PETROPHYSICAL CHARACTERISTICS OF ROCKS IN GIREI LOCAL GOVERNMENT AREA OF ADAMAWA STATE, N.E. NIGERIA.

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ABSTRACT
Petrophysical measurements namely; electrical resistivity, density, porosity, electrical resistivity anisotropy and water saturation were performed on fourteen representative surface rock samples from Girei, part of the Yola arm of the Upper Benue trough, NE Nigeria. The purpose was to provide information required for determining the electrical conductivity mechanism of these rocks. This will further aid in the interpretation of down hole, ground and air-borne electromagnetic surveys. The two electrode method was used in the resistivity measurements while density and porosity were measured following Olhoeft and Johnson, 1990 and Scromeda and Connell, 2001 techniques. Results obtained showed that the dry bulk density, ñ$_d$, were in the range of 1.86 to 2.23g/cm^3 with an average of 2.08$\pm$0.03g/cm^3, wet density, ñ$_w$ ranged from 2.11 to 2.55g/cm^3 with an average of 2.23$\pm$ 0.03 g/cm^3 and particle or grain density ñ$_g$ ranged from 2.47 to 2.81g/cm^3 having an average of 2.59$\pm$0.03 . Porosity, Ô values were in the range of 0.12-0.28 with a mean value of 0.20$\pm$0.01. Results of the electrical resistivity of the saturated rock samples gave values of 7.485 to 10.690 x 10^3 m with an average of 8.160 $\pm$ 0.229 x 10^3 m. Investigation of the relationship of porosity and water saturation showed a direct proportionality with saturation increasing with increasing porosity. The preferred orientation of the water wet pores results in low electrical anisotropy values from 1.2:1 to 1.7:1.

Key words: Electrical resistivity, Density, Porosity, Anisotropy, Petrophysical.

Introduction

Petrophysical properties of rocks are valuable information for the interpretation of down hole ground and air borne electromagnetic surveys. They are also useful in determining the electrical conductivity mechanisms of rocks. The petrophysical parameters usually measured include density, porosity, electrical resistivity, temperature, pressure, permeability, water saturation, thermal conductivity etc. In this study the parameters measured include: density, porosity, electrical resistivity and water saturation.

Electrical conductivity in porous media or rocks bearing water is controlled by two main mechanisms: the pore fluid (ionic or electrolytic) conductivity and the fluid-solid (surface) conductivity (Salem and Chilingarian, 1999 and Attia *et al*, 2007*)*. The electrolytic conductivity depends on the fluid conductivity, which is affected by the ionic composition (salinity), ionic-exchange capacity of the solid matrix and acidity-alkalinity of the pore fluid. The surface conductivity depends on the clay conductivity, which is affected by the content and type of clay, and the large ions concentrating at the grain boundaries. In the process of electric current conduction, the surface conductivity becomes dominant when the pore fluid has a low concentration of ions (fresh water). When the pores are saturated with saline water, ionic conductivity becomes dominant, because the conduction of electric current takes place through the saline water (Salem and Chilingarian, 1999). In electrolytic conductivity, the geometry of the pore or crack

space determines the geometry of the conductive path (Schon, 1996). This includes properties like porosity and tortuosity. The electrical resistivity of rocks is also influenced by the metal content, permeability, temperature and pressure.

There have been no available petrophysical data of rocks from Girei, hence the need to provide a firsthand database for these rocks.
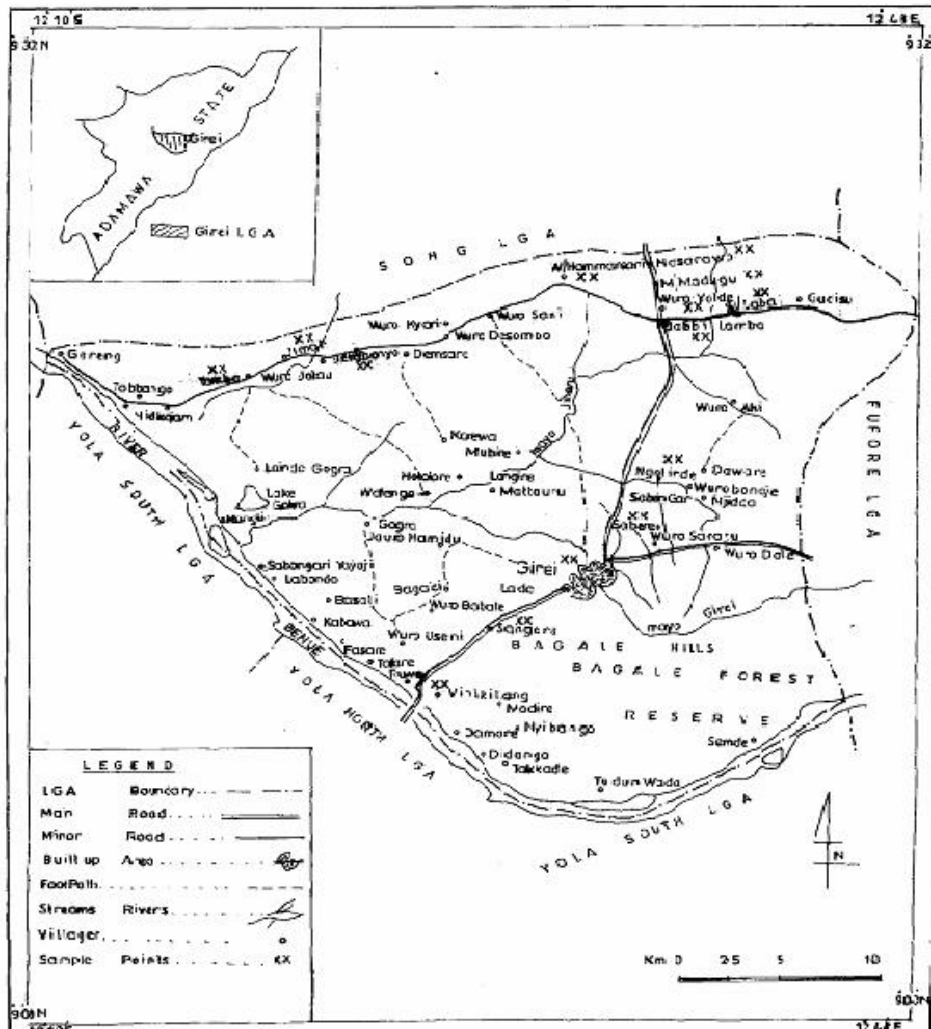

Figure 1.0: Map of study area showing sample locations

Geology of the Study Area

The trough is composed mainly of the Bima sandstone formation and quartenary river coarse alluvium. The Bima sandstone comprises the oldest sediments in the upper Benue trough which directly overlie the crystalline basement rocks. Carter et al (1968) and Allix (1983) gave descriptions of the sequence exposed there and recognized three fold subdivisions; namely: the upper Bima (B3), the middle Bima (B2) and the lower Bima (B1).

The upper Bima is fairly homogenous, relatively mature, fine to coarse-grained, thick-bedded sandstone with abundant sedimentary structures. It is widespread and may attain more than 1700m in thickness. The sequence was deposited under fluvatile to deltaic environment. (Carter *et al*, 1968). The late Albian to early Cenomanian age is assigned to this upper member (Whiteman, 1982).

The middle Bima (B2) is a fairly uniform unit composed of very coarse-grained, feldspathic sandstone with thin Bands of clay, silts, shale and occasional calcareous sandstone. It varies in thickness from 300m to 1200m. A tentative middle Albian age has been assigned to it by Whiteman (1982) on the basis of pollens and radiometric data obtained from intercalated lavas.

The Lower Bima appears in the core of the Lamurde anticline. It is consists of coarse- grained feldspathic sandstone alternating with red, purple shale and occasional bands of calcareous sandstone and siltstone. It is a highly variable unit with an over all thickness of 0 to over 500m. An upper Aptian/Albian age has been assigned to this part of Bima sandstone (Kogbe, 1989).

Methods of investigation/sample collection and preparation

Fourteen representative surface rock samples labeled S_1-S_{14} were collected from different locations in the study area. The samples locations were determined using a Global Positioning System (GPS). The method used by Scromeda et al (2000) was adopted for sample preparation. Firstly, the samples were cut into rectangular shapes, each with a cross sectional area of 2.0cm by 2.0cm and a thickness of 1.5cm. This is to ensure accurate determinations of their dimensions that will be useful in resistivity calculations. Thereafter, a lapping disk machine (or shaping-up rock machine) was used to smoothen the surface for good electrode contact.

Each sample was then placed in a beaker containing about 400ml of borehole water labeled Sw_1-Sw_{14} obtained from the study area to saturate them for 48hours. A brief description of the sample types, locations, and positions are shown in table 1.0.

Table 1.0: Samples description and location

Sample	Description	Location	Latitude	Longitude
S_1	Very fine-grained sandstone	Wuro Ngolirde	$9^0 26' 28.3''$N	$12^0 34' 07.0''$N
S_2	Fine-grained sandstone	Wuro Labai	$9^0 30' 14.9''$N	$12^0 39' 22.7''$E
S_3	Limonitic feldspathic coarse-grained sandstone	Jabbi Lamba	$9^0 30' 17.8''$N	$12^0 36' 15.1''$E
S_4	Weathered conglomerate	Nasarawo	$9^0 31' 22.7''$N	$12^0 33' 47.6''$E
S_5	Weathered coarse-grained sandstone	Mallam madugu	$9^0 31' 12.4''$N	$12^0 34' 11.5''$E
S_6	Limonitic medium-grained sandstone	Wuro yolde	$9^0 30' 46.8''$N	$12^0 34' 30.0''$E
S_7	Limonitic coarse-grained sandstone	Tambo	$9^0 29' 59.8''$N	$12^0 20' 59.9''$E
S_8	Slightly ferrigenous coarse-grained sandstone	Jimoh	$9^0 29' 12.7''$N	$12^0 23' 05.7''$E
S_9	Feldspatic ferrigenous sandstone	Jera Bonyo	$9^0 29' 40.9''$N	$12^0 26' 54.2''$E
S_{10}	Fine-grained sandstone	Wuro Hamsani	$9^0 31' 27.8''$N	$12^0 31' 50.5''$E
S_{11}	Medium-grained sandstone	Sabere	$9^0\ 23' 53.4''$N	$12^0 33' 26.2''$E
S_{12}	Coarse-gritty sandstone	Girei	$9^0\ 21' 09.1''$N	$12^0 31' 46.8''$E
S_{13}	Medium-grained sandstone	Sangere (FUTY)	$9\ 18' 18.8''$N	$12^0 29' 47.3''$E
S_{14}	Coarse-grained sandstone	Vaniklang	$9^0 18' 18.8''$N	$12^0 28' 46.0''$E

Density measurement

Density measurement of the samples was carried out. This is also part of the porosity determining procedure. The dry weight of the sample were first measured in air and then in water using an analytical balance. After 48 hours of water saturation, the wet weight of the samples were determined in air and then in water. The dry bulk density,

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64

$ñ_d$, wet or saturated density, $ñ_w$ and the grain or particle density $ñ_g$ were then determined. Following Ajakaiye, (1989), Olhoeft and Johnson, (1990), and Scromeda and Katsube,(2000) the dry bulk, wet and grain density were determined as follows;

$$\rho_d = \frac{M_d}{M_w - M_w^*} \qquad\qquad 1.0$$

$$\rho_w = \frac{M_w}{M_w - M_w^*} \qquad\qquad 2.0$$

$$\rho_g = \frac{M_d}{M_d - M_w^*} \qquad\qquad 3.0$$

where: M_d is dry weight in air

M_w is wet weight in air

M_w^* is wet weight in water.

Porosity measurement
Following Olhoeft and Johnson (1990), and Scromeda and Connel, (2001) the porosity of the samples was determined using the relation:

$$\phi = \left(1 - \frac{\rho_d}{\rho_g}\right)100 \qquad\qquad 4.0$$

Where, Ø, $ñ_d$, and $ñ_g$ are porosity, dry bulk density and grain density respectively. The methods of obtaining $ñ_d$ and $ñ_g$ have been discussed in section 3.1. Porosity values ranges from 0 – 1 or 0 – 100%.

Measurement of the rock resistivity
Laboratory measurement of the electrical resistivity of the rock samples were performed using the two electrode method proposed by Telford et al, (1978) and Contreras et al, (1986). The experimental set-up is as shown below:
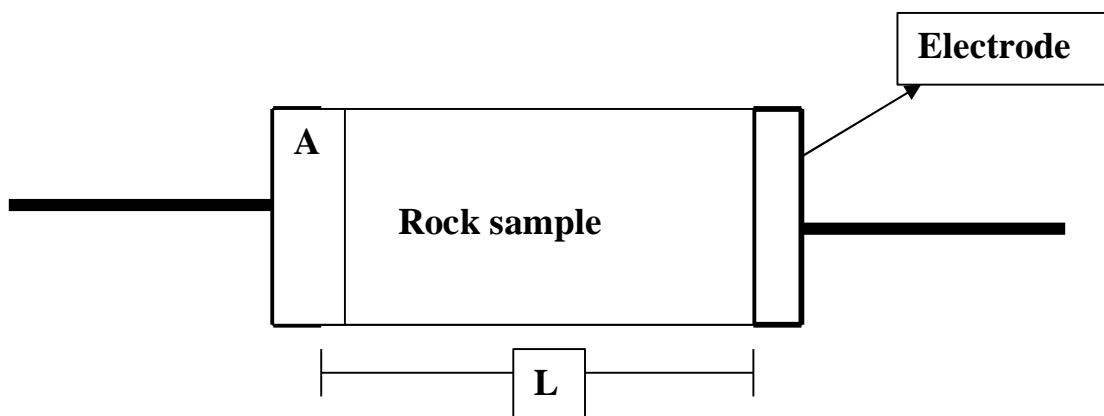

Figure 2.0: A schematic diagram showing experimental set-up for measurement of resistivity of rock sample.

The end electrodes were made of brass plates cut into square shapes (2cm x 2cm) and designed to cover each end of the sample perfectly well. A modest axial pressure

was applied to ensure complete electrode contact with the sample. A constant voltage (V) of 1100V was applied and the current through the sample was measured. About five measurements of the current (I) were made for each sample and the mean taken. The voltage and current values were measured using the Leakage Current-Breakdown Voltage and Tera ohm-meter. The sample resistance, r_s is then obtained from the relation:

$$r_s = \frac{V}{I} \qquad\qquad 5.0$$

And the resistivity, R

$$R = r_s\left(\frac{A}{L}\right) \qquad\qquad 6.0$$

where: A is the cross sectional area, and L the length of the sample.

Following standard procedures applied by Connell *et al*, (2000) and Scromeda *et al*, (2000), the electrical resistivity (R_o) of the rocks at 100% water saturation was measured at 24 and 48 hours after saturation with borehole water and the mean taken. This was to ensure that the electrical resistivity values were stable with time. Under this state, it was expected that the water had chemically equilibrated with the rock and represented in situ conditions. Before measurements, the surfaces of the rock samples removed from the beaker were first wiped with tissue paper. This action rendered the samples saturated-surface dry.

Measurement of resistivity of water samples

Water samples used to saturate the rocks were collected from fourteen functional boreholes/wells from different locations within the study area. The conductivity of the water samples were first measured using conductivity meter at 35^0C. The resistivity, R_w of the water samples were then obtained by taking the reciprocal of the conductivity.

Measurement of water saturation

From the annual book of ASTM (American Society of Testing and Materials) as quoted by http:/en.wikipedia.org/wiki/water-content, the total evaporable moisture content (water saturation) in aggregate (C566) can be calculated with the formula:

$$S_w = \frac{100(W - D)}{D} \qquad\qquad 7.0$$

where:
S_w is the water saturation,
W is the mass of the saturated sample in grammes and
D is mass of the dried sample in grammes.
The above formula was used to obtain various values of water saturation.

Electrical anisotropy determination

Electrical anisotropy characteristics of the rocks were also investigated. Eleven samples were chosen and tested for anisotropy, ë. Resistivity measurements were carried out on the three sides of the sample. The values of electrical resistivity anisotropy was obtained by taking the ratio of the resistivity value for the side showing the largest value over the resistivity value for the direction showing the smallest value (Connell, 2000a).

Analytical results

The results of density and water saturation determination are presented in table 2.0. the values of the dry bulk density, $\tilde{n}_d$ are in the range of 1.86-2.33g/cm^3 with an average of 2.08 ± 0.03 g/cm^3 ,the wet density $\tilde{n}_w$ are in the range of 2.11-2.55g/cm^3 with an average of 2.23 ± 0.03 g/cm^3 while the grain density $\tilde{n}_g$ ranges from 2.47- 2.81g/cm^3 having an average of 2.59 ± 0.03 g/cm^3. Water saturation values ranges from 4.13 to 15.08% with an average of 9.60 ± 0.78%.

Table 2.0: Masses, water saturation, the bulk density, wet density and grain density.

Sample	M_d (g)	M_t (g)	M_w (g)	M^*_w (g)	S_W (%)	$\tilde{n}_d$ (g/cm^3)	$\tilde{n}_w$ (g/cm^3)	$\tilde{n}_g$ (g/cm^3)
S_1	17.72 ± 0.01	9.87 ± 0.03	19.64 ± 0.02	10.97 ± 0.02	10.84	2.04 ± 0.02	2.27 ± 0.01	2.63 ± 0.02
S_2	16.21 ± 0.00	9.24 ± 0.02	18.13 ± 0.02	9.67 ± 0.02	11.85	1.92 ± 0.02	2.14 ± 0.01	2.48 ± 0.04
S_3	21.16 ± 0.02	12.81 ± 0.00	22.44 ± 0.00	13.65 ± 0.01	6.05	2.41 ± 0.03	2.55 ± 0.04	2.82 ± 0.04
S_4	22.47 ± 0.02	12.56 ± 0.00	24.99 ± 0.01	13.72 ± 0.01	11.22	1.99 ± 0.03	2.22 ± 0.02	2.57 ± 0.02
S_5	25.23 ± 0.01	14.58 ± 0.00	28.21 ± 0.02	16.24 ± 0.02	11.81	2.11 ± 0.02	2.36 ± 0.02	2.81 ± 0.03
S_6	19.61 ± 0.02	11.71 ± 0.01	22.11 ± 0.01	12.27 ± 0.02	12.75	1.99 ± 0.02	2.11 ± 0.02	2.47 ± 0.01
S_7	31.54 ± 0.00	18.42 ± 0.02	33.59 ± 0.01	19.14 ± 0.00	6.50	2.18 ± 0.02	2.46 ± 0.01	2.54 ± 0.02
S_8	19.84 ± 0.00	11.59 ± 0.02	21.78 ± 0.02	12.37 ± 0.00	9.78	2.11 ± 0.01	2.32 ± 0.01	2.66 ± 0.03
S_9	29.11 ± 0.02	16.59 ± 0.02	30.82 ± 0.01	17.63 ± 0.03	5.87	2.21 ± 0.02	2.34 ± 0.01	2.54 ± 0.06
S_{10}	13.36 ± 0.01	7.80 ± 0.01	14.92 ± 0.02	8.10 ± 0.03	11.68	1.96 ± 0.05	2.19 ± 0.02	2.54 ± 0.03
S_{11}	22.96 ± 0.02	13.03 ± 0.01	25.04 ± 0.01	13.94 ± 0.02	9.06	2.07 ± 0.03	2.26 ± 0.04	2.55 ± 0.01
S_{12}	22.36 ± 0.00	12.49 ± 0.00	24.09 ± 0.02	13.65 ± 0.01	7.74	2.14 ± 0.03	2.31 ± 0.04	2.57 ± 0.01
S_{13}	19.60 ± 0.02	11.17 ± 0.02	20.41 ± 0.01	11.86 ± 0.02	4.13	2.23 ± 0.02	2.32 ± 0.02	2.53 ± 0.02
S_{14}	13.33 ± 0.01	7.69 ± 0.00	15.34 ± 0.01	8.16 ± 0.03	15.08	1.86 ± 0.01	2.14 ± 0.02	2.58 ± 0.01

Table 3.0 shows electrical resistivity values for the saturated rock samples, R_o resistivity of water used for saturating the rocks, R_w and the samples porosity, $\hat{O}$. Porosity values range from 11.9-27.9% (0.12-0.28). R_w values were in the range of 1.01-26.32 m. Ro ranges from 7.485×10^3-10.690×10^3 m with an average of $8.160 \pm 0.229 \times 10^3$ m. Plots showing variation of porosity and wet and dry bulk density of

Girei sandstones are shown in figure 3.0 while that showing the relationship between water saturation and porosity is displayed in figure 4.0.
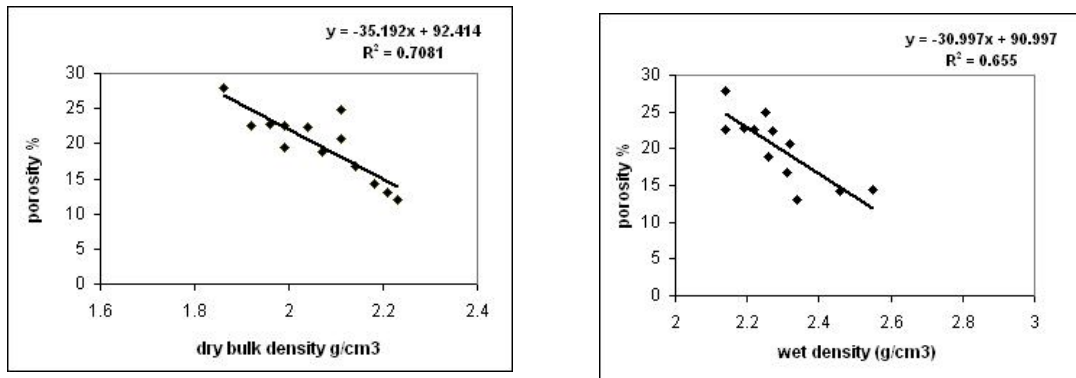

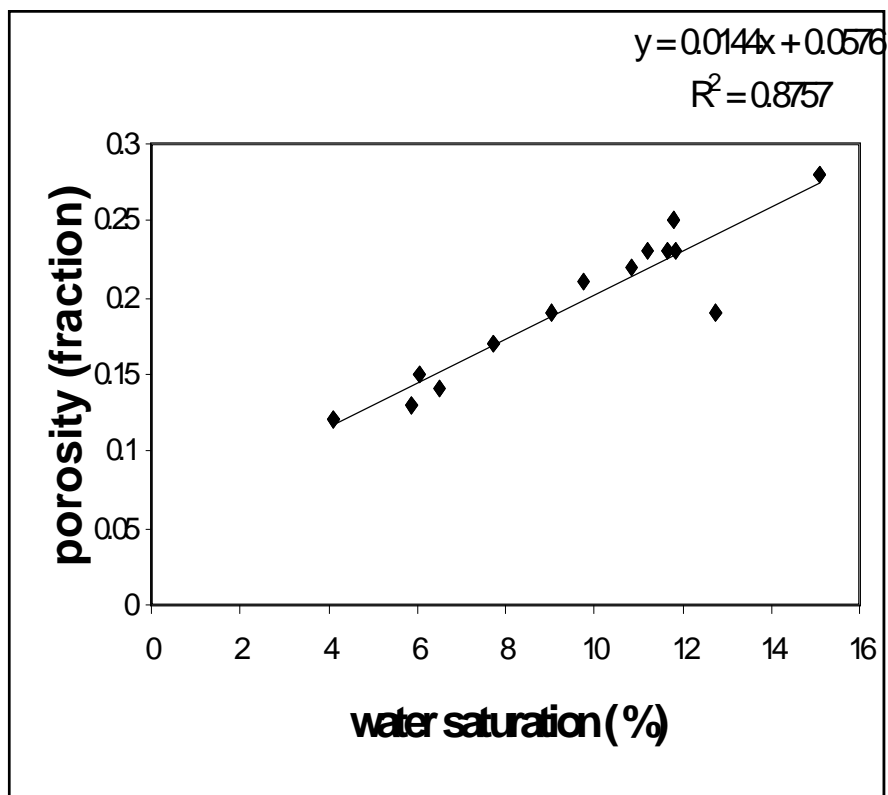Figure 2.0: Variation of porosity with dry bulk density and wet density

Figure 3.0: Variation of porosity with water saturation

Table 3.0: Conductivity of saturating water samples ($á_w$), electrical resistivity for saturated samples (R_o), Resistivity of saturating water samples(R_w) and porosity($Ô$)

Sample	$á_w$ (mho)	R_w (m)	R_o X10^3(m)	$Ô$ (fraction)	log $Ô$
S_1	0.046	21.739	7.817$\pm$0.198	0.22	-0.658
S_2	0.044	22.727	7.890$\pm$0.261	0.23	-0.638
S_3	0.640	1.560	10.690$\pm$1.485	0.15	-0.854
S_4	0.520	1.920	7.674$\pm$0.191	0.23	-0.638
S_5	0.180	5.560	7.560$\pm$0.039	0.25	-0.602
S_6	0.099	10.100	7.824$\pm$0.303	0.19	-0.721
S_7	0.038	26.320	8.562$\pm$0.963	0.14	-0.854
S_8	0.019	52.910	8.569$\pm$0.684	0.21	-0.678
S_9	0.990	1.010	7.485$\pm$0.115	0.13	-0.886
S_{10}	0.050	20.000	8.160$\pm$0.012	0.23	-0.638
S_{11}	0.049	20.41	8.050$\pm$0.331	0.19	-0.721
S_{12}	0.481	2.080	7.975$\pm$0.174	0.17	-0.770
S_{13}	0.270	3.700	8.118$\pm$0.410	0.12	-0.921
S_{14}	0.040	25.000	7.774$\pm$0.155	0.28	-0.553

Table 4.0 shows electrical resistivity anisotropy values for the eleven rock samples investigated. Results showed low anisotropy of 1.2:1 to 1.7:1

Table 4.0: Results of electrical anisotropy measurements

Sample	Mean R_o (x 10^3 m)			Anisotropy $ë$
	á	**â**	**ã**	
S_1	7.817$\pm$0.198	4.714$\pm$0.000	4.588$\pm$0.223	1.7:1
S_2	7.980 $\pm$0.261	5.519$\pm$0.019	6.837$\pm$0.429	1.5:1
S_3	10.690$\pm$1.435	9.137$\pm$2.622	10.298$\pm$2.694	1.2:1
S_6	7.824$\pm$0.303	4.941$\pm$0.054	5.286$\pm$0.178	1.6:1
S_7	8.562$\pm$0.963	5.393$\pm$0.018	6.410$\pm$0.063	1.6:1
S_8	8.569$\pm$0.684	5.202$\pm$0.488	6.112$\pm$0.046	1.7:1
S_9	7.485$\pm$0.115	4.912$\pm$0.681	5.222$\pm$0.028	1.5:1
S_{11}	8.050$\pm$0.331	5.143$\pm$0.145	5.080$\pm$0.110	1.6:1
S_{12}	7.975$\pm$0.174	4.668$\pm$0.046	4.603$\pm$0.020	1.7:1
S_{13}	8.118$\pm$0.410	5.881$\pm$0.230	6.097$\pm$0.504	1.4:1
S_{14}	7.774$\pm$0.155	4.683$\pm$0.318	4.833$\pm$0.491	1.7:1

Discussion

The density values of the fourteen samples studied are in the range of 1.86 – 2.23g/cm^3 with an average value of 2.08$\pm$0.03 g/cm^3, 2.11 – 2.55 g/cm^3 having an average of 2.23$\pm$0.03 g/cm^3 and 2.47 – 2.81g/cm^3 with an average value of 2.59$\pm$0.03 g/cm^3 for the dry bulk density, wet density and grain density respectively. This result is

in agreement with established literatures with a difference of ± 0.20. (Grant and West, 1965, Keary and Brooks, 1996 and Lowrie, 2002).

The porosity of the samples investigated varied between 11.9 27.9% (0.12 – 0.28). For most part, samples with higher porosities have lower dry bulk and wet densities as would be expected. This is seen in the good correlation coefficient of 0.7081 and 0.655 respectively in figure 3.0. On the basis of the conceptual relations between porosities and densities, this can be interpreted as indicating that porosity is the main cause of density variation.

Investigation of the relationship between water saturation and porosity shows an excellent linear correlation. This is shown in figure 4.0. The correlation coefficient R^2 is 0.8754. The plot shows that the amount of water contained in a rock depends on the available pore space. Thus, increase in porosity increases the amount of water a rock can absorb and vice versa. This also explains why sedimentary rocks which are highly porous absorb more water than igneous rocks with low porosity.

Results of electrical resistivity measurements of the saturated rock samples showed values between 7.485 x 10^3 to 10.690 x 10^3 m with an average of 8.160$\pm$0.229 x 10^3 m. This resistivity values obtained are in general agreement with established literature (Grant and West 1965, Telford et al, 1978, Keary and Brooks, 1996 and Schon, 1996). The variation in the values obtained is due to the differences in the concentration of ions of the saturating liquids and the paths through which the electrolytic conduction takes place. Rocks with interconnected pores have a lower electrical resistivity values since it allows a smooth passage of the conducting fluid. In the other hand rocks with unconnected pores or tortuous paths have high electrical resistivity owing to uneasy passage of the conducting liquid. This further explains why care must be taken in trying to ensure tight electrical contacts, since it might lead to an increase in pressure which tends to close up the pore spaces, thereby decreasing electrical conductivity in the rocks.

The electrical anisotropy (ë) measurement of the eleven samples investigated showed that the rocks exhibit low anisotropy with values from 1.2:1 to 1.7:1. The anisotropy of the electrical resistivity in natural rocks is caused by the preferred orientation of conducting minerals or accessories (for example graphite, ores); the preferred orientation of the wet or water saturated pores or cracks, and fine layering of rock components with different conductivity (clay-sand sandwich layering) (Schon, 1996). The low anisotropy values indicate that there is almost uniform orientation of the conducting minerals and water saturated pores. The highest ë value of 1.7:1 is exhibited by samples S_1, S_8, S_{12} and S_{14}. Samples S_8, S_{12} and S_{14} are coarse-grained sandstones; hence the possibility that there may be varying orientation of the conducting mineral grains and water saturated pores. The reason for the behavior of S_1 being a fined-grained sandstone is yet unknown. The lowest anisotropy value of 1.2:1 is exhibited by sample S_3. Being a coarse-grained sandstone, the grains may be uniformly oriented, hence its low ë value.

Conclusion

This paper presents the results of some petrophysical measurements (electrical resistivity, porosity, density electrical anisotropy and water saturation) of fourteen rock samples from Girei. Local Government Area of Adamawa State, N.E of Nigeria.

Results of density measurements gave average values of 2.08 $\pm$ 0.03g/cm^3, 2.23 $\pm$ 0.03g/cm^3 and 2.59 $\pm$ 0.03g/cm^3 for the dry bulk, wet and grain density respectively.

Porosity values ranged from 0.12 to 0.28 while water saturation values varied from 4.13 to 15.08% with and average of 9.60 ±0.78. a mean value of 8.160±0.229 x 10^3 m was obtained for the electrical resistivity while low anisotropy was also evident and ranged from 1.2:1 to 1.7: 1 showing that the rocks grains are uniformly oriented.

Plots of porosity versus dry and wet density showed an inverse relationship between both parameters, while that of porosity and water saturation showed that both parameters are directly related.

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