3.12	473	0.77	483

TABLE 3: Energy gap (activation energy) E of three Ghanaian metamorphic rocks for some temperature ranges

SAMPLE	$E_\perp/eV$	TEMP.RANGE/K	$E_{\parallel}/eV$	TEMP.RANGE/K
Hornblende garnet gneiss	1.11	453-513	0.71	513-563
Nsuta Phyllite	0.91	473.563	0.57	410.553
Tarkwa Phyllite	0.97	483-543	2.20	483-543

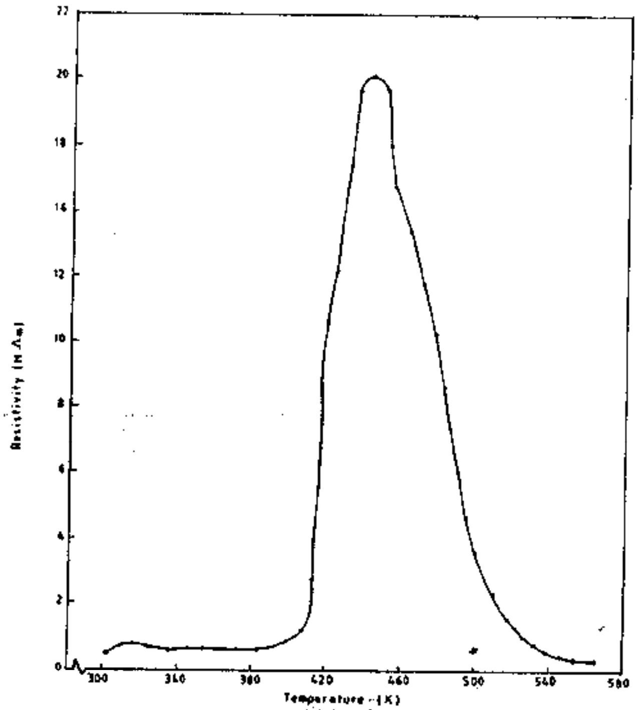

Figure 2:1: Temperature dependence of resistivity for hornblende garnet gneiss in current direction parallel to rock foliation.

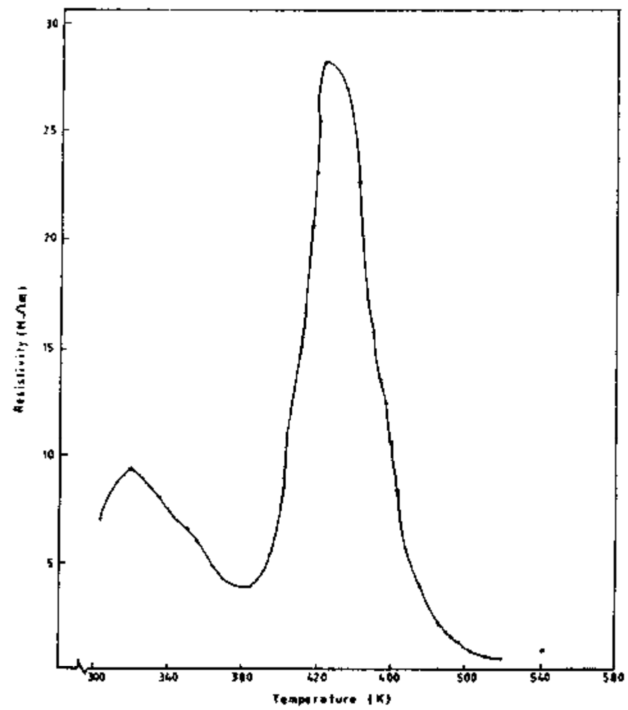

Figure 2:2: Temperature dependence of resistivity for hornblende gernet gneiss in current direction perpendicular to rock foliation.

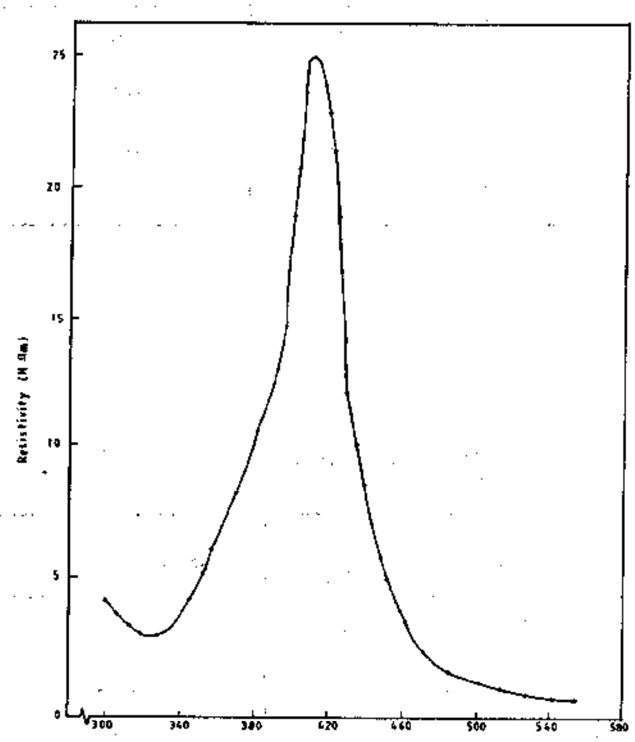

Figure 2:3: Temperature dependence of resistivity for Nsuta Phyllite in current direction parallel to rock foliation.

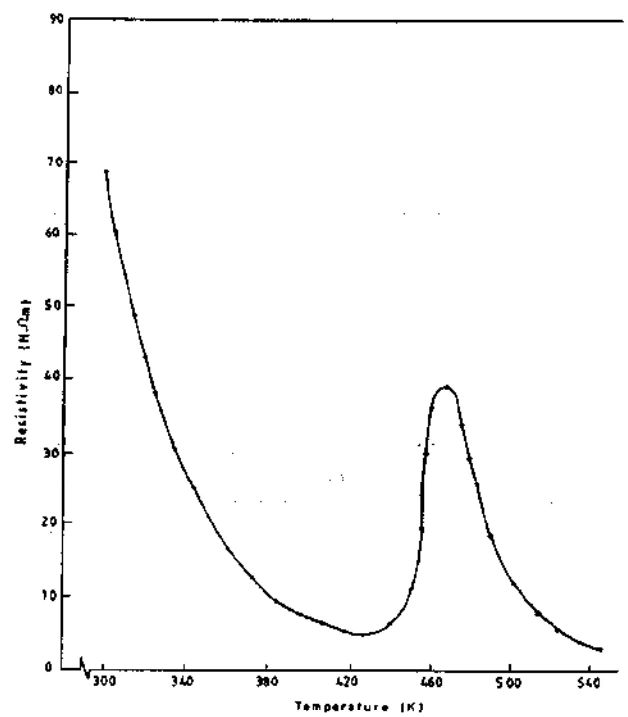

Figure 2:4: Temperature dependence of resistivity for Nsuta Phyllite in current direction perpendicular to rock foliation.

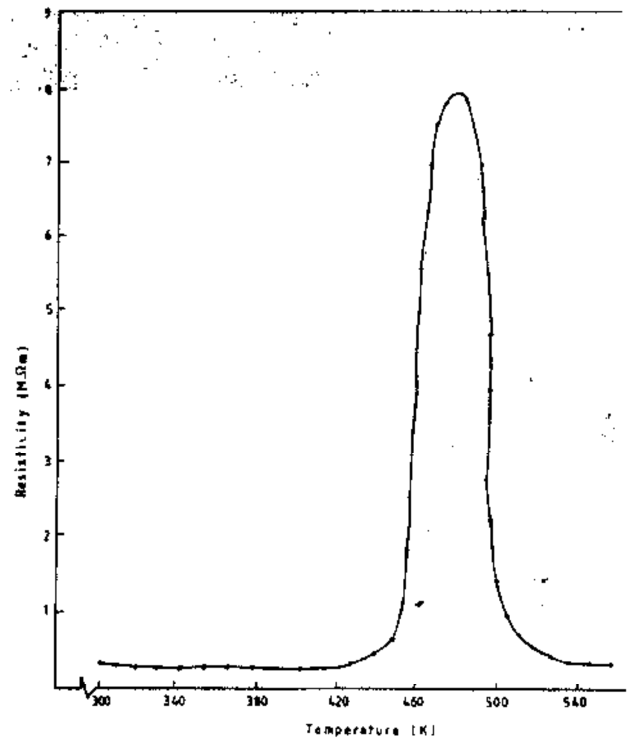

Figure 2:5: Temperature dependence of resistivity for Tarkwa Phyllite in current direction parallel to rock foliation.

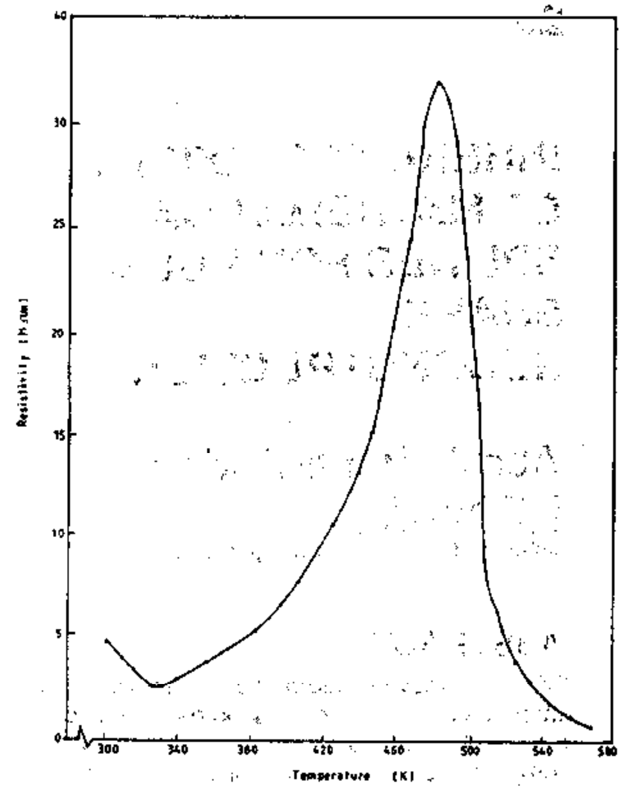

Figure 2:6: Temperature dependence of resistivity for Tarkwa Phyllite in current direction perpendicular to rock foliation.

CONCLUSIONS

This study has provided electrical resistivity data for three Ghanaian metamorphic rocks. It has also confirmed the anisotropic nature of some rocks. Further, an important feature has been observed in behaviour of temperature dependence of resistivity of the rocks between room temperature 300K and 573K. After an initial decrease in resistivity with increasing temperature, a sudden increase in resistivity is observed at a particular temperature (transition temperature) below which the resistivity decreases in exponential fashion and this behaviour has been found to agree with that of a semiconductor. Thus charge carriers are predominantly responsible for the flow of electricity beyond the transition temperature. On the other hand, electrical conduction below the temperature has been attributed on the whole, to ions within the electrolytes filling the pores of the rocks.

REFERENCES

1. Taidzi,K.E.N.; A quantitative petrofabric characterisation of metamorphic rocks. Bull. Int. Assoc. Eng. Geology, Vol.33, pp 3-12, 1986.

2. P. Keary and M. Brooks, An Introduction to Geophysical Exploration, Blackwell, London, 1984.

3. D.S. Parasinis, Principles of Applied Geophysics, Chapman and Hall, London, 1986.

4. W.M. Telford, L.R. Geldart, R.E. Sheriff and D.A. Keys, Applied Geophysics, Cambridge, 1981.