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Variability of Surface Air Temperature on the Electrical Conductivity of Rock Types

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Abstract: The results of electrical conductivity are often needed in studying the interior of the earth, which indirectly describes other physiochemical parameters of matter under high pressure and temperature. In this study, electrical conductivity and the temperature effects of some rock types have been measured, using ex-situ technique based on utilizing lee's disc apparatus. Six rock types were studied, which are granite, rhyolite, shale, limestone, quartzite and marble. The mean electrical conductivity ranged from 0.183124±0.02 S m^{-1} for rhyolite to 0.259971±0.03 S m^{-1} for limestone. Investigation shows that limestone has the highest electrical conductivity which increase as the air temperature increases while rhyolite have the lowest electrical conductivity at all levels of temperature range.

Key words: Electrical conductivity, rock samples, ex-situ techniques, surface air temperature, physiochemical

INTRODUCTION

Rocks one of the natural gifts of nature is extensively used by mankind. Tools such as knives and axis were crafted from Chalcedony and other varieties of quartz; the dietary use of mineral halite (Sodium chloride- common salt), the use of clays to make bricks and pottery, limestone for producing cement: production of metals like iron, copper, silver, lead and bronze, as well as to provide raw materials for modern industry like fuel rods in Nuclear reactor to mention but for few (Robber, 1982). There has been increasing interest in the electrical properties of rocks at the depth within the earth and the moon. This is due to the use of electrical properties in studying the interior of the earth and its satellite, particularly to the depths of tens or hundreds of kilometer. At such depth pressure and temperature have been used to predict what the electrical properties at depth actually are, since the earth's crust is zoned electrically (Graw Hill, 1977).

As temperature increases with depth, this effect becomes more pronounced and resistivity decreases markedly. The surface zone consists of a sequence of sedimentary rocks along with fractured crystalline and metamorphic rocks all of which are moderately good conductors of electricity because they contain relatively large amount of water in pore spaces. These zones which may range in thickness from a km to several tens of km, has conductivities varying from about ½ Ω-m or more in weathered crystalline rocks (Graw Hill, 1977).

The basement rocks beneath this surface zone are crystalline, igneous or metamorphic rocks which are denser having little pore space in which water may collect. Conduction of electricity in this type of rocks is determined almost entirely by the water in them. They are therefore, electrically resistance (Graw Hill, 1977). However, thermal conductivity of rocks depends on several factors such as mineralogy, the size, shape and arrangement of grain with porosity and texture. Those factors may vary with rock (Deer *et al*., 1969).

The objective of this study, is to make use of laboratory method for measurement of electrical conductivity and surface air temperature of some rocks. To date, there are numerous experimental difficulties involved in trying to measure the electrical properties of this part of the earth crust, such as getting cylindrical rock shape, preparation of rock sample, constant power supply etc. The method utilized in this has been able to get rid of some of these difficulties.

THERMAL AND ELECTRICAL PROPERTIES OF ROCKS

Electrical prospecting involves the detection of surface effects produced by electric current flow in the ground. Using electrical methods, one may measure potential and electromagnetic fields, which occur naturally or we introduced artificially into the earth. Maxwell's equation relates the electromotive force to the time derivative of the magnetic displacement and the electromotive force to the total current around a loop. Since both electric and magnetic field are radiated into space as Electromagnetic Wave (EMW) using the relation (Jordan, 1973).

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$$\nabla x E - \left(\sigma + \varepsilon \frac{\partial}{\partial t}\right) E = 0 \quad (1)$$

Where ε and σ are permittivity and conductivity of the medium and if the variations of the electric field E with time is sinusoidal then

$$\nabla x H = \frac{\partial}{\partial t}\left(\varepsilon - j\frac{\sigma}{\omega}\right) E \quad (2)$$

Where ω is a measure of the frequency of the wave.

Some measurement techniques: A lot of models are used for measurement of effective electrical characteristic of the earth; the self-potential, telluric currents and magneto telluric, audio-frequency magnetic fields resistivity, equipotential point and line and mise-ala-masse, electromagnetic and induced polarization. The type of energy source involved often classifies them. In electrical potential, several electrical properties of rocks and minerals are significant in electrical prospecting; they are: natural electrical potentials, electrical conductivity and the dielectric constant. Magnetic permeability is also an indirect factor. Of these, electrical conductivity is by far the most important, while others are of minor significance. Most researchers basically measured the ground electrical conductivity of the geophysical technique in planning antenna installation, among are Kuhn and Tahmer that used the wave-tilt method to measure the field strength distribution to derive ground conductivity (Kuhn and Taumer, 1974) also used geophysical prospecting method (Ajewole and Arogunjo, 2000)

In this study where the thermal conductivity as well as temperature variation of the rocks is needed; a lot of laboratory techniques (Ex-situ method) can be adopted. Among these; needle probe method, divided bar method, Cell technique and Lee disc method to mention but a few.

Lee disc method is adopted in this very study because it is simple, versatile and easy-to-use with thermometer (Deer *et al.*, 1969).

Lee disc method of measuring thermal conductivity and temperature variation of rock types: The diagram is as depicted in Fig. 1, the apparatus is made of a polished wood and it consists of disc A, B and C, heater and the space for sample to be inserted to determine its thermal conductivity and the corresponding voltage V and current I supplied for powering the heater which lead to the determination of temperature effect on the electrical conductivity. Each of the discs contains a hole into which the thermometer is inserted. The apparatus is arranged in the order; disc C followed by heater followed by disc B, then the sample and lastly disc A which is connected to the external circuit that contains a rheostat, Voltmeter and Ammeter.

Theory: Assuming that the heat transferred between an object and it's surrounding depends on the exposed surface of the object and temperature difference between the object and the surroundings. Let *e* Joules of energy be emitted from each exposed unit surface area (m^2) per second per °C above the initial temperature and assume that this is the same for disc A, B, C and specimen.

Assume also that the temperature of the specimen is the mean temperature of disc A and B, then the total heat emitted from the apparatus is

$$H = e[Q_A T_A + Qs \frac{(T_A + T_B)}{2} Q_B T_B + QcTc] J/s \quad (3)$$

Where Q_A, Q_B, Qc, Qs are the exposed surface area (m^2) of A, B,C, S respectively. Area Q_A and Qc include the flat end section of the disc. T_A, T_B, Tc are temperature of the disc A, B, C at the steady state above the initial temperature. The temperature is then applied by the heating element

$$H = IV \ J/s \quad (4)$$

Where I and V are current and voltage respectively, from Eq. 3 and 4

$$e = IV \ Q_A T_A + Qs \frac{(T_A + T_B)}{2} Q_B T_B + QcTc]^{-1} J/s/A$$

The heat flowing through the specimen (hs) is

$$hs = k \pi r^2 \frac{(T_B - T_A) \ J/s}{d} \quad (6)$$

Where r is the radius, d is the diameter and k is the thermal conductivity of the specimen(s).

Assuming that the heat flowing through S is the mean of the heat entering S from B (h_{AS}) and that leaving S from A, the heat entering S from B(h_{bS}) is that which is emitted by S and A together, then

$$hbs = e[Qs \frac{(T_A + T_B)}{2} + Q_A T_A] J/s \quad (7)$$

If the heat leaving S from A is that which is emitted by A alone then

$$h_{AS} = eQ_AT_A \text{ J/s} \tag{8}$$

$$\text{The mean hs} = \frac{e}{2}\left[Qs\,\frac{(TA + TB)}{2} + 2Q_AT_A\right]\text{J/s} \tag{9}$$

From Eq. (6) and (7)

$$k\,\pi r^2\,\frac{(T_B\text{-}T_A)}{d}\text{ J/s} = \frac{e}{2}\left[Qs\,\frac{(TA + TB)}{2} + 2Q_AT_A\right]\text{J/s} \tag{10}$$

$$k = \frac{ed}{2\pi\, r^2\,(T_B - T_A)}\left[Qs\,\frac{(T_B - T_A)}{2} + 2QATA\right] \tag{11}$$

The electrical conductivities: The electrical resistivity of a cylindrical solid of length L and cross sectional area A having a resistance R between the end faces was also considered and it is given by

$$\rho = RA/L \tag{12}$$

The resistance R is given in terms of the voltage V applied across the ends of the cylinder and the resultant current I flowing through it by Ohm's law is

$$R = V/I \tag{13}$$

Equation (13) becomes

$$\rho = \frac{\Delta V\,(A/L)}{I} \tag{14}$$

For infinitesimal change in the conductor size

$$\rho = \frac{\Delta V/L}{I/\Delta A} \tag{15}$$

But, the reciprocal of resistivity gives the conductivity

$$\sigma = \rho^{-1} \tag{17}$$

Then, $\sigma = \rho^{-1} = L/RA$

$$= \frac{I/A}{V/L} = J/E \tag{18}$$

Where J is the current density (A m^{-2}) and E is the electric field (V m^{-1}) (Telford *et al*., 1984).

MATERIALS AND METHODS

Sample preparation: The samples were picked from different location in the southwestern Nigeria. The samples were Shale and limestone-sedimentary rock; granite and rhyolite- igneous rock and quartzite and marble - metamorphic rock. The percentage compositions of the rock samples are summarized in Table 1. The samples were properly identified and taken to the laboratory for pulverization. Pulverization of rock samples involves crushing the samples and finally pulverizing the sample into fine granules of grain size with bore mill machine. The samples were then sieved using a laboratory test sieve. The samples were then weighed in a beam-balance to determine the quantity of the powder. Equal quantities of the rock types were to form a paste. The paste was then placed inside a round object to form a disc type with a specific thickness. After molding, the samples were dried at room temperature for two days in order to remove the remaining water content in the sample as mixture and little starch were used as binding agent. A disc-like material was therefore obtained after molding.

Experimental set-up: The prepared samples were made flat and smoothen almost with uniform thickness as the disc so as to ensure good thermal contact over its entire

Table 1. Summary of the percentage composition of the rock samples

Specimen	Content	Mineral percentage
Shale	Clay,	90-96
	Quartz	4-10
Limestone	Calcite,	50-100
	Dolomite	50-100
Granite	Quartz	5-20
	Mica	20-40
Rhyolite	Quartz	5-20
	Mica	20-40
	Feldspar	
Quartzite	Quartz	80-100
	Clays	5-10
	Calcite	1-20
Marble	Calcite	80-100
	Dolomite	20-100
	Quartz	5-20

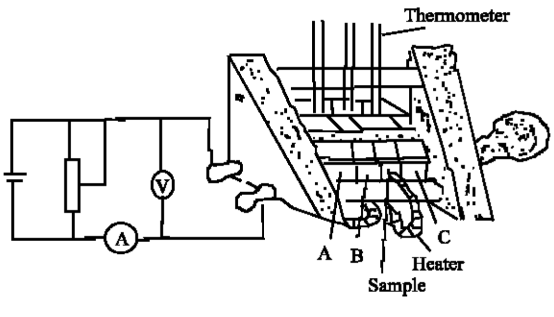

Fig. 1: The circuit diagram with Lee disc apparatus

Table 2: The results of the thermal conductivity, electrical conductivity and the mean temperature of the samples at the respective voltages

	6V	8V	10V	12V
Granite				
Thermal Cond.	0.370789401	0.335943243	0.393803943	0.661250495
Electrical Cond.S m^{-1}	0.240931204±0.03	0.240931204±0.03	0.240931204±0.03	0.240931204±0.03
Temperature °C	32.5	71.5	102.5	126.5
Rhyolite				
Thermal Cond.	0.16845075	0.470272801	0.389582768	0.270163213
Electrical Cond S m^{-1}	0.183124297±0.02	0.183124297±0.02	0.183124297±0.02	0.183124297±0.02
Temperature (°C)	41.5	63	98.5	149
Shale				
Thermal Cond.	0.757845827	0.676546928	0.69189510	0.712856114
Electrical con S m^{-1}	0.259484703±0.03	0.259484703±0.03	0.259484703±0.03	0.259484703±0.03
Temperature (°C)	25.5	68	102	140
Limestone				
Thermal Cond.	0.29159088	0.67630789	0.687721689	0.708498913
Electrical Cond S m^{-1}	0.259970698±0.03	0.259970698±0.03	0.259970698±0.03	0.259970698±0.03
Temperature (°C)	34	66.5	92.5	117.5
Quartzite				
Thermal Cond.	0.339359634	0.33561535	0.58171045	0.38156112
Electrical Cond S m^{-1}	0.198760355±0.02	0.198760355±0.02	0.198760355±0.02	0.198760355±0.02
Temperature (°C)	27.5	62.5	105	154.5
Marble				
Thermal Cond.	0.188655768	0.320020866	0.533765607	0.407238624
Electrical Cond S m^{-1}	0.249284658±0.03	0.249284658±0.03	0.249284658±0.03	0.249284658±0.03
Temperature (°C)	24	56.5	104	151

surface. The diameter and thickness of disc A, B, C and the specimen(s) were measured and recorded. The heater and the entire disc were wiped and clean of dirt with a white cloth. It was then placed in the frame in the order disc A, sample B, disc B, heater, disc C. All thermometer holes were made to point upward and the clamp screw was tightened to hold all the discs firmly together.

A small quantity of glycerine was pored in each thermometer holes to aid conductivity and the experiment was performed away from drought to give reasonably constant thermal conditions. The heater terminals were connected to a variable power supply via an ammeter and rheostat, while a voltmeter was connected across the heater terminal. Another thermometer was placed fairly close to the apparatus to measure the ambient temperature. The whole connection is as shown in Fig. 1.

Heat at a minimum rate was made to pass from the power supply through ammeter and voltmeter and heat passes in through disc C into the heater and from the heater to disc B, the heat then travels through the samples into the last disc A. The whole setting was allowed to reach thermal equilibrium by heating it for 1h before the temperature is taken in disc C. After equilibrium in disc B, its temperature was taken and the temperature in disc A follows. The fourth thermometer measures the temperature of the surrounding. Voltages were varied from 6-12V and their corresponding current I were from 0.3-0.6A. The electrical resistivity and ultimately the conductivity were deduced from Eq. (13) and (18) so also the corresponding thermal conductivity was deduced from Eq. (12).

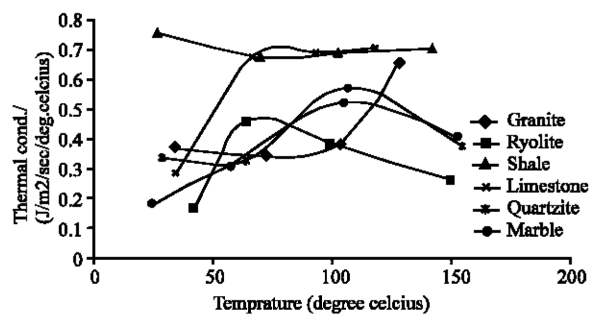

Fig. 2: Thermal conductivity against temperature

RESULTS

The results of the thermal conductivity, electrical conductivity and the mean temperature of the specimen at the respective voltages are as summarized in Table 2. It is noted that limestone that has the mineral contents of calcite and dolomite has the highest electrical conductivities while Rhyolite with mineral contents of quartz, mica and feldspar is lowest. The low value of the conductivity is of the fact that rhyolite belongs to igneous rock, which is known for its poor conductivity (Deer *et al*., 1969).

Figure 2 shows a typical variation of temperature effect on the thermal conductivity of the rock samples at varied voltages. It is observed that as the voltage increases, the temperature also increases leading to the fluctuation of the thermal conductivity of some of the samples. In all the rock samples investigated, limestone is

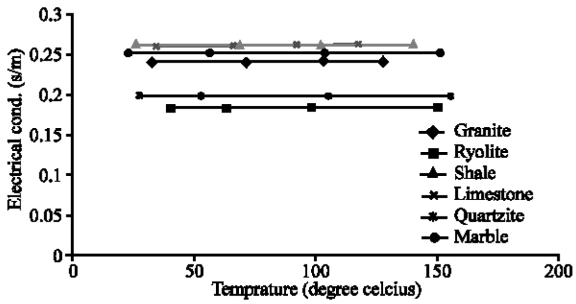

Fig. 3: Electrical conductivity against temperature

the only one that its thermal conductivity increases as the temperature increases at all levels of the voltages. The increase in temperature leads to an increase in the thermal conductivity, this is due to the impurities that contribute under a weak thermal excitation.

Also from the graph, the thermal conductivity of Granite at initial stage drops as the temperature increases and it later rises gradually. Rhyolite starts to increase as the temperature increases and it later decreases as the temperature increases. This is due to the higher resistivity of rhyolite. At 8 V, thermal conductivity of quartzite drops compared with thermal conductivity at 6 V. The thermal conductivity fluctuates with increase in temperature slowly. The thermal conductivity of marble increases as the temperature rises and at the peak of the temperature, the thermal conductivity falls slightly.

Figure 3 shows the variation of electrical conductivity with temperature, it was observed that the rock sample of the same material has the same electrical conductivity at all levels of the voltages (6-12 V). This is due to the fact that the resistances obtained during the experiment were the same at all level.

CONCLUSION

An ex-situ method utilizing the Lee's disc apparatus has been employed to determine the effect of temperature on the electrical conductivity of some rock types. From the study, it was observed that in some cases as the temperature increases, the thermal conductivity fluctuates but later increases as the temperature increases. The increase in temperature leads to an increase in conductivities, which is attributed to the impurities that contribute ions under a weak thermal excitation. It was also observed that granite and rhyolite are of poorer conductivity at all temperature when compared to other rock types. This shows that igneous rock 'family' is a poor conductor of electricity and thus can be used in fabrication of insulating materials. The six rock samples studied shows that limestone has the highest conductivity of 0.259971±0.03S m^{-1} while rhyolite has the lowest conductivity of 0.183124 ±0.02S m^{-1}.

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