

Investigation of Frequency-dependent Conductivity Signatures of Geological Materials from Ewekoro, Eastern Dahomey Basin

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Abstract: Frequency-dependent conductivity measurements can be used to study the electrical behaviour of rocks for rock typing and petrophysical evaluation. In this study, frequency-dependent conductivity was computed from dielectric measurements under ambient conditions on dry, humidified/hydrated and saturated samples of limestone, sandstone, shale and glauconite from Ewekoro within the eastern Dahomey Basin. The frequency of the applied field was varied from 40 Hz to 110 MHz using a precision impedance analyzer (Agilent 4294) and a test/measurement probe specially fabricated for parallel plate measurement. Geochemical analysis was also conducted on pieces obtained from the geological materials during sample preparation. Siliclastic sandstone and shale have similar SiO_2 and Al_2O_3 concentrations but shale samples have slightly higher concentrations of Fe_2O_3 and TiO_2 . Limestone and glauconite also share similar CaO concentrations but in SiO_2 concentration. All the geological types show dispersion of conductivity in dry, partial-water saturation as well as full-water saturation. However, the frequency range of this dispersion varies depending on the type of material and is somehow influenced by the saturation level. Except for magnitudes, the conductivity changes with frequency for both dry and partially water-saturated rocks are comparable. The electrical properties of the rocks rise as a result of greater polarization that takes place after partial saturation. As a result, the hydrated samples have slightly higher conductivity values. Due to the presence of mobile ions in the conduction process, polarization is further strengthened and the liquid's overall effect gives higher conductivity values under complete saturation. Compared to both dry and hydrated samples, the conductivity values for fully saturated samples are at least one

order of magnitude higher. The conductivity of shale and glauconite is found to be a significant order of magnitude higher than that of limestone and sandstone, regardless of whether the rocks are dry or saturated, according to frequency-dependent properties. This behaviour is partially explained by the clay-like conductive (charge particle) properties of glauconite and shale. Additionally, at very high frequencies, sample-electrode effects have relatively little effect on conductivity across the measurement frequency range. These discernible variations in electrical characteristics can serve as robust tool for classifying different types of rocks and in petrophysical analyses.

Keywords: Dielectric measurement; electrical properties; frequency dependent conductivity; geological materials; eastern Dahomey Basin

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1.0 Introduction

The electrical properties of rocks are of great interest for the exploration of the subsurface materials and features such as rocks, minerals, groundwater, faults, fissures etc. in the Earth's crust (Olhoeft, 1976). The electrical properties of rocks and minerals can be characterised in terms of dielectric permittivity, dielectric loss, resistivity and conductivity (Knight and Nur, 1987; Knight and Endres, 1990; Knight and Abad, 1995; Kyritsis et al., 2000; Olatinsu et al., 2017). Dielectric parameters are the most significant electrical properties of rock since most rocks have high resistivity (Ward and Fraser, 1967; Olhoeft, 1976; McNeil, 1980). The investigation of these properties is particularly important when using alternating-current methods of electrical exploration (Keller and Frischknecht, 1966; Ward, 1967; Swift, 1988). Alternating current conductivity of rocks and minerals is extremely sensitive to physical conditions such as temperature and pressure, the chemical composition of the solid and liquid phases (e.g. water, oil, brine etc), oxygen fugacity and microstructural factors such as porosity (Chelidze et al., 1999; Friedman, 2005; Carcione et al., 2007; Stillman and Olhoeft, 2008; Pimienta et al., 2019). Rocks are multi-component systems which consist of crystals, as well as amorphous solids, liquids, and gases. This makes the study of their physical properties complex. While the main constituents of a rock are the solid minerals, properties such as dielectric permittivity and electrical conductivity are determined mainly by the water content (Parkhomenko, 1967; Taherian et al., 1990; Garrouch and Sharma, 1994; Nettelblad and Niklasson, 1994; Knight and Abad, 1995). The electrical conductivity of different rocks and soils lays the foundation for large-scale non-invasive subsurface techniques such as electrical and electromagnetic methods as well as electrical logging that have been extensively used for near-surface, environmental, and hydrogeological investigations (Archie, 1942; Waxman and Smits,

1968; Ward, 1990; Chelidze et al., 1999; Chelidze and Gueguen, 1999; Glover, 2015; Qi and Wu, 2022). In oil and gas reservoirs, the interaction between the injected fluids and the reservoir fluids and rocks plays a major role in the productivity of any oil and gas field. Investigating the ion exchange between reservoir fluids and the injected fluids for water flooding or chemical-enhanced oil recovery purposes has been very useful in optimizing the oil displacement process and hence the productivity from such secondary recovery mechanisms (Saw and Mandal, 2023).

In general, the conductivity in rocks and minerals is electrolytic and takes place through the moisture-filled pores and passages which are present within the insulating matrix (Ward and Fraser, 1967; McNeil, 1980). Most rocks have pore spaces which are often partially filled with ionic fluids such as freshwater, brackish water, ocean water and brine (Chinh, 2000). Electrical current typically favours flowing through the porespace whenever feasible due to the higher conductivity of pore fluids compared to the majority of rock-forming minerals. Therefore, the rock's porosity, fluid saturation, and the kind of fluid that is held within the pore space all have a substantial impact on its bulk conductivity (Schepers and Milsch, 2013). The only material that occupies the pore space in unsaturated rocks is air and it compels the current to pass through the minerals that make up the rock because it is resistive (Makhnenko and Labuz, 2016). Unsaturated rocks are therefore not very conductive. The pore fluid can provide a more effective current channel when a significant portion of the pore-space is saturated (Berg et al., 2022). Therefore, when fluid saturation rises, rocks' bulk conductivity typically rises as well. Ionic conduction is the process by which current moves through the pore-fluid of a rock. Consequently, the concentration of dissolved ions determines the conductivity of the pore-fluid (Klein, and Santamarina, 2003). As dissolved ion concentration rises, so does pore-fluid conductivity. This suggests that rocks with a higher



concentration of ionic fluid are more conductive than those with fresh water.

The conductivity of rocks is important because it can be used to study the interaction between fluids and rocks in oil and gas reservoirs. It can be measured using dielectric techniques and this can also be used to investigate other properties of rocks, such as their wettability, fluid-rock interaction, porosity, oil and gas productivity, and mineralogy (Geng et al., 1983; Wright and Nelson, 1993; Bona et al., 2001; Alarifi and Mahmoud, 2022). When free ions and salts are present in fluids, dielectric laboratory experiments can identify the change in conductivity at high frequencies. Previous researchers' attempts to evaluate the electrical conductivity and dielectric constant of moist rock and soil samples in the laboratory have resulted in surprisingly high dielectric constant values at low frequencies. Some workers have questioned the validity of these high findings, attributing them to measurement error (Scott et al., 1967). However, in recent times, the instrumentation and techniques have improved tremendously. In this present work, conductivity signatures of sedimentary geological materials (limestone, sandstone, glauconite and shale) from a quarry site in Ewekoro using laboratory dielectric measurements have been investigated in the frequency range of 40 Hz to 110 MHz. The analyses of conductivity data via dielectric measurement on these representative siliclastic and carbonate samples could be a robust and valuable

tool of evaluating the influence of moisture and water saturation on reservoir characteristics.

2.0 Material and Methods

2.1 Sample Description and Preparation

Twenty-two (22) rock samples consisting of limestone (8), sandstone (4), shale (5), and glauconite (5), were collected by random sampling from some locations at Ewekoro. The coordinates of these locations fall within: elevation, 72 – 125 ft; latitude, 06° 54.082' – 06° 55.492'; and longitude, 003° 10.359' – 003° 12.279'. The colour and texture of the various samples vary considerably. Some limestone samples are similar to some of the other samples (Fig. 1). Table 1 summarizes the physical properties of the samples collected for this study.

Preliminary sample preparation involved cutting the samples into approximately disc shapes with the aid of a diamond saw electrically operated through a Siemens Angle cutter. A range of values of diameter and thickness were obtained, depending on the size of the original lump of sample (Table 2). The disk-shaped sample surfaces were later ground and polished using a grinding machine to obtain as nearly as possible smooth, parallel faces. Sandstone samples due to porosity/pore spaces generally retained some very small degree of roughness. They were then kept in polyethene bags and later glass containers to avoid moisture. The rock pieces obtained from the process of obtaining disc-shaped samples were used for the geochemical analysis.

Table 1: Physical characteristics of the rock samples from Ewekoro

Rock Type	Colour	Texture
Limestone	Chalk white, light grey, grey, greenish, brown	Fine-to-medium, coarse grains
Sandstone	Brown, reddish-brown	Medium, coarse grains
Shale	Light grey, grey	Slaty, laminated, smooth pellet-like grains
Glauconite	Greenish	Hard, pellet-like grains



2.2 Geochemical Analysis

Rock pieces from the lumps worked on during sample preparation to obtain disc-shaped specimens were analysed for major and trace elements using the aid of an Atomic Absorption Spectrophotometer (AAS). 0.25g of pulverized sample was digested in 10 ml HCl of 1:1:1 mixture of HNO₃: HClO₄: HF in a Teflon beaker. The residue was further digested in 10 ml HCl resulting in a near total digestion. The cake formed was allowed to cool and then leached with dilute HCl. Solutions were introduced into the plasma by several devices such as the nebulizer and the flow injector which is the commonest and its main function is to turn the sample solution into tiny droplets (aerosol). The aerosol was then carried via a spray chamber in a stream of argon gas through a plasma torch to the plasma. The geometry of the torch ensures that the vertical funnel is blown through the flat base of the plasma by the central

flow of argon gas that carries the sample material. The specimens were passed through the funnel and reached a temperature of about 7500 K. At this temperature, the sample becomes completely atomized. The result of the geochemical analysis reveals the elemental oxide composition of the samples in this study.

2.3 Dielectric measurements

In this study, frequency-dependent conductivity was computed from dielectric measurements under ambient conditions carried out on dry, humidified and saturated samples of limestone, sandstone, shale and glauconite from Ewekoro within the eastern Dahomey Basin. The frequency of the applied field was varied from 40 Hz to 110 MHz. The dielectric measuring system is made up of a precision impedance analyzer (Agilent 4294) and a test/measurement probe specially fabricated for parallel plate measurement at the Petrophysics Laboratory of the CSIRO

Table 2: Thickness and diameter of the rock samples from Ewekoro

Sample	Thickness(mm)	Diameter (mm)
LM1	8.45	36.90
LM2	7.39	37.08
LM3	9.83	37.29
LM4	7.34	38.57
LM5	10.84	37.69
LM6	4.97	36.99
LM7	7.33	36.70
LM8	8.66	37.67
SA1	6.54	37.62
SA2	7.74	37.59
SA3	8.45	38.49
SA4	8.04	37.14
SH1	6.83	36.96
SH2	7.61	36.79
SH3	5.92	37.64
SH4	7.67	36.37
SH5	6.99	36.90



GL1	9.08	36.59
GL2	6.20	36.92
GL3	6.36	37.25
GL4	7.53	36.88
GL5	9.10	37.74

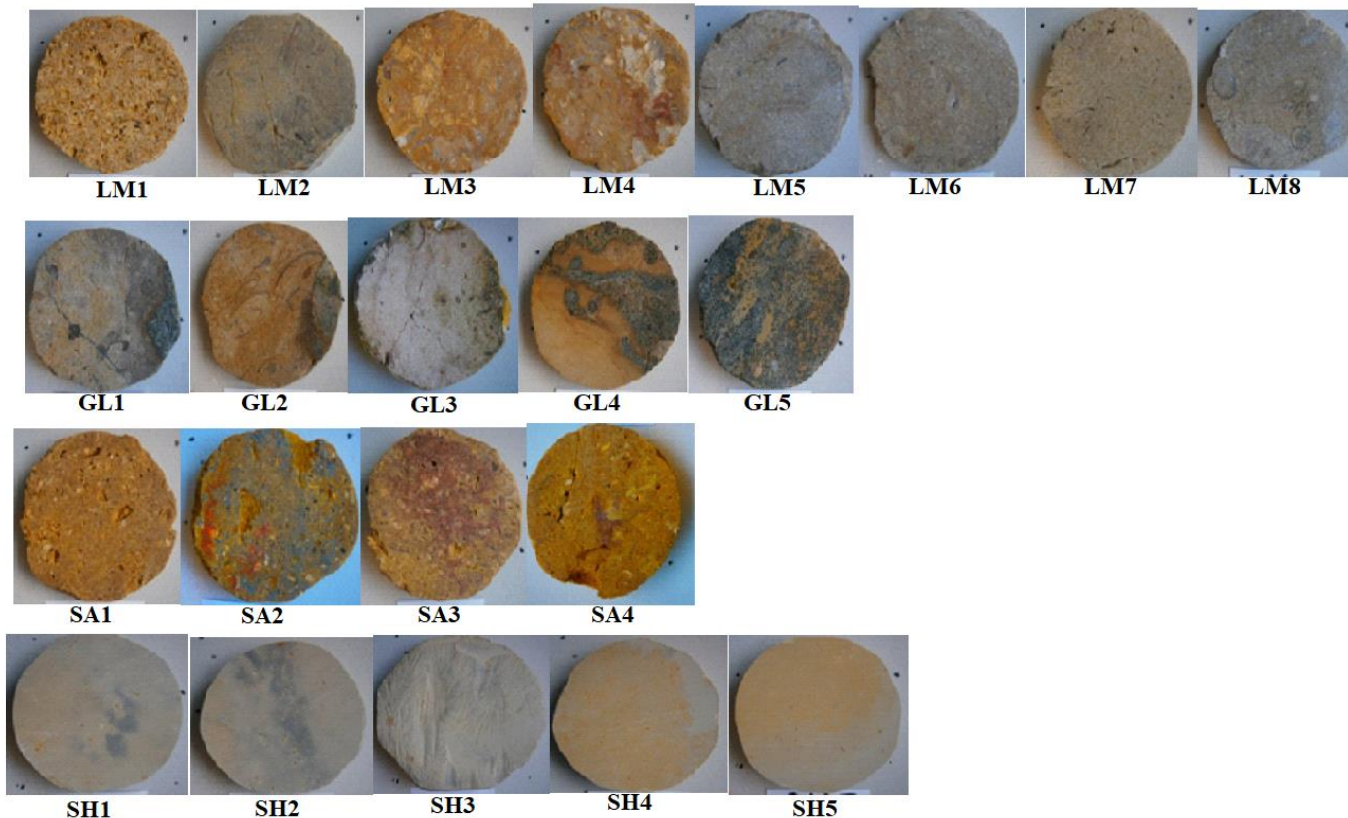


Fig. 1: Photograph of the disc-shaped rock samples (dry) used for the dielectric measurements.

Earth Science and Resource Engineering (CESRE) Unit of the Australian Resources Research Center, Kensington, Western Australia. The 52% saturation was achieved in a controlled manner by placing the samples for several days in a desiccator containing $MgNO_3$ as the desiccant while 100% saturation was accomplished with an injection pump at 2 MPa. The output parameters from the analyzer are the parallel capacitance C_p and the parallel resistance R_p , dielectric parameters such as real relative dielectric permittivity (dielectric constant) ϵ'_r , imaginary relative dielectric

permittivity (dielectric loss) ϵ''_r , conductivity σ and loss tangent D can be computed for each frequency using Equations (1) – (5). Good electromagnetic shielding was implemented on the whole sample holder to reduce common noise problems, especially at low frequencies. The material was mounted in a sample cell between the parallel circular electrodes thus forming a sample-capacitor arrangement. The material placed in the capacitor can be considered as an equivalent electrical circuit which consists of a capacitance, $C(\omega)$, in parallel with a resistance, $R(\omega)$. These values are the output of the dielectric analyzer and are related to the real parts (ϵ'_r), imaginary parts (



ϵ_r'') of the complex dielectric permittivity (ϵ^*), conductivity (σ) and tangent loss (D) through equations (1) – (5) (Josh *et al.*, 2009):

$$\epsilon^* = \epsilon_r' - i\epsilon_r'' \tag{1}$$

$$\epsilon_r'(\omega) = \frac{C(\omega)d}{\epsilon_o A} \tag{2}$$

$$\epsilon_r''(\omega) = \frac{\sigma(\omega)}{\omega\epsilon_o} = \frac{R^{-1}(\omega)d}{\omega\epsilon_o A} \tag{3}$$

$$\sigma(\omega) = \frac{d}{R(\omega)A} \tag{4}$$

$$D = \frac{\epsilon_r''}{\epsilon_r'} \tag{5}$$

d is the distance in meters (m) between the electrodes, A is their area in meters squared (m^2), $\omega = 2\pi f$ is the angular frequency in radian per second (rad/s) and ϵ_o is the permittivity of free space in farad per meter (F/m).

3.0 Results and Discussion

3.1 Elemental Oxide Compositions

The major and trace element compositions of the analysed samples are presented in Table 3. A comparison of the average compositions shows that there are geochemical similarities between limestone and glauconite samples on one hand and between sandstone and shale on the other. The proportion of lime (CaO) in limestone and glauconite is quite close (about 90%) which suggests a very high carbonate content. It is also likely that the glauconite samples are glauconitic limestone. Silica (SiO₂) content although very low in both samples is higher in some limestone samples than in glauconite samples. The trace elements composition is generally similar in the two geological materials. In sandstone and shale samples, silica (about 55%), alumina (about 25%), and ferrous oxide (about 4.5%) are in a similar proportion. The high silica content reveals a high proportion of quartz in the two rock types from Ewekoro. This also suggests that they are alumina-silicates with some siltyquartz. Generally, the magnesia (MgO) proportion in limestone and glauconite is lower than in sandstone and shale.

Table 3: Summary of results of geochemical analysis showing elemental composition of the samples. Typical siliclastic materials (sandstone and shale) show similar composition.

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	P ₂ O ₅	K ₂ O	MnO	MgO	Na ₂ O
LM1	3.76	1.07	0.12	-	53.35 ^z	-	0.18	0.01	0.28	0.16
LM2	2.69	0.56	0.24	-	54.64 ^z	-	0.12	0.01	1.20	0.14
LM3	2.66	0.46	0.16	-	54.86 ^z	-	0.12	0.01	0.24	0.16
LM4	0.79	0.60	0.40	-	55.97 ^z	-	0.14	0.00	0.32	0.16
LM5	3.64	0.82	1.90	-	55.21 ^z	-	0.18	-	0.36	0.18
LM6	0.72	0.56	0.40	-	54.64 ^z	-	0.16	-	0.44	0.16
LM7	0.84	0.60	0.16	-	54.92 ^z	-	0.18	-	0.24	0.21
LM8	0.71	0.26	0.16	-	54.86 ^z	-	0.14	0.01	0.32	0.18
SA1	57.95 [*]	28.06 [*]	4.74 [#]	1.12 ⁺	1.51 ^x	0.03	0.80	0.06	4.13	0.79
SA2	58.54 [*]	26.06 ^{**}	4.72 [#]	1.17 ⁺	1.54 ^x	0.02	0.91	0.07	4.40	0.91
SA3	59.38 [*]	27.06 ^{**}	4.11 [#]	1.15 ⁺	1.58 ^x	0.02	0.93	0.06	4.83	0.85
SA4	58.53 [*]	27.93 ^{**}	4.27 [#]	1.10 ⁺	1.54 ^x	0.03	0.93	0.06	4.68	0.90
SH1	56.08 [*]	29.97 ^{**}	4.81 [#]	1.16 ⁺	1.59 ^x	0.01	0.87	0.08	4.56	0.83
SH2	54.82 [*]	31.27 ^{**}	4.98 [#]	1.23 ⁺	1.61 ^x	0.01	0.85	0.08	4.29	0.83
SH3	53.61 [*]	30.82 ^{**}	5.30 [#]	1.34 ⁺	1.74 ^x	0.01	1.14	0.08	4.93	0.92



SH4	52.78*	31.95**	5.25#	1.21 ⁺	1.70 ^x	0.01	0.89	0.07	5.21	0.90
SH5	56.39*	29.60**	4.66#	1.13 ⁺	1.66 ^x	0.01	0.89	0.07	4.69	0.87
GL1	0.78	0.56	0.12	-	54.97**	-	0.09	-	0.18	0.16
GL2	0.74	0.82	0.24	-	54.58**	-	0.16	0.02	0.34	0.22
GL3	0.46	0.22	0.12	-	55.21**	-	0.12	-	0.08	0.18
GL4	0.36	0.04	0.40	-	55.23**	-	0.12	0.01	0.18	0.18
GL5	0.45	0.25	0.15	-	55.20**	-	0.12	0.01	0.11	0.21

3.2 Frequency Dependent Conductivity

Systematic experimental measurements of the electrical properties of rock materials have shown that conductivity and dielectric permittivity are dispersive (Shelukhin and Terentev, 2009; Liu et al., 2017). Although individually for both water and most minerals these properties are almost independent of frequency, the composite properties vary appreciably with frequency. Figs. 2-5, Figs. 6-9 and Figs. 10-13 show the plots of conductivity in S/m against frequency in Hz for dry, partially saturated (humidified) and fully saturated samples, respectively.

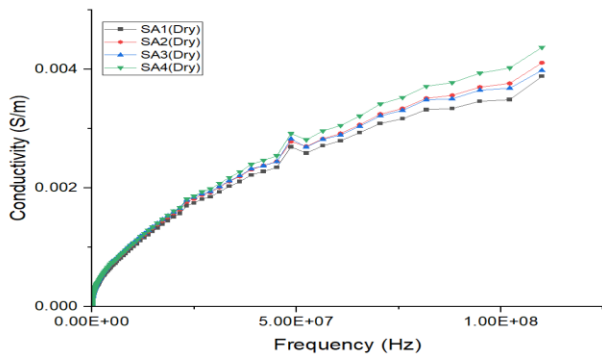


Fig. 2: Conductivity vs frequency response for dry sandstone samples. Close conductivity values across frequencies reflects homogeneous composition and microstructures of the sandstone samples.

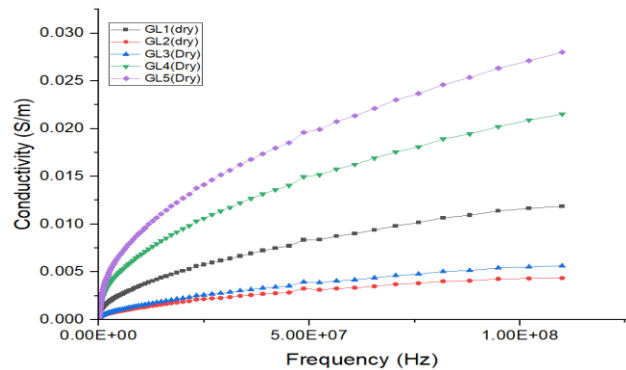


Fig. 3: Conductivity vs frequency response for dry glauconite samples. Observed conductivity variation shows some degree of inhomogeneity in composition and microstructures of the glauconite samples.

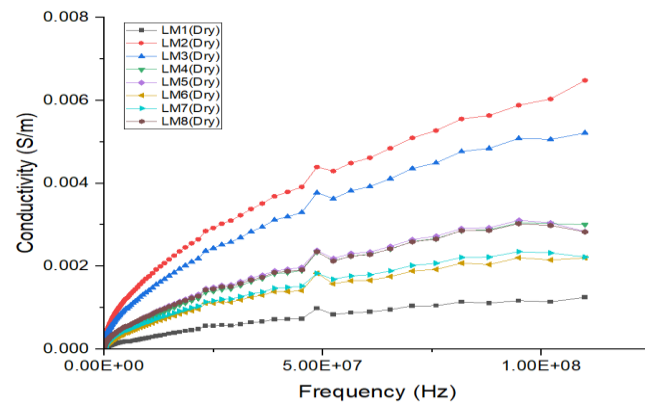


Fig. 4: Conductivity vs frequency response for dry limestone samples. Observed conductivity variation shows some degree of inhomogeneity in composition and microstructures of the limestone samples.



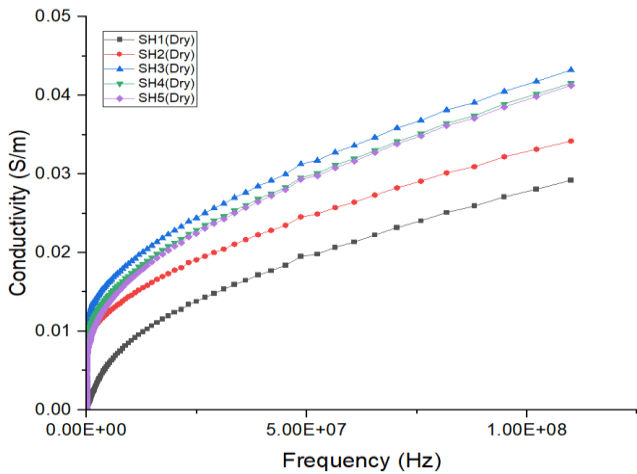


Fig. 5: Conductivity vs frequency response for dry shale samples. Close conductivity values across frequencies indicates homogeneous composition and microstructures of the shale samples. Sample-electrode contact effect is conspicuous at very low frequencies.

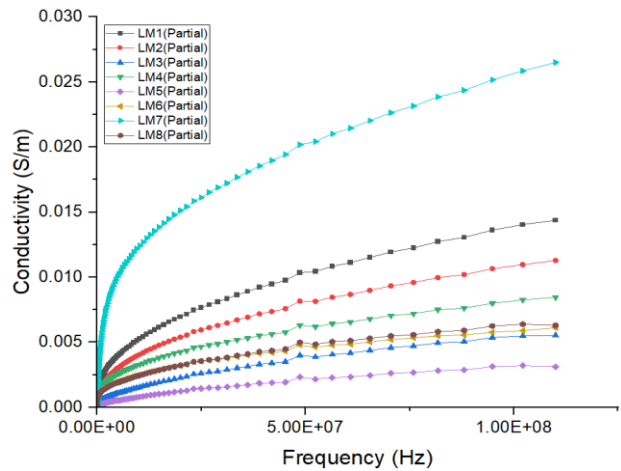


Fig. 7: Conductivity vs frequency response for partially saturated limestone samples. The effect of hydration on conductivity and sample-electrode polarization is more on LM7 and relatively uniform for the other seven samples.

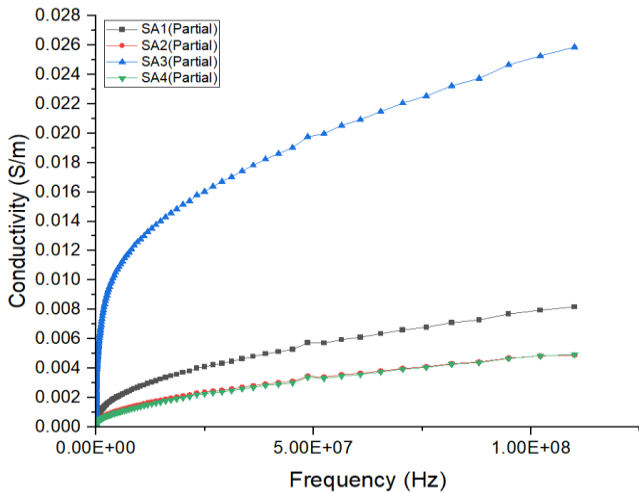


Fig. 6: Conductivity vs frequency response for partially saturated sandstone samples. The effect of hydration on sample-electrode polarization and on conductivity values for SA3 is remarkable. Hydration effect on conductivity is fairly uniform for the other samples.

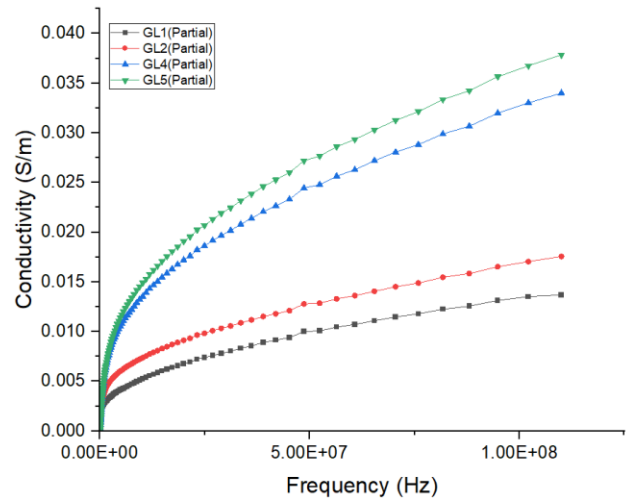


Fig. 8: Conductivity vs frequency response for partially saturated glauconite samples. The effect of hydration is more on GL1 and GL4 than the other GL2 and GL5.



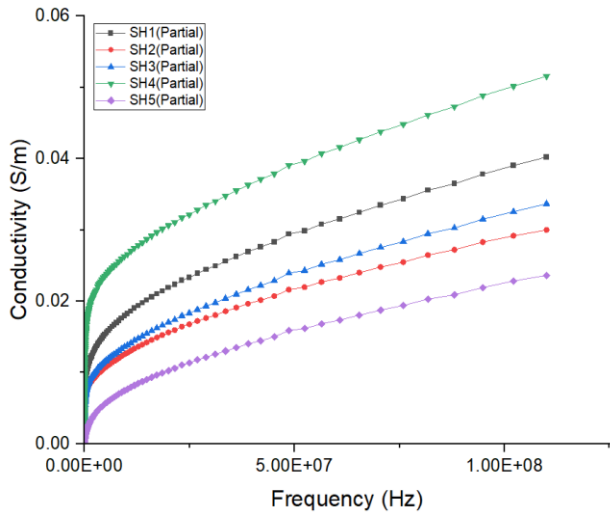


Fig. 9: Conductivity vs frequency response for partially saturated shale. The effect of hydration is fairly uniform for all the shale samples. Electrode-sample contact effect is noticeable at very low frequencies.

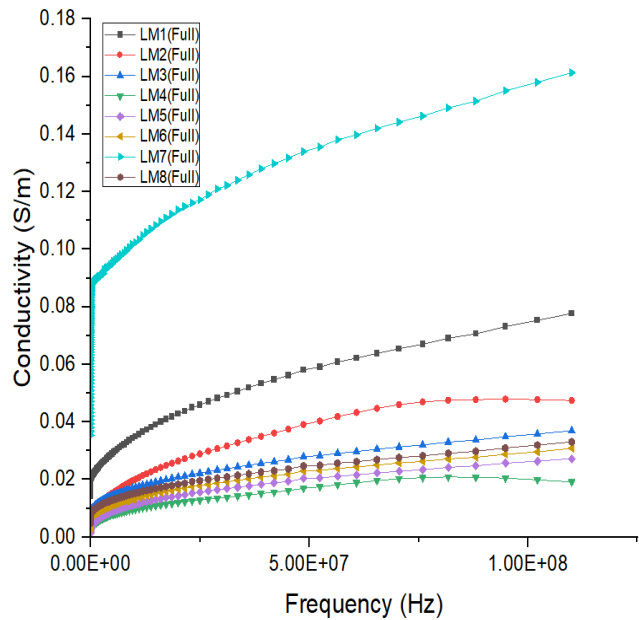


Fig. 11: Conductivity vs frequency response for fully saturated limestone samples showing greater impact of the low frequency sample-electrode phenomenon.

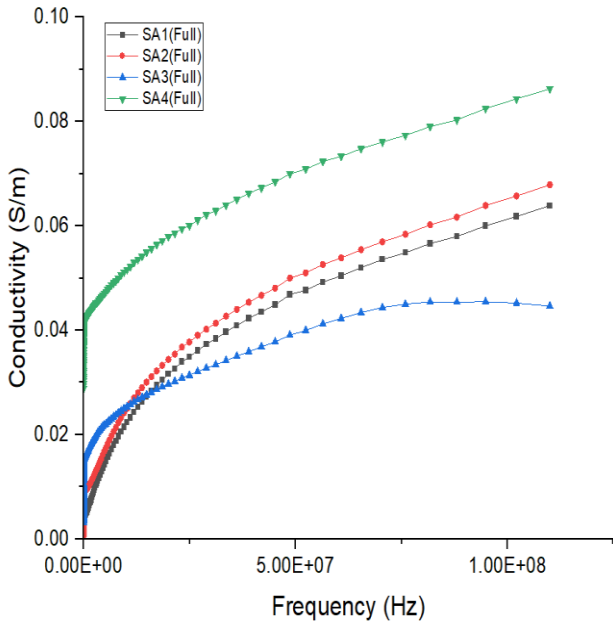


Fig. 10: Conductivity vs frequency response for fully saturated sandstone samples showing greater impact of the low frequency sample-electrode phenomenon.

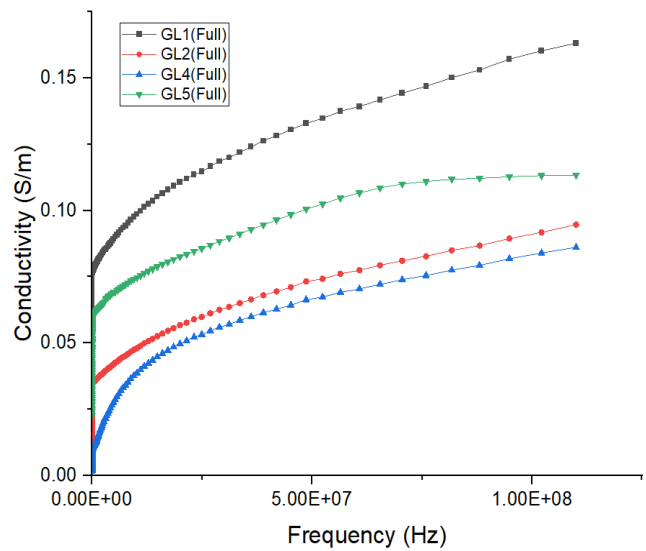


Fig. 12: Conductivity vs frequency response for fully saturated four glauconite samples showing greater impact of the low frequency sample-electrode phenomenon.



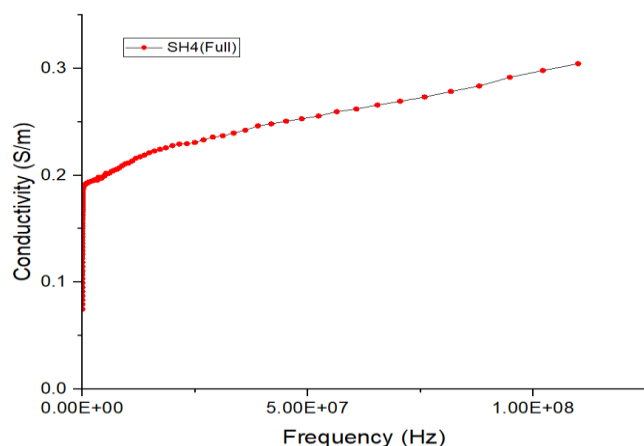


Fig. 13: Conductivity vs frequency response for fully saturated shale sample SH4 showing the greater impact of the low frequency sample-electrode phenomenon. Other shale samples crumbled due to wetness.

Frequency dependence of electrical properties of materials results from different mechanisms of charge transport and charge storage. Some of these mechanisms operate rapidly and are observed at relatively high frequencies, while slow mechanisms are observed at lower frequencies. At low frequencies, the electrical properties of rocks and minerals are dominated by charge transport or conduction mechanisms, whereas at high frequencies, charge storage or polarization mechanisms dominate (Olhoeft, 1976; Frolich, 1990). Materials with clay/clay-like constituents which are usually charged will develop additional contributions which will manifest in the dielectric properties of such rocks. The conductivity dispersion of the investigated geological samples in dry conditions (Figs 2-5) shows that conductivity increases steadily with frequency. These characteristics have been interpreted as being caused by geometric or textural heterogeneities in the rock system (Sen, 1981, 1984). Also, these plots for all the samples show well pronounced frequency dispersion at higher frequencies. Low frequency effect (sample-electrode contact effect) is greatest for shale,

followed by glauconite and least for limestone and sandstone. This is probably due to the different microstructures of the samples (Schwartz et al., 1989; Wu et al., 2010). The conductivities of shale and glauconite are about an order of magnitude higher than those of limestone and sandstone. Conduction is expected to be by the motion of weakly bound ions in the lattice or defects in the ionic bonded structure (Sengwa and Soni, 2008). Close conductivity values for the siliclastic rock samples viz (sandstone and shale, respectively, across frequencies reflect their homogeneous composition and microstructures (values of SiO_2 and Al_2O_3 in Table 3). However, shale samples have slightly higher concentrations of Fe_2O_3 and TiO_2 . Observed conductivity variation in limestone and glauconite which share some similar oxide concentrations (values of CaO in Table 3) shows some degree of inhomogeneity in composition (values of SiO_2) and microstructures of these two geological materials. In addition, for the dry samples, only the shale samples exhibit the characteristic low-frequency sample-electrode effect.

For wet rocks, due to sensitivity to ionic content in addition to surface texture, frequency dispersions of conductivity are influenced by a variety of petrophysical factors. Factors as diverse as fluid saturation, porosity, pore morphology, thin wetting films and electrically charged clay affect the response of rocks. Previous works have shown that the dielectric of partially saturated sandstone varies as a function of the level of water saturation (Knight and Endres, 1990; Knight and Abad, 1995). Rock/water interaction, at low saturations, has a large effect on the measured dielectric response. Clay particles which are highly surface active and plate-like, will contribute further to the conductivity (Sen and Chew, 1983). Also, interactions between charged clays and aqueous electrolytes give rise to an ionic double layer. Glauconite structure is similar to the layer (clay families) and. Due to its supposed clay-like mineral content (similar to structures of mica, kaolinites,



vermiculites, or chlorites) and sheet-like structure and presence of pellets (Schneider, 1927; Gruner, 1935; Jarrar *et al.*, 2000), the conductivity of glauconite under partial saturation are a little less than those of shale. Conversely, limestone and sandstone have grain-like and coarse structures and as a result, have lower conductivity relative to those of shale and glauconite. Conductivity variation at partial saturation (Fig.s 6-9) follows a similar trend observed in dry samples but the values are quite slightly higher than the values for dry samples. This means that effective conductivity is minimally impacted from low to high frequencies for hydrated samples. The effect of hydration on low-frequency sample-electrode polarization is also remarkable. The hydration effect on this phenomenon is greatest for the shale samples, followed by sandstone and limestone, and least for glauconite samples.

Under full saturation conditions (Fig.s 10-13), there is an appreciable increase in conductivity values. These are at least an order of magnitude greater than the values for the dry and hydrated samples. That comparatively higher conductivities are obtained with full water-saturated condition is not a strange occurrence, because mobile ions in liquid will contribute to increased conduction in the rock-liquid system.

4.0 Conclusion

This study has investigated the conductivity signatures of limestone, sandstone, glauconite and shale samples from Ewekoro in the eastern part of the Dahomey basin. All the rock types show dispersion of conductivity in dry, partial-water saturation as well as full-water saturation. However, the frequency range of this dispersion differs for each rock type and is in some way dependent on the level of saturation. The variations of conductivity with frequency are similar for both dry and partial water-saturated rocks except in magnitudes. In partial saturation, enhanced polarization occurs with a consequent increase in the electrical parameters of the rocks. Hence,

conductivity values are slightly greater for the hydrated samples. Under full saturation, polarization is further enhanced and the overall effect of liquid yields greater conductivity values due to the presence of mobile ions in the conduction process. The conductivity values for full saturated samples are at least an order of magnitude greater than the values for both dry and hydrated samples. Frequency-dependent characteristics of these rocks show that irrespective of their conditions (dry or saturated), the conductivity of shale and glauconite are found to be some significant order of magnitude higher than those of limestone and sandstone. This behaviour is partly attributed to the conductive (charged particles) clay-like nature of shale and glauconite. These observable differences in electrical properties/signatures can be used as effective tools for rock-type characterization. Furthermore, conductivity aacross the frequency range of measurement is minimally impacted by sample-electrode effects at very high frequencies. Therefore, conductivity measurements through the dielectric technique can provide a robust means of evaluating rock specimens and as an evaluation tool in petrophysical analyses.

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5.0 References

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Compliance with Ethical Standards

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Ethical Approval

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Authors' Contributions

All authors contributed to the work.

Olawale Babatunde Olatinsu designed the work, the draft manuscript was jointly written by Mathew Osaretin Ogieva and Amidu Abiola Ige-Adeyeye and Olawale Babatunde Olatinsu

