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# APPLICATION OF SEISMIC REFRACTION METHOD IN GROUNDWATER STUDIES IN CALABAR SOUTHEASTERN NIGERIA.

**Ugwu,S.A. and Nwankwoala,H.O**
Department of Geology,University of Port Harcourt,
P.M.B 5323, Choba, Port Harcourt,Nigeria.

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***Abstract***
*Calabar, the Cross River State capital, is underlain by Benin Formation. The formation is partly marine, partly deltaic and partly fluviolacustrine in origin. Seismic refraction surveys in the area show that the aquiferous zone has seismic wave velocity of 700-800ms while the non aquiferous zone has velocity ranging from 400-600ms. The velocity is larger in the aquiferous zone because the density in the water bearing sand is higher. Vertical electric sounding confirms the hydrogeologic boundaries between these zones established by the seismic refraction survey.*

***Key words****: Seismic Refraction, Groundwater, Velocity, Vertical Electrical Sounding, Aquifer.*

## Introduction

No geophysical method has yet surpassed the electrical resistivity methods in groundwater studies so far. Here in Nigeria, there is a dearth of scientific equipment especially geophysical equipment. In some areas, the equipments are not in existence while in other cases, they are either out of use or out-dated. For these reasons we decided to try other methods, other than resistivity, to prospect for groundwater in our environment.

Seismic refraction method has been extensively used in petroleum, mineral and engineering investigations and sometimes in hydrologic applications in the past. Advances in equipment, sound sources and computer interpretation have made seimic refraction application effective and economical for obtaining data for groundwater modeling studies (Haeni, 1986). Seismic refraction should be one of the methods to be considered especially in planning stages of groundwater studies and could be used as a tool by a hydrogeologist to solve problems associated with pump tests, simulation models, test holes, geologic maps etc (Haeni, 1986). The use of seismic refraction could reduce to the bearest minimum the expenditure on borehole drilling and groundwater studies.

Many text books (Dobrin,1976; Telford *et al* 1990) and journal articles (Ackerman *et al* 1986, Lay and Wallace, 1995; Ivanov *et al* 2005a, 2005b; Xia *et al* 2005) present the details of seismic refraction theory, problems and limitations.

## Brief Geology of the Coastal area of Southeastern Nigeria

The area under study (Fig.1) is underlain by Benin Formation, one of the Tertiary-Recent sediments of the Niger Delta. This formation had earlier been referred to as the coastal plain sands (Simpson, 1955) and was renamed the Benin Formation (Reyment, 1965). The formation is an extensive stratigraphic unit in the southern Nigeria Sedimentary Basin.

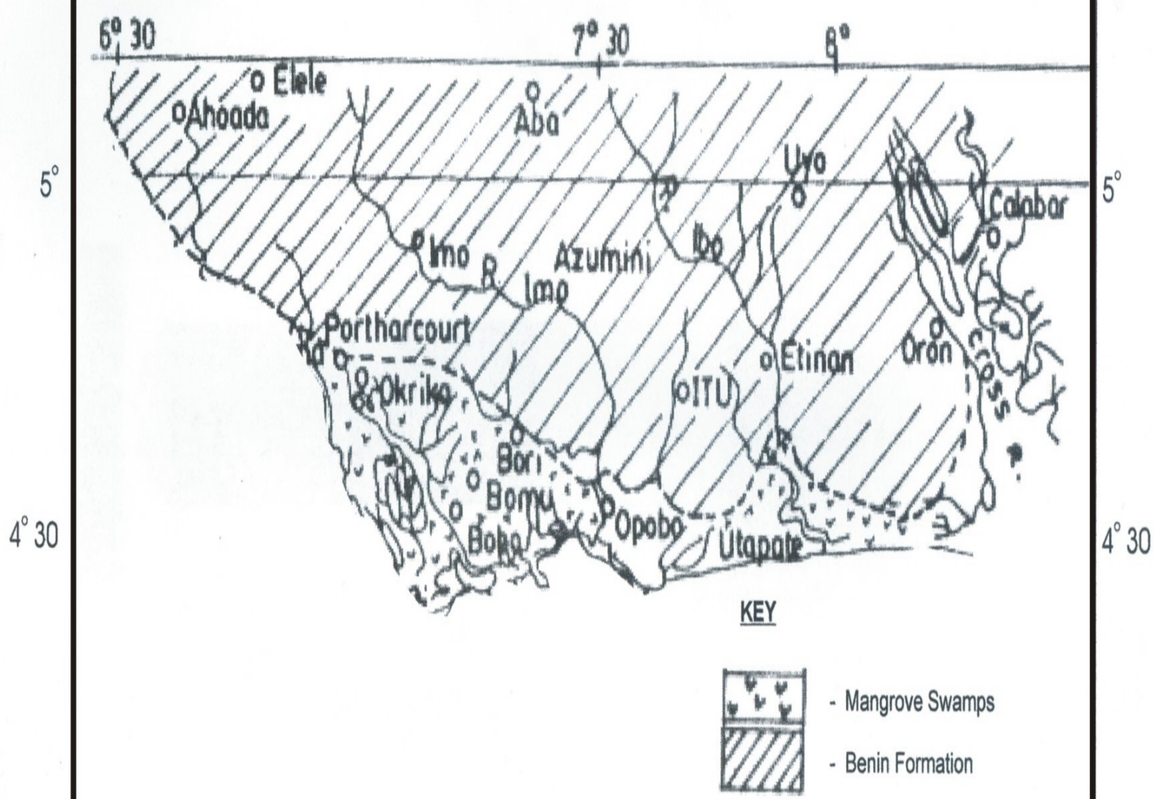


**Fig. 1**: Geologic map of the coastal area of Southeastern Nigeria

The stratigraphic development of the area during the Miocene as a result of NW-SE rifting was dominated by vertical tectonics of fault blocks and by eustatic sea level changes. The major tectonic events of the area include the Ikang trough which is a mobile depression and the Ituk high which is a stable mobile submarine ridges. The terrain is characterized by nearly flat topography. The ground level however slopes gently from the higher ground towards the Niger flood plains being dissected mainly by the Cross River, Imo, Kwa, and the Sombreiro rivers Systems (Offodile, 2000).

Various structural units such as point bars, channel fills, natural levees, back swamp deposits and Ox-bow fills are identifiable within the formation indicating the variability of the depth of shallow water depositional medium (Asseez, 1976). The otherwise

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continuous body of the Benin Formation is interrupted by the Afam Clay member which consists mainly of clay with few intercalations of sandstone bodies. The Formation consists generally of lenticular unconsolidated, friable, coarse grained, poorly sorted sands with intercalations of shales. It is partly deltaic, partly estuarine, partly lagoonal and fluviolacustrine in origin (Reyment, 1965). Disturbed laminations such as reported in Ajali sandstone (Hoque and Ezepue, 1977) are also common in the Benin Formation.

**Brief Hydrogeology of the coastal area of Southeastern Nigeria**

Benin Formation is one of the major aquiferous formation in Imo – Kwa Iboe River Basins (Offodile, 2000). In the southward part, the Benin Formation appears to be in hyrdrogeological contact with the Ameki and the alluvial deposits of the Niger River and hence provide combined aquiferous horizons (Offodile, 2000). The Formation outcrops in the northeast of the coastal belt and dips at the low angle, in the southeast. The sediments consist generally of lenticular, unconsolidated dominantly sandy formations. Pebble beds occur in places and have given rise to high yielding boreholes e.g in Port Harcourt. The sand –shale intercalations in the formation suggest a multi-aquifer system. The first aquifer is unconfined and generally exists almost throughout the coastal area. Depth to water table ranges from 2-15m. Lenticular clays and shales occur particularly in the eastern areas where they comprise small but moderately high yielding aquifers e.g Calabar, Uyo and some of them gave rise to artisan wells. Recharge is in most cases direct by precipitation through the generally copious permeable sands of the Benin Formation.

**Methodology**

**Data Acquisition**

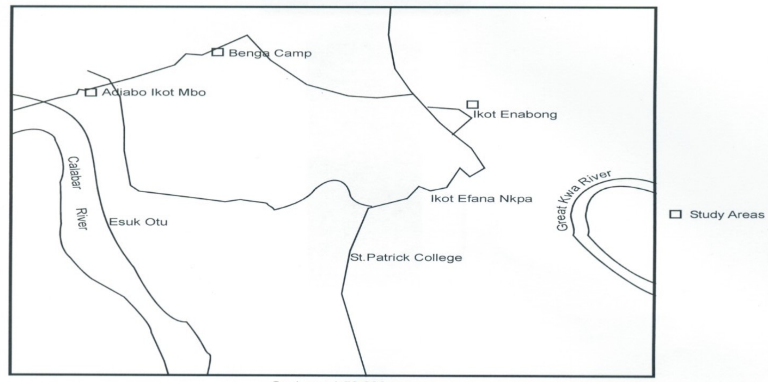
The equipment used in the acquisition of seismic refraction data in the area include: geophones, strikeplate, tape, cables, sledge hammer and seismograph. The 50m-tape was used to measure geophone distances from each other and the geophones were planted at 5m intervals. These geophones were connected by the cables to the seismograph. The strike plate was placed beside the trigger geophone. Energy was generated by striking the strike plate with the sledge hammer.

Data were acquired from three locations (Fig.2) within the Calabar capital territory namely: Adiabo Tinapa; the direction of the traverse is $174^0$ SE Banga, the direction of tranverse is $352^0$ NW and Ikot Nkebre-$196^0$ SW. In all the locations, both forward and reverse transverse were taken and the transverse lines were 60m each. Also in all the locations, the profile lines were arranged to be sufficiently long to ensure that refracted arrivals from target layer were recorded as first arrivals.

**Results**

**Data Reduction/Interpretation**

From a series of geophones planted on the ground, the seismic arrival time(ms) versus the shot to detector distances (m) were plotted to give a time-distance curve (Fig.3). This figure also shows that at distances less than the cross over distance, the sound has traveled directly from the sound source to geophones. At the crossover distance, the sound wave that has traveled through layer one, then along the interface of the high-speed layer (layer two) then back up to the surface through layer one, arrives before the wave that has been in the slower layer. All first compressional wave arrivals at geophone with distances larger than the cross over distance will be refracted waves from layer two. A two layer model (Fig.3) was obtained in the time-distance curve with $V_1$ equal to inverse slope of the plotted line




Scale = 1:50,000

Figure 2 : Map Showing the Study Area

$$V1 = \frac{\Delta x(m)}{\Delta y(ms)}$$

Where $V_1$ = the velocity of sound in layer I
$\Delta x$ = change in distance (m)
$\Delta y$ = change in time (ms)

The depth to the second layer or the thickness of the first layer is

$$d = \frac{Xc}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

Where Xc = crossover distance
$V_1$ = velocity of sound in layer one
$V_2$ = velocity of sound in layer two

The results of the survey are tabulated below:

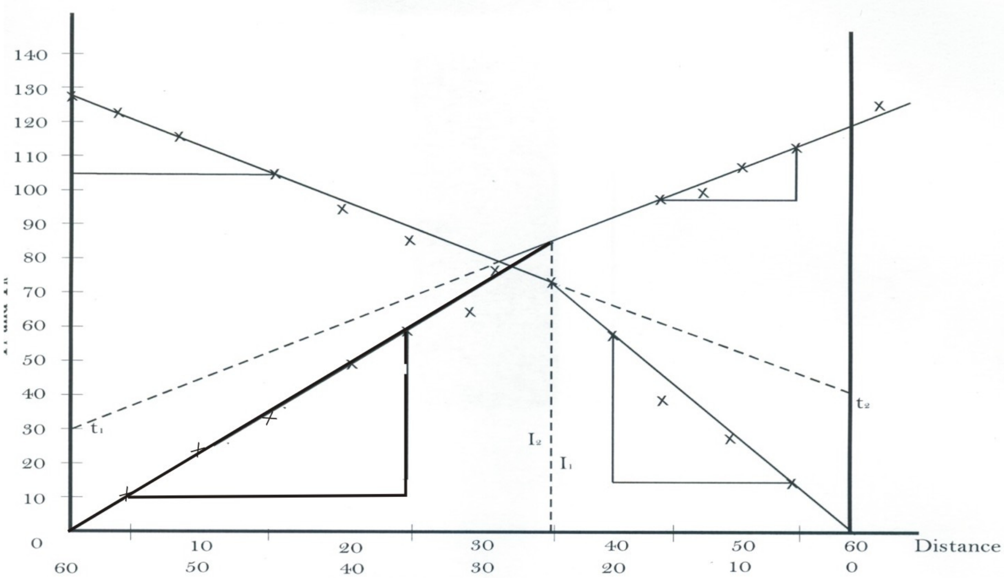



Figure 3 : A Two layer Seismic Model

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**Table 1 Result of the Survey**

| Location | $V_1$ (ms) | $V_2$ (ms) | Depth (m) |
|---|---|---|---|
| 1 | 400 | 800 | 7.47 |
| 2 | 400 | 600 | 3.57 |
| 3 | 400 | 700 | 9.1 |

**Table 2: Established standard P – wave Velocities**

| **Rock Type** | Standard P-Wave Velocity (ms0 |
|---|---|
| Granite | 5520 – 56040 |
| Sandstone | 1400 – 4300 |
| Limestone | 1700 – 4200 |
| Clay | 1100 – 4200 |
| Loose sand | 1800 |
| Coarse sand (wet) | 1150 – 1670 |
| Sand with gravel (wet) | 690 – 1150 |
| Sand with gravel (dry) | 490 – 690 |
| Sandy clay | 360 - 430 |

*(After Zblyth and Freitas, 1979)*

The results of the survey (Table 1) are compared with the established standard p – wave velocity in different rock types (Table 2). From the first table the velocity in the first layer in all the locations is 400ms and falls within the range 360 – 430ms and the rock type is sandy clay. The second layer in location one has a velocity of 800ms (Table 1) and falls within the range 690 – 1150ms (Table 2) which is wet sand with gravel. In locations two the velocity in layer two is 600ms which falls in the range of 490 – 690ms indicative of dry sand with gravel at a depth of 3.57m. The last location showed that layer two has a velocity of 700ms and falls within the range 690-1150ms indicating the rock type as wet sand and gravel.

As a check, vertical electrical soundings (VES) using the popular Schlumberger method were carried out along the same transverses in the three locations. The data were interpreted using Offix and IP12win computer software. Both the geology and borehole data were incorporated in arriving at the above results.

**Table 3**. Location 1

| Layer | Apparent Resistivity (Ωm) | Thickness (m) | Depth (m) | Rock type |
|---|---|---|---|---|
| 1 | 927 | 0.51 | 0.51 | Top sand |
| 2 | 10878 | 0.92 | 1.43 | Dry SS |
| 3 | 211205 | 5.85 | 7.28 | Dry SS |
| 4 | 481 | - | - | Saturated SS |

**Table 4 Location 2**

| Layer | Apparent Resistivity (Ωm) | Thickness (m) | Depth (m) | Rock type |
|---|---|---|---|---|
| 1 | 2244 | 0.92 | 0.92 | Dry top soil |
| 2 | 674 | 2.42 | 3.34 | Saturated SS |
| 3 | 10160 | 1.97 | 5.31 | Dry SS |
| 4 | 335 | 10.58 | 15.89 | Silt/Clay |
| 5 | 2313 | - | - | Dry SS |

**Table 5 location 3**

| Layer | Apparent Resistivity (Ωm) | Thickness (m) | Depth (m) | Rock type |
|---|---|---|---|---|
| 1 | 407.50 | 0.67 | 0.67 | Top wet sand |
| 2 | 4564.36 | 0.99 | 1.66 | Dry SS |
| 3 | 367.59 | 2.63 | 4.29 | Silty/clay |
| 4 | 1232.48 | 4.63 | 8.94 | Dry SS |
| 5 | 491.68 | - | - | Saturated SS |

A look at Tables 3-5 one should notice some near agreement in the figures. In Table 1, the depth to the saturated zone in location 1 is 7.47m and in Table 3 the depth to the same saturated zone is 7.28m and the thickness of this zone is undefined. In location two, Table 1 shows that the depth to the dry sand is from 3.57m and it correlates well with Table 4 which shows the depth to the dry zone as 5.31m. In the last location, Table 1 indicates that the depth to the saturated zone is 9.1m. The depth to the same horizon in Table 5 is 8.94m. It is seen that the difference between seismic refraction results and resistivity results are insignificant.

## Discussion

A two layer model (Fig. 3) seismic refraction showed two aquiferous horizons in location 1 and 3 and dry horizon in location 2, though at different depths. The velocity in the aquiferous zones (700 – 800ms) are larger than those in the non aquiferious regions because the density in the water bearing sand is higher. The result is confirmed by the vertical electrical sounding (VES) results (Tables 3 – 5). The high resistivities of the unsaturated zone and compact non-porous rock usually have a distinguishable contrast with the intermediate resistivity of the saturated zone and the very low resistivities of less permeable silts and relatively impervious clays. Depending on the ratio of layer resisitivities and thicknesses in a vertical profile, layer parameters are non unique to a degree due to the principle of equivalence (Frohlich and Kelly, 1987). Considering the small thickness in Tables 3-5 the VES results can be reduced to two layer model; therefore the results of the geophysical methods are the same.

## Conclusion

Seismic refraction techniques can be used effectively in groundwater studies especially in the Benin Formation. Aquifers in the Benin Formation have seismic velocity of about 700 – 800ms and contrast at major hydrogeologic boundaries. The result so far confirms that seismic refraction technique can compete favourablly well with resistivity methods.

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