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The Use of Integrated 2D Electrical Methods for the Investigation of Road Failure Along Ozalla-Uhonmora Road, Edo State, Nigeria

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ABSTRACT
In this study, 2D Resistivity Imaging and Induced Polarization methods were used to survey a transverse that runs across some failed portions of Ozalla-Uhonmora road in Edo State, to ascertain the possible causes of the failure which appeared as potholes, cracks, and bulges. The result of the study shows that the foundation of the road consists of deposits of clay materials which range from swollen, moderate to non-swollen clay. The swollen clay material was identified as montmorillonite due to it tenacity to rain water. Results further reveal that the combining force of unequal overloading from vehicular movement along the road exerted more pressure on the montmorillonitic clay which in turn resulted into volumetric change of bedrock as swollen clay that led to diapiric deformation of the overlying asphalt by piercing, thus, causing the asphalt to fail as cracks, bulges, and potholes.
Keywords: Road failure, Diapiric deformation, integrated 2D Electrical Methods, Ozalla- Uhonmora road.

INTRODUCTION
Road failure is a discontinuity in a road network as a result of cracks, displacement, bulges, potholes, and depression due to natural cause like faults, joints, sinkholes, incompetent geological materials like clay minerals, and artificial cause by using inferior materials, or human errors such as poor engineering design, inadequate maintenance and improper road usage.
Prevention of failure on a road is the major priority of geotechnical engineers or engineering geologists. There are numerous ways geotechnical engineers use to identifying areas that are prone to failure in engineering structures (road, building, stadium, and airport e.t.c). Some of these methods include; remote sensing technique- to identify clay minerals that are easily responsible to foundational failure, and using ground based shortwave infrared reflectance spectrometry technique. This method has pitfall of discriminatory capacity to identify clay minerals (Osueni, 2009). Other methods are; X-ray diffraction analysis which is very costly and stressful, Atterberg limits for deriving the swelling index. These techniques can only identify failure that is caused by incompetent foundation, clay mineral presence, and high water content. However, they can't identify failures that are caused by geological structures such as faults, joints, and sinkholes.
Road failures are caused by incompetent foundation, high water content, presence of clay minerals, geological structures (fault, joint, sinkholes, and underground caves), and use of inferior materials, and engineering error (human errors). Okechukwu and Okogbue (2011); Onuoha and Onwuka (2014); Van Der Merive (1980); and several authors used standard geotechnical engineering method to delineate areas that are prone to failures without considering the aspect of failures caused by geological structures. However, this present work aims at using integrated two dimensional (2D) electrical methods; Electrical Resistivity Tomography and Induced Polarization Tomography (ERT and IPT). Many authors have used

one dimensional (1D) vertical electrical sounding (VES) technique, while some used only one electrical method to study foundation without getting appreciable results due to undetailed information. In reality, factors that cause or initiate failure in roads and other engineering structures do not occur in one dimension but in two and in some cases three dimensions. Fahad and Syed (2012) used electrical resistivity method to determine soil's strength properties. The pitfall of this is that the soil's strength does not have any correlation with resistivity properties of soil. Baked shale that has no strength may show high resistivity, which can easily be good rock strength as granite with high resistivity and good rock strength.

To be well abreast with details relating to foundation of any proposed road project, it is necessary to use integrated electrical imaging methods to study potential failure as used by (Osinowo *et al*., 2011). In recent past, workers like Aigbedion (2007) and Momoh *et al*. (2008), Ozegin *et al*. (2011) used very Low Frequency Electromagnetic (VLF) method to investigate road failure. The pitfall of using VLF in investigating failed road is its inability to penetrate layers of clay mineral deposits**.** However, one unique physical property of clay minerals is their ability to produce chargeability. These chargeability can be measured with the use of Induce polarized (IP) method. A best way to investigate portions of any failed road is by integration of IP and resistivity methods. While the IP method is capable of properly delineating failures due to presence of clay mineral and high water content, the resistivity method helps to delineate failure caused by incompetent geologic materials and geological structures (joints, buried caves, buried sink holes and fault).

LOCAL GEOLOGIC SETTING OF THE STUDY AREA

The study area is underlain by Imo Shale (Fig.1). The Imo Shale trends across the area with undulating, hilly to sloppy lowland form. The formation comprises friable sandstone, shale, oolitic indurated to moderately indurated sandstone, and heterolith of very fine grained white sandstone and grey to faint black shale. In some cases, the shale has lenses of very fine grained sandstone within the sequence of the heterolith. The section of Imo Shale underlying Ozalla is cut across by a normal fault. The section has general trend of 40°NE-220°SW, dipping in direction of 318°NW, and has general dip amount of 3°.The section comprises heterolith which graded upward into poorly sorted ferruginized coarse grained sandstone. The sandstone passes upward unto fossiliferous black grey shale. The sequence continuous upward as oolitic ironstone and ferruginized mud rock and later transits into friable poorly sorted clayey sandstone bed that is overlain by overburden of about 5m.

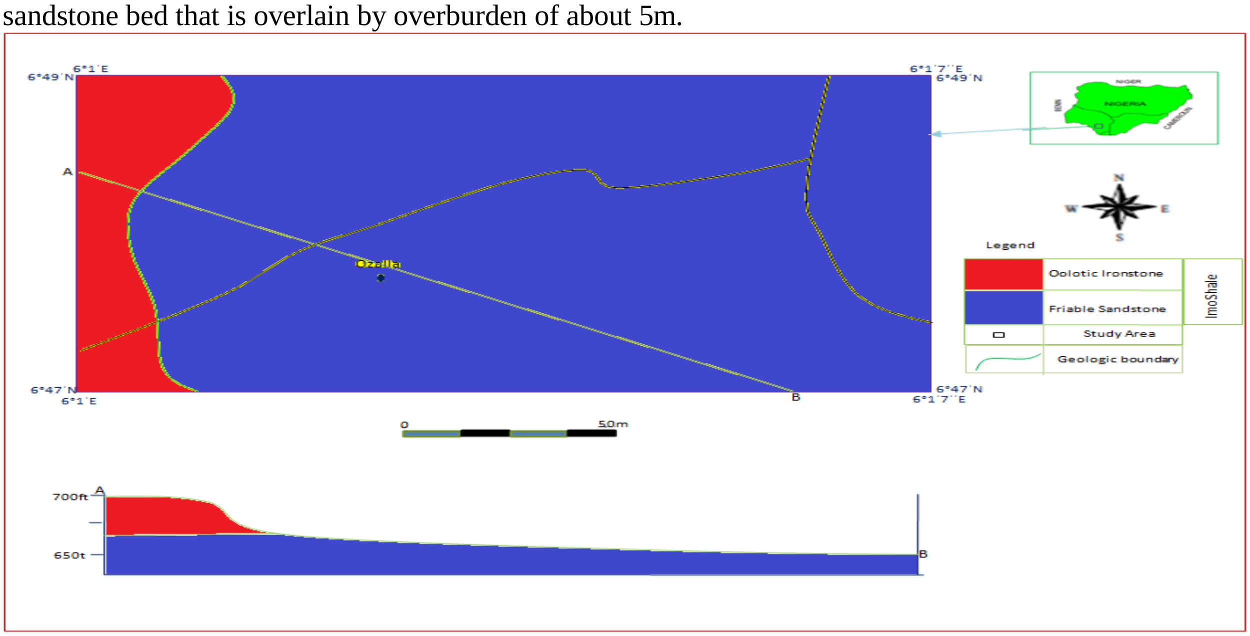

Fig.1: Geologic map of the Study Area

MATERIALS & METHODS

First, a geological investigation of the Ozalla-Uhonmora road was conducted. This was followed by an appraisal of the failed portions of the road (Fig.2). A transverse of about 120m (Fig.3) which run parallel to the failed portion of the road was taken. Along the transverse, the electrical resistivity and IP methods were employed simultaneously to acquire field data using the dipole-dipole arrays configuration because of the low E.M. coupling between the current and potential circuit. This was done to map vertical structures such as cavity, faults, diaper/piercing structures, so as to identify any cause of road failure arising from vertical geological structures and incompetent geological layers.

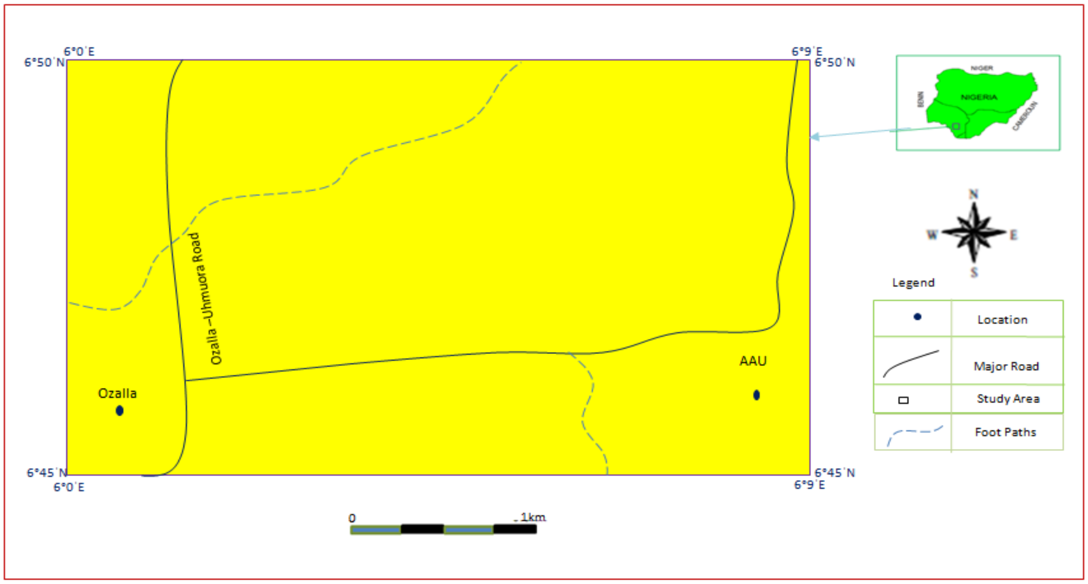

Fig.2: Location map of the study area.

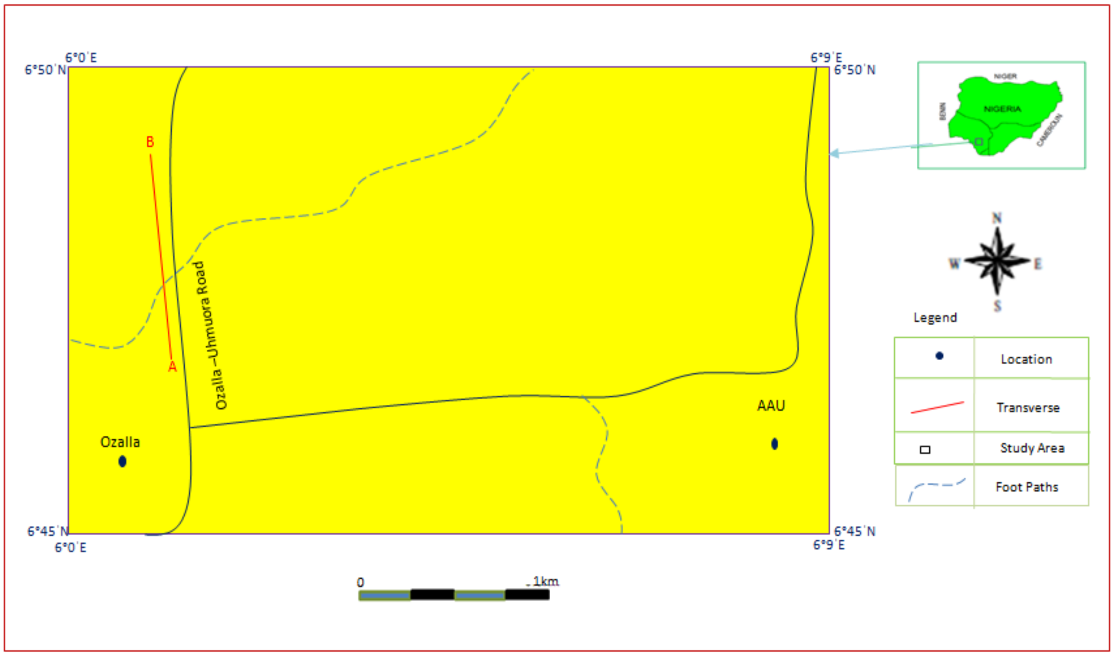

Fig.3: Transverse map showing a transverse line taken parallel to the failed road portion for data acquisition.

SAS 4000 resistivity meter was used to acquire the resistivity and IP data. During the period of data acquisition, extra care was taken so as to maintain error level below 0.09%. Total data points of 156 were collected. Afterwards, the data was processed using RES2Dinverse. The inversion model for both resistivity and IP was least square method, which is expressed as follow:

$$\left(J^T i + UF\right)d^1 = J^T g \qquad (1)$$

Where

$$F = f_X f_X T + f_z f_z T \qquad (2)$$

f_X = horizontal flatness filter

F = vertical flatness filter

U = damping factor

d = model perturbation vector

g = discrepancy vector

The resistivity meter was used to measure the resistance of materials that underlay the failed road portion in order to identify the cause of failure on the road. IP values of the failed road portion were also acquired using the same resistivity meter by measuring the transient decay of the voltage when the transmitted current is turned off. The voltage with length of the different time intervals is expressed as:

$$\Delta t_i = n.f^{i-1}\Delta t_o \quad (3)$$

Where

Δt_o = Fundamental time interval

n =Multiplier factor (default = 1)

f =An incremental exponent

i =Time window index (1, 2, 3, …, 10)

The time domain quantity or chargeability $Mt_it_i + 1$ is measured using equation (4) below:

$$Mt_it_i + 1 = \frac{1}{V_0}\int_{t_i}^{t_{i+1}} V(t)\,dt \qquad (msec) \quad (4)$$

Where

$V(t) = decaying\ voltage$

$t_i \quad = start\ time\ interval$

$t_i + 1 = stop\ time\ interval$

$v_0 = Measured\ voltage\ before\ current\ is\ turned\ off$

Equation (4) can be further expressed as equation (5) in order to have IP unit in form of mV/v as:

$$Mt_it_i + 1 = \frac{1}{V_0(t_{i+1})}\int_{t_i}^{t_{i+1}} V(t)\,dt \qquad (mV/v) \quad (5)$$

RESULTS AND DISCUSSION

Both the 2D resistivity and IP imaging results show contrasts displayed in various colours which represents the signature of resistivity and chargeability response of geological materials in the subsurface of the study area (Fig. 4 and 5).

Integrating the resistivity and IP interpreted results, couple with the background knowledge of the local geology of the study area, shows that the area is underlain with large thick layer of clay minerals that range in thickness from 7.1m to 10m (Fig.4) capped with a lateritic clayey sandstone layer of less than 3m at some point to a little over 3m (Fig.4) at some other point. The resistivity signature displayed in the 2D resistivity imaging result shows that red-purple colours are lateritic clayey sandstone, while green to dark green, blue, and grey colours represent clay beds (Fig.4). The structural nature, shape, and trend of colours signature of clay in the 2D resistivity imaging (Fig.4) represents piercing structure that is, severe movement of underlying clay upward into the overlying 3m sandstone thus, causing failure of the road portion of Ozalla-Uhonmora road in form of cracks, bulges depression and potholes. The IP result gives high values chargeability signature (Fig.5) indicating high presence of clay minerals that easily swell and expand. The IP result correlates well with the resistivity imaging result earlier showed. The dome shapes near the surface show very high chargeability values, this confirms that it is a swollen/expansion upward movement of clay material from beneath to the surface thus, causing crack (Fig.6a) and potholes (Fig.6b) of asphalt. The result of the 2D resistivity shows vividly clay diapir at 18-23m (Fig.4) and the upward piercing of clay thus forming bulge (Fig.6c) of the clay into the overlying asphalt on the road.

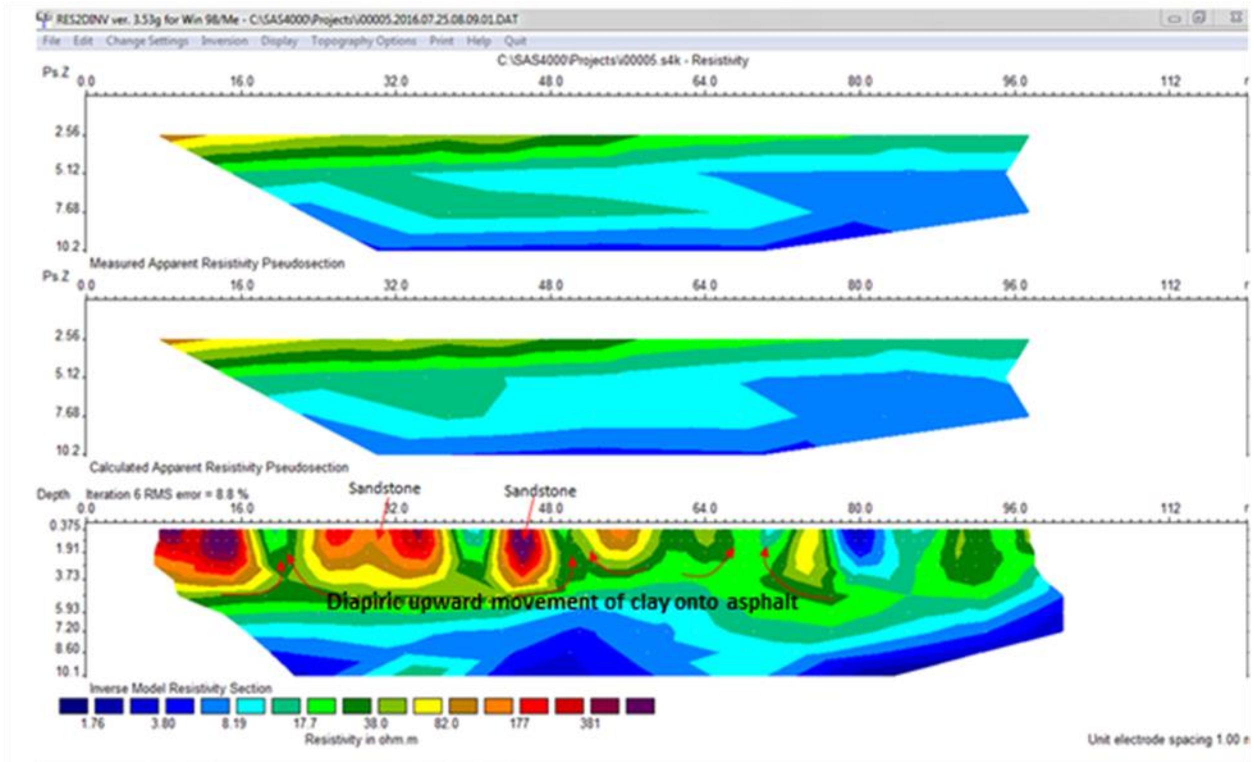

Fig.4: The result of 2D resistivity imaging acquired along Ozalla-Uhonmora failed road

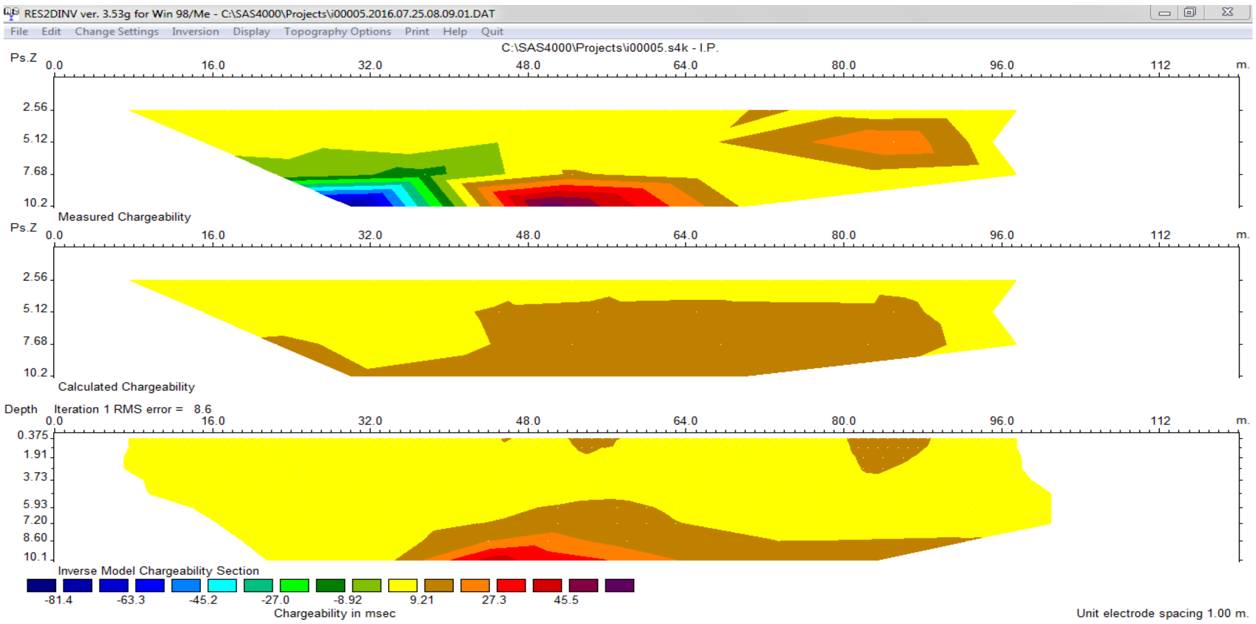

Fig.5: The result of 2D induced polarization imaging acquired along Ozalla-Uhonmora failed road.

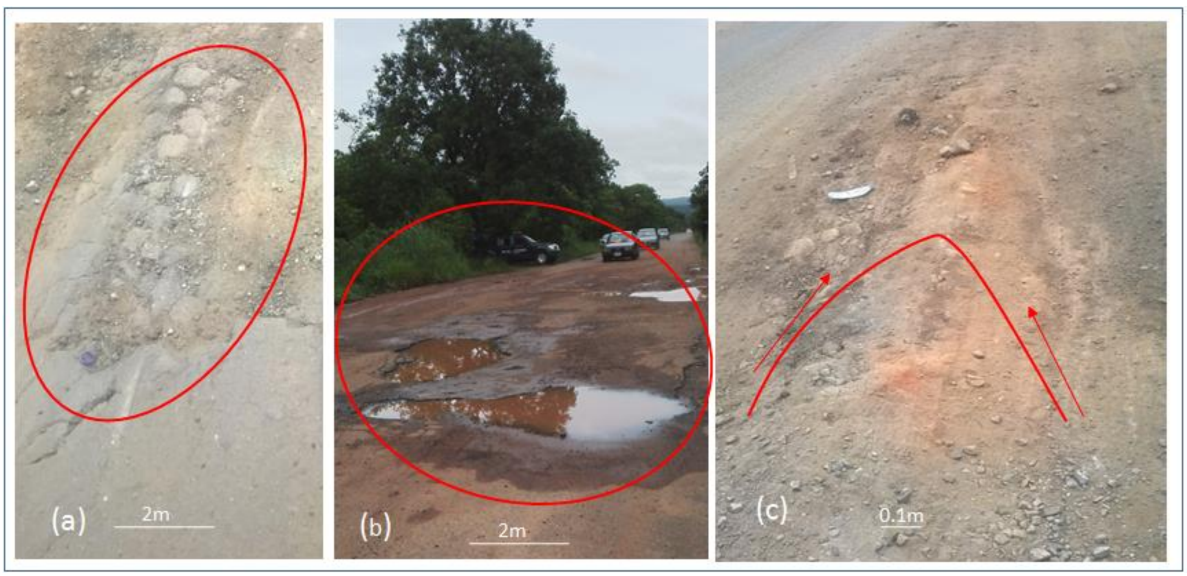

Fig.6: Failed portions of Ozalla-Uhonmora road. (a) appears as cracks, (b) appears as potholes, and (c) appears as bulge.

CONCLUSIONS

The saturation of the underlying clay minerals (montmorillonite), by rain water resulted into the swollen clay observed in the study area thus caused volumetric change in the bed rocks. Uneven daily loading of the foundation of the road by vehicular objects of varying sizes and weights, led to severe upward mass movement of the underlying swollen clay material into the overlying asphalt. These caused the clay diapiric deformation observed on the Ozalla-Uhonmora road.

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