The Porosity Effect on the Electrical Resistivity Properties of Geologic Formations: A Table Top Basket Test Approach

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Abstract:- The factors that influences the electrical properties of a geologic material are; porosity, the water content or saturation, water rock interaction and alteration, the resistivity of the water, the clay content, temperature, pressure and the content of metallic minerals in the formation. This laboratory research work was carried out with the key objective of establishing the relationship and the effect of porosity and water saturation on the electrical resistivity properties of earth materials.

A table top basket test was carried out where two of the factors (i.e. porosity and water saturation) were controlled in order to observe the corresponding electrical resistivity property of the concerned geologic unit. The table top basket was turned to the earth's subsurface by adding choice homogenous geologic material. The electrical properties of the soil was obtained through electrical resistivity techniques using Wenner Electrode configuration (constant separation techniques. Measurements were taken in the totally dry sand basket as a reference. The same procedure was repeated for three other instances; when porosity was increased, when water saturation was increased and when porosity was reduced.

The obtained curves show positive trends with high resistivity values obtained from small electrode separation and high values obtained from large electrode separation distances. Analysis also revealed that increase in water saturation of the geologic material lowered the resistivity value by 70%, a reduction in porosity of the geologic material increased the resistivity value by 27%. This study concludes that; water saturation and porosity has an inverse relationship with the electrical resistivity properties of geologic materials.

Keyword:- *Compaction, Electrical Resistivity, Geologic Material, lithification, Porosity Effect, and Water Saturation.*

I. INTRODUCTION

Electrical resistivity method of prospecting still remain one of the most efficient and versatile technique for mapping the subsurface. Electrical resistivity is by far the most variable. It could have its values range as much as 10 orders of magnitude. Individual rock types can have their resistivity values vary by several orders of magnitude thereby enhancing efficient mapping of different rock units [4]. It is established that porosity and water content (Saturation) are part of the key factors that affect the electrical resistivity of geological formation; others are; the resistivity of the water content, Temperature, Water rock interaction and alteration, pressure, steam content in the water and the content of metallic minerals such as sulphides [1], [2], [3], [5]. This laboratory research work was carried out with the key objective of establishing the relationship and the effect of porosity and water saturation on the electrical resistivity properties of earth materials. During field geophysical exploration, geophysicists have less control over the factors that affect the electrical properties of the earth materials in the concerned location. In this research, the team have sought for a way to control two of these factors, i. e. porosity and water saturation through a table top basket test and observed the corresponding electrical resistivity variations of the unit. Telford, 1990 [8] pg. 288 said; in order to measure directly the true resistivity of a rock, mineral, electrolyte and so forth, it is necessary to shape the sample in some regular form, such as a cylinder, cube or bar of regular cross section; this table basket was turned to earth's subsurface when filled with a homogeneous geologic material – garden soil.

- *General Principles*

Groundwater acquires its electrical properties through the various dissolved salt it contains. The dissolved salts allows electric current to flow into the ground and consequently help in predicting the presence of water in the formation.

Archie's law helps to relate a couple of factors to the resistivity that is being measured from a rock formation. The factors are; the formation factor, comprising of the porosity of the rock and the resistivity of the contained water [1]

$$\varrho = a\phi^{-b}f^{-c}\,\varrho_w$$

Where ϕ - porosity, F – fraction of pores containing water, ϱ_w is the resistivity of water and a, b, and c are empirical constants, ϱ_w can vary considerably according to the quantity and conductivities of dissolved materials [6].

This shows that there is a direct relationship between porosity of a rock with its electrical resistivity. The porosity of a rock is the amount of pore spaces (filled with fluids) to the volume of the rock (see figure1). In sedimentology, the porosity of sediments or sedimentary rocks is reduced through compaction and lithification which occurs over time (See figure 1), in this research work, an effort was made to reduce the porosity of the collected soil through mechanical compaction using a medium sized sledge hammer (2 kg). Also, an effort was made to increase or enhance the porosity (water saturation) of the sample by adding table water carefully to the sample. The electrical resistivity values for the stated instances were correlated to establish relationship and effects of porosity and water saturation with the electrical resistivity properties of a chosen earth material.

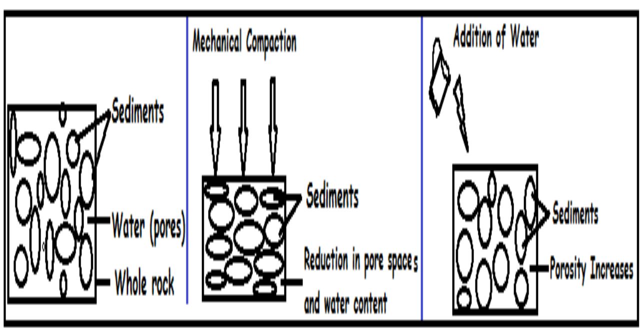

Fig 1:- Image of rock constituents describing what happens during water saturation, compaction and lithification.

II. MATERIALS AND METHODS

A garden soil was collected in a mildly perforated basket of dimension; length – 0.45 m, breath – 0.33 m, height – 0.24 m. A table top basket test was established using a plastic basket that would not conduct electricity or contribute less to electron interactions and would also be able to contain water. Another reason for choosing the basket was to allow the monitoring of the water level from the outside holes. The basket was filled with a homogenous geologic material thereby turning the test basket to earths subsurface. The electrical properties of the soil was obtained through electrical resistivity techniques using Wenner Electrode configuration (constant separation techniques). Vertical electrical sounding was achieved by making use of a multicore cable to which the number of electrodes are attached at standard separations

Electrodes were set at five different distances a = 0.1 m, 0.08 m, 0.06 m, 0.04 m, 0.02 m. Measurements were taken in the totally dry sand basket as a control or reference for the other instances.

The same procedure was repeated for three other instances;

- When tap water is being poured carefully in a corner of the basket in order to allow infiltration (increased porosity).
- When the water table has been maintained (i. e. water saturation has been established).
- And when the soil was compacted mechanically using a medium sized sledge hammer (reduced porosity and water saturation).

Compaction was carried out at two layers, the first compaction was carried out when the basket was filled to 0.1 m and the second compaction was done when the basket was at 0.22 m (See Figure 2).

DGGeo-ERM 01, a terrameter manufactured by Dextol Global Geophysicals was used for data collection. Here, artificially generated electric currents are introduced into the ground and the resultant potential difference are measured at the surface [6].

The meter displays the resistance of the respective electrode separation and the apparent resistivity of the configuration was calculated using the formula;

$$\varrho = 2\pi aR$$

Where ϱ is the apparent resistivity, a is the electrode separation distance and R is the measured resistance.
The apparent resistivity values was used to produce a plot for the four various instances; i. e. when the soil sample is dry, when water infiltration is allowed, when water table is established and when the soil is compacted. The results are displayed in histograms to compare the electrical resistivity for the various instances.

Fig 2:- a. showing the perforated basket during mechanical compaction b. showing the configuration for the dry sample while data is being acquired.

III. RESULTS AND DISCUSSION

The results of the VES using the CST revealed a one layer curve, this is traceable to the homogenous geologic material used for the study. The obtained curves have positive trends with high resistivity values obtained from small electrode separation.

The resistivity values for each cases increases as the separation distances is being increased. This implies that; deeper depth has higher resistivity while shallow depth has lower resistivity. The observed increase in resistivity at deeper depth could be responsible to reduction in porosity or water content which is justifiable based on the load caused by sediments of the shallower depth. However, this interpretation given for this case may not always be applicable on field as nature presents various instances to geoscientists. Much more that the porosity or water saturation are not the only factors that affects or determines the electrical resistivity of geologic materials.

The results of the four cases at a particular electrode separations was analysed using histogram. Results for a = 0.02 m, 0.04 m, 0.06 m, 0.08 m, and 0.1 m was displayed in Histogram (Figure 4). A similar trend was observed for all the five results; the dry sample case which is our reference has the highest resistivity readings followed by the infiltration case, then the compacted case and then the water table case (See Figure 4).

For a = 0.02 m; the resistivity of dry case is; 300.12 Ωm, the resistivity of infiltration case is; 259.809 Ωm, the resistivity of wet case is; 87.66 Ωm, the resistivity of compacted case is; 144.859 Ωm.

For a = 0.04 m; the resistivity of dry case is; 698.612 Ωm, the resistivity of infiltration case is; 282.936 Ωm, the resistivity of wet case is; 103.381 Ωm, the resistivity of compacted case is; 174.301 Ωm.

For a = 0.06 m; the resistivity of dry case is; 1016.151 Ωm, the resistivity of infiltration case is; 546.082 Ωm, the resistivity of wet case is; 398.145 Ωm, the resistivity of compacted case is; 428.267 Ωm.

For a = 0.08 m; the resistivity of dry case is; 1450.55 Ωm, the resistivity of infiltration case is; 751.439 Ωm, the resistivity of wet case is; 487.469 Ωm, the resistivity of compacted case is; 600.210 Ωm.

For a = 0.1 m; the resistivity of dry case is; 1756.507 Ωm, the resistivity of infiltration case is; 943.755 Ωm, the resistivity of wet case is; 614.799 Ωm, the resistivity of compacted case is; 846.723 Ωm.

Further quantitative analysis reveals that the increase in water level or water saturation in the basket test was responsible for the gross reduction in electrical resistivity of the geologic material by 71 % when a = 0.02 m, by 85 % when a = 0.04 m, by 61 % when a = 0.06 m, by 66 %, when a = 0.08 m, by 65 %, when a = 0.1 m.

On the average, the increase in the saturation of water in the sample has decreased the electrical resistivity by 69.6 %.

Also, a side by side quantitative analysis of the effect of compaction was done. It revealed that compaction of sediment increased the resistivity by 39 % when a = 0.02 m, by 41 % when a = 0.04 m, by 7 % when a = 0.06 m, by 19 %, when a = 0.08 m, by 27 %, when a = 0.1 m.

On the average, the reduction in porosity of the sample has increased the electrical resistivity by 26.6%.

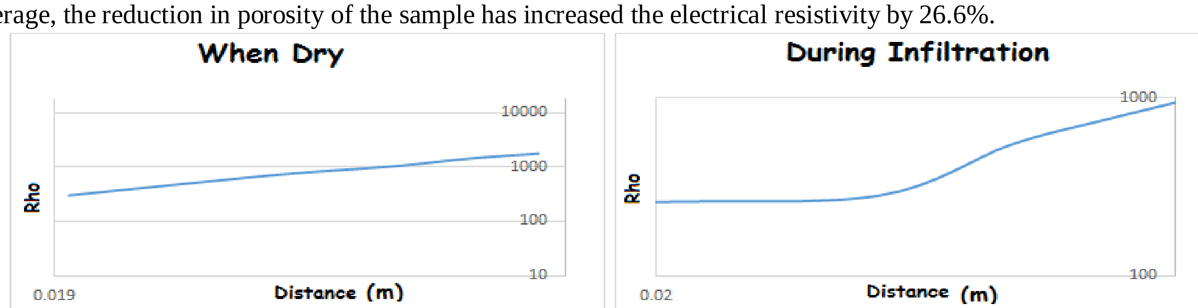

Fig 3:- (a). Showing the apparent resistivity against distance for dry and loose garden soil (b). Showing the apparent resistivity against distance during infiltration.

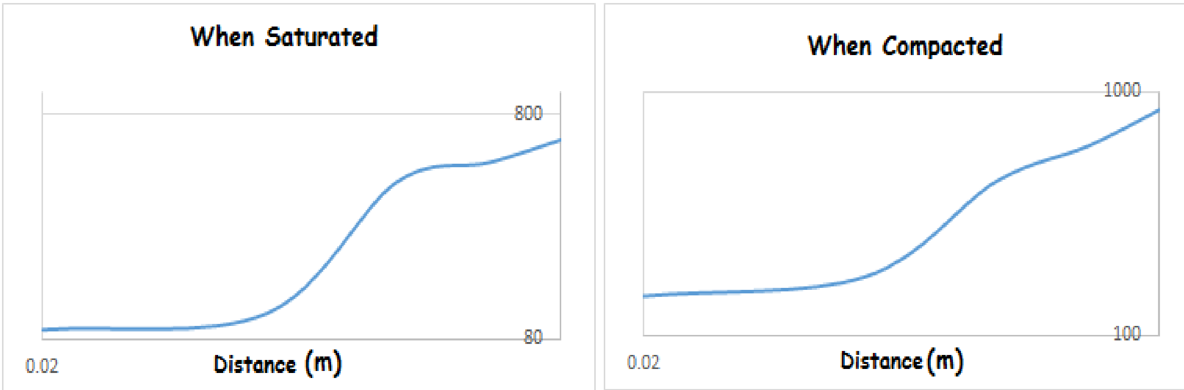

Fig 4:- (c). Showing the apparent resistivity against distance when saturated (d). Showing the apparent resistivity against distance when compacted.

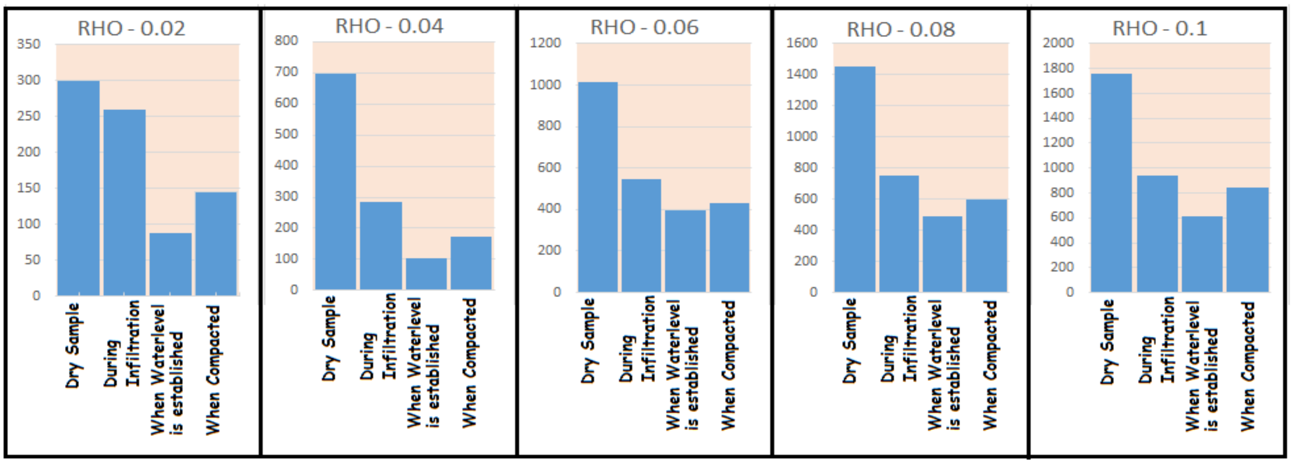

Fig 5:- Histograms of the various instances when a is 0.02 m, 0.04 m, 0.06 m, 0.08 m, 0.1 m.

IV. CONCLUSIONS

This research work has clearly revealed that water saturation and porosity has so much to do with the electrical properties of geologic formations. From this research work, one can easily conclude that a loose and dry geologic material (i. e. one that has air filling its pores rather than water) would be highly resistive than a geologic material that has water filling its pores. Also, the loose and dry geologic material would be highly resistive than a lithified formation that has water molecules in its pore spaces (this has been shown in figure 4).

This is usually the case with compacted clay formation, low resistivity reading is usually observed with clay because it is characterised with high porosity and low permeability. When undergoing compaction and lithification, it dispels some of its pores but still has some water retained in its pores, this water bodies contribute to the low resistivity reading that is being observed from clay formations.

Also, this study has proved Archie's relationship to be true. When an attempt to increase the water saturation (porosity) was made, the resistivity is greatly reduced. i. e. it becomes more conductive. Also, when an attempt was made to reduce the water bodies and porosity through mechanical compaction, the resistivity increased. This clearly reveals that porosity and water saturation has so much to do with the electrical properties of geologic formation.

Other basic conclusions that could be made from this study is that; the electrical resistivity of a geologic formation reduces when there is an increased porosity or traces of water. Conversely, there is an increase in resistivity when porosity is reduced provided the formation does not have stint of metallic minerals, salt water or other dissolved salts which could contribute to increased electron interactions.

V. ACQUIRED FIELD DATA

When Dry

a (m)	a (cm)	R (Ω)	RHO (Ωm)
0.02	2	2387.969	300.12
0.04	4	2778.577	698.6122
0.06	6	2694.43	1016.151
0.08	8	2884.61	1450.55
0.1	10	2794.44	1756.507

During Filtration

a (m)	a (cm)	R (Ω)	RHO (Ωm)
0.02	2	2066.66	259.809
0.04	4	1125.317	282.936
0.06	6	1447.945	546.0822
0.08	8	1494.34	751.439
0.1	10	1501.42	943.755

When Wet

a (m)	a (cm)	R (Ω)	RHO (Ωm)
0.02	2	697.321	87.66
0.04	4	411.176	103.3815
0.06	6	1055.688	398.1454
0.08	8	969.3989	487.469
0.1	10	978.0898	614.7994

When Compacted

a (m)	a (cm)	R (Ω)	RHO (Ωm)
0.02	2	1152.29	144.859
0.04	4	693.24	174.301
0.06	6	1135.56	428.2667
0.08	8	1193.925	600.21
0.1	10	1347.058	846.7226

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