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Determination of Hydraulic conductivity of Sandstones of Ajali Formation in Uturu Area (Southeasthern Nigeria) Using Grain Size Analysis.

Obasi, P. N. [1]*, Aghamelu, O. P.[1] and Akudinobi, B. E. B. [2]
[1]Department of Geology and Exploration Geophysics, Ebonyi State University, P.M.B 053, Abakaliki, Nigeria.
*Email of the corresponding author: Obasiphilip26@gmail.com
[2]Department of Geological Sciences, Nnamdi Azikiwe University, Awka, Nigeria

Abstract
The determination of hydraulic conductivity of sandstones of Ajali Sandstone Formation in Uturu area (southeasthern Nigeria) was carried out using grain size analysis. The Ajali Sandstone Formation consists of whitish to reddish friable, poorly sorted cross bedded sandstone. A total of twelve (12) samples were randomly collected and subjected to laboratory analysis such as porosity test and sieve analysis. Results indicates that the Ajali Sandstone has porosity values that ranged between 20% and 26% and the hydraulic conductivity values range from 136.9m/day to 916.837m/day. These values of porosity and hydraulic conductivity are indications of high specific yield for the sandstone which is reasonable for economic water supply. The unconfined aquifer of Ajali Sandstone is the basic characteristic aquifer unit of the area.
Keyword: Hydraulic conductivity, Aquifer, Ajali Formation, Grain size analysis.

1. Introduction

The storage and transmission of groundwater is influenced by the hydraulic conductivity and porosity of the medium. Hydraulic conductivity (k) is a measure of the permeability of a porous medium. It is also defined as the rate at which a geologic material can transmit a liquid (water) under a hydraulic gradient.

Groundwater is one of the major natural sources of water on earth. It is stored and transmitted through the pore or void spaces of sediment or rock. Porosity is the volume of void space in a geologic material. It determines how much water a rock or sediment can hold when saturated. Porosity can be expressed quantitatively as the ratio of the volume of voids to the total volume of materials,

$$\eta = \frac{\text{volume of voids}}{\text{total volume of material}} = \frac{V_v}{V} \quad \ldots\ldots (1)$$

Where, η is porosity, V_v is volume of voids and V is total volume of material.

Primary porosity is the original void space created when the rock or soil was formed. In soil and sedimentary rock, the primary voids are the spaces between the mineral grain or pebbles sediment shape (sphericity and roundness). Orientation, sorting and packing generally determine primary porosity, angularity of sediment may increase or decrease porosity, depending on the particles size (Vukovic and Soro, 1992). Well sorted sediment has greater porosity compared to poorly sorted sediments (Freeze and Cheery, 1979). This is because in poorly sorted sediment the smaller grains take up spaces between the larger grains which reduce the porosity. Fine grained materials tend to be well sorted and generally have large porosities. The cementing agent in sedimentary rocks reduces primary porosity because it occupies part of the voids spaces in the rocks.

Secondary porosity develops after processes of sedimentation have taken place. It is much more important in the exploration for water in igneous and metamorphic terrains. Secondary porosity is evidenced by fractures, joints and faults which help to increase porosity and transmissivity. Effective porosity refers to the interconnectivity of the pore spaces. This allows water to be transmitted from one point to another.

Hydraulic conductivity (k) is dependent on the diameter (d) and shape (β) of the pore spaces through which water flows, it is also dependent upon a hydraulic gradient (Δh/L). Mathematical models can be used to calculate hydraulic conductivity of porous media.

This work characterizes the outcrops of the Ajali Sandstones in the Uturu area and uses mathematical models to determine the hydraulic conductivity of the formation from the results of grain size analysis.

2. Description of the Study Area

2.1 Location

The study area is Uturu and its environs in Isuikwuato Local Government Area of Abia State, Southeastern

Nigeria (see fig 1). The area is bounded between latitudes $5^{\circ}45^{'}$N and 5° $50^{'}$N and longitude $7^{\circ}25^{'}$E and $7^{\circ}30^{'}$E. It is located within the forest belt of Nigeria.

2.2 Geology, Physiography and Drainage

The area is underlain by a series of geologic formations. These include the Asu River Group, Nkporo Shales, Ajali Sandstone and Mamu Formations. Simpson (1955) noted that in Uturu, the Asu River Group is overlain unconformably by the Nkporo Shales. The Asu River Group consists largely of olive-brown sandy shale, fine-grained micaceous sandstones and micaceous mudstones. Bluish-yellow or olive-brown shale which weather to a rusty brown colour are also present. The sequence is poorly fossiliferous although there are occasional outcrops of thin shally limestones. Reyment (1965) and Kogbe (1976) have described the Nkporo Shales as comprising of dark shales and mudstones with subordinate sandstone and shelly limestone. Kogbe (1989) have described the Ajali Sandstone Formation as comprising of thick friable, poorly sorted sandstones, typically white in colour but sometimes iron stained. A mark banding of coarse and fine layers is displayed. This formation is often overlain by a considerable thickness of red earth; which consist of red, earthy sands, formed by the weathering and ferruginzation of the formation. On the Udi Plateau, the red earth may be as much as thirty meters thick. Here the formation has a thickness of about 45 meters (Amajor, 1987). Good exposures of the sandstone occur in the gullies incise along the higher slope of the scarp. Although this Formation is overlain by a considerably thickness of weathered red earth, fresh samples are exposed at Ohokabi Community in Umunekwu Village and Ogbe borrow pit, Amokwe along Akara - Okigwe road in Uturu. Nwajide and Reijers (2001) noted that this unit occurs as a narrow strip trending north-south from the Calabar flank, swinging west round the Ankpa Plateau and terminating at Idah near the Niger River. In Uturu, good exposures are found about 1.5km away from Abia State University, along Afikpo - Uturu Road and at another road-cut through the escarpment at Leru on Enugu-Port Harcourt expressway. The Mamu comprises of white fine grained and poorly sorted sandstones that are usually well bedded and tabular.

The Uturu area has a characteristics physiography. The area is comprised of hills and valley. The hills range from 400m to 1000m above sea-level respectively. The low lying plain is the inland extension of the coastal plain from the Bight of Benin. The Umunekwu River and Ihuku stream, which take their sources from the high lands, drain the area.

3. Materials and Methods

3.1 Sampling and Laboratory

Twelve (12) samples were collected from the Ajali Sandstone Formation and subjected to porosity and sieve analyses. The samples were very friable, therefore, disaggregation was done without disturbing their original properties such as grain size, grain shape and grain roundness. After drying, each sample was carefully split into four equal parts to create homogeneity for the samples. 50 grams of each sample was weighed accurately and was sieved for fifteen (15) minutes using a set of Jurgen's and Endecott's laboratory sieve at ½ phi interval on a Fritsch sieve Ro top shaker. The consistent lateral and vertical vibration of the shaker carried out the sieve operation. The material on each sieve was carefully weighed and recorded using a chemical balance. The cumulative weight and other parameters were deduced. The arithmetic log probability graph was used in the plot of log/normal cumulative frequency curves of the grain size distribution. The percentile values were deduced graphically.

The Volume method (Kasenow, 2002) was used to determine porosity. A sample of 50g of the sandstone sample was dried and then saturated. Porosity is equal to the difference between the saturated volume and the original volumes.

3.2 Determination of Hydraulic Conductivity from Grain Size Analysis

Hydraulic conductivity (k) is dependent on the diameter (d) and shape (β) of the pore spaces through which water flows. It is also dependent upon a hydraulic gradient (Δh/L) (Kasenow, 2002). The product of βd^2 is called intrinsic permeability. Kasenow (2002) stated that hydraulic conductivity is also dependent on dynamic or absolute viscosity (μ) and specific weight (γ). Specific weight is dependent on the density (η) of the liquid and acceleration due to gravity (g). However, the density and specific weight of water are dependent on water temperature which allows Darcy's law to be expressed as,

$$Q = \frac{(\beta d^2)\gamma}{\mu}\frac{\Delta h}{L} = -\frac{(\beta d^2)(pg)}{\mu}\frac{\Delta h}{L} \quad \ldots\ldots (2)$$

where, β is shape of pore space, d is diameter of pore space, Δh/L is hydraulic gradient
γ is specific weight, μ is viscosity, η is density and g is acceleration due to gravity.

From eqn (2) the following proportionality constant can also be obtained.

$$Q \times d^2 Q \times \gamma\ Q \times \frac{1}{\mu}$$

As Hubbert (1956) has pointed out, the constant of proportionality in Darcy's law, which has been christened the hydraulic conductivity, is a function not only of the porous medium but also of fluid. This was demonstrated in his experiment with ideal porous media consisting the uniform glass beads of diameter (d). When various fluids of density ρ and dynamic viscosity μ are run through the experimental apparatuses with constant hydraulic gradient dh/dL, the following proportionality relationships are observed together with Darcy's original observation that Vx – dh/dL, these three relationships leads to a new version of Darcy's law

$$V = -\frac{Cd^2 pg}{\mu}\frac{dh}{dL} \qquad (3)$$

The parameter C is yet another constant of proportionality. It includes the influence of other media properties that affect flow, apart from mean grain diameter for example the distribution of grain sizes, the sphericity and roundness of the grains and the nature of their packing.

Reducing equation (2) to functions of the fluid alone, then

$$K = \frac{kpg}{\mu} \qquad (4)$$

The parameter k is known as the intrinsic permeability while K is the hydraulic conductivity.

Hydraulic conductivity is one of the most important and useful parameters in the study of groundwater. It is needed in the equation that described Darcy's law and groundwater velocity. Other parameters, such as transmissivity, are dependent on its value.

Hydraulic conductivity can be expressed as

$$K = \frac{QL}{A\Delta h} = \frac{Q}{\Delta I} \qquad (5)$$

Where,

K	is	Hydraulic conductivity
Q	is	Groundwater discharge
A	is	Cross sectional area of flow
Δh	is	Head loss
L	is	Distance
I	is	Δh/L is slope of potentiometer surface

According to Kasenow (2002) the mechanics of equation (5) can be expressed as

$$K = \frac{QL}{A\Delta h} = \frac{Ki\,(pg)}{\mu} = \frac{(\beta d^2)(r)}{\mu} = \frac{(\beta d^2)(pg)}{\mu} \qquad (6)$$

β	is	Shape factor
d	is	Mean or effective grain diameter of sediment
P	is	Density of water
g	is	Acceleration due to gravity
γ	is	Specific weight of water
μ	is	Dynamic viscosity

3.2 Calculation of Hydraulic Conductivity Using Empirical Formulas

The hydraulic conductivity of porous medium depends on the characteristics of the medium and the properties of the fluid. For the purpose of this work, and the variables available, the The United State Bureau of Reclamation USBR formular was used.

$$K = 0.36\,(d_{20}^{2.3})$$

Where

K is hydraulic conductivity (cm/s)

d_{20} is effective grain diameter (mm)

4. Result and Interpretation

Results of porosity, hydraulic conductivity and summary of univarient statistical parameters are shown in table 1 and 2 respectively.

The analysis shows that hydraulic conductivity values ranged from 136.9 m/ day to 916.83m/days while porosities values of the sandstone ranged from 20% to 26%. This value is good for geologic materials of sandstones, Kasenow (2002). Freeze and Cheery (1979), also indicated that unconsolidated sands have porosity values of 25- 50% while Todd, (1980) gave porosity values of 33% and 37% for fine and medium grained sandstone respectively. However, the low porosity values of these sandstones may be due to external factors like transportation which might increase compaction. Sieve analysis results reveal that 18.2% of the sandstone samples are fine grained, 54.5% medium grained and 27.3% coarse grained sandstone. Average sorting analysis of the sandstones; indicate that the samples are moderately sorted. This indicates a high degree of sorting for the sandstone aquifer. Aquifers of such sandstone have specific yields which are reasonable for economic water supply.

5. Summary and Conclusion

Hydraulic conductivity is a very useful parameter in the study of groundwater. It is very important in the evaluation of groundwater resources (Freeze and Cherry, 1979). The hydraulic conductivity of a soil or rock is dependent on a variety of physical factors including porosity, particle size and distribution, shape of particles, arrangement of particles and other factors (Todd, 1980). The Ajali Sandstone is a very typical sandstone formation; it consists of whitish, friable, poorly sorted, fine to coarse grained cross bedded sandstone. Calculations of the hydraulic conductivity of this sandstone from empirical formular shows values from 136.90m/day to 916.84m/day while the porosity values range between 20-26%. This indicates a high specific yield for the aquifer and is reasonable for economic water supply.

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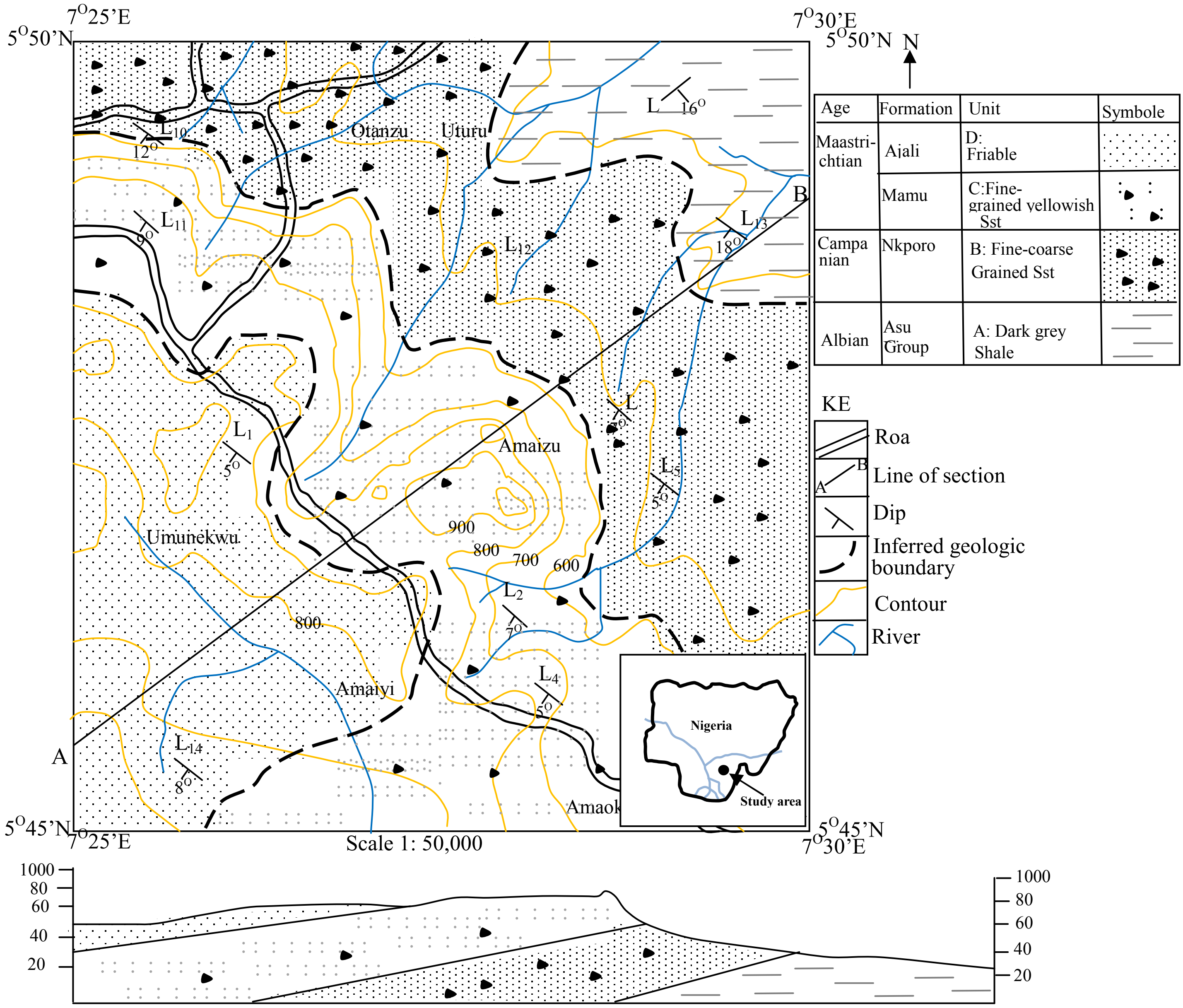

Geologic cross section across A-B

Fig 1: Geologic map Uturu and Environs.

Table 1: Showing porosity and Hydraulic conductivity of the samples analysed.

SAMPLE NO	POROSITY%	HYDRAULIC CONDUCTIVITY (m/day)
OP/01 Bed 1	24	96.065
OP/01/Bed 2	22	14.036
OP/01/Bed 3	26	96.065
OP/01/Bed 4	22	75.39
OP/10/Bed 5	26	186.176
OP/03/Bed 1	22	75.39
OP/03/Bed 2	20	27.808
OP/03/Bed 3	20	22.627
OP/04/Bed 1	24	916.837
OP/04/ Bed 2	24	49.568
OP/04/ Bed 3	22	136.8

Table 2: Summary Of The Results Of Univariation Analysis

Sample No	Mean size (Mc)	Sorting	Skewness (Ski)	Kurtosis
OP/01 BED 1	1.45 Medium	0.008 Very well sorted	-0.16328 Nearly Symmetrical	1.1349 Loptokurtic
OP/01 BED 2	0.2166 Coarse	1.53864 Poorly Sorted	0.09676 Nearly Symmetrical	1.03739 Mesokurtic
OP/01 BED 3	4.35 Silt	0.99167 Moderaterly Sorted	0.87522 Very positive Skew	1.03532 Mesokurtic
OP/01 BED 4	0.8 Coarse	1.07311 Poorly Sorted	-0.018117 Very negative Skew	1.0177 Mesokurtic
OP/01 BED 5	1.5667 Medium	0.89 Moderately Sorted	3.451400 Very positive Skew	1.078516 Mesokurtic
OP/03 BED 1	1.333 Medium	1.0557 Poorly Sorted	0.33432 Very positive Skew	1.1384 Loptokurtic
OP/03 BED 2	1.2 Medium	1.21061 Poorly Sorted	0.401095 Very positive Skew	1.2131 Loptokurtic
OP/03 BED 3	0.41667 Coarse	1.088636 Poorly Sorted	0.372278 Very positive Skew	1.7472 Very Loptokurtic
OP/04 BED 1	2.25 Fine	0.9705 Moderately Sorted	-1.613494 Negative	1.34128 Loptokurtic
OP/04 BED 2	1.2466 Medium	1.052 Poorly Sorted	-0.00123 Very negative Skew	1.2024 Loptokurtic
OP/04 BED 3	1.383 Medium	4.67 Extremely Sorted	0.08530 Nearly Symmetrical	1.405 Lopptokurtic
Average	1.47 Medium	0.99 Moderately sorted	0.35 Very positively skewed	1.21 Leptokurtic