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Analysis and Characterization of Njaba River Gully Erosion, Southeastern Nigeria: Deductions from Surface Geophysical Data.

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Abstract: A detailed geophysical survey was carried out at the Njaba River gully erosion site at Awo-Omamma, southeastern Nigeria using the electrical resistivity vertical and azimuthal sounding techniques as well as the self potential method. The objective of the study was to evaluate the subsurface structure at the gully site and adjacent areas and to offer geological/ geophysical explanation on the cause of the sudden landslide that occurred at the site recently. Results of the study revealed that the azimuths of the major axes of the anisotropy diagrams correlate significantly with the strikes of the geological formations with the coefficient of anisotropy varying from 1.30 to 1.70, indicating that structural in-homogeneities exist. The evidence spontaneous potential data indicated that the strike of the gully which is oriented in the NW-SE direction is characterized by low SP values ranging from -50 to -100mV; and low electrical resistivity values both flanked by a zone of higher SP and resistivity values. Similarly, it was also revealed that the maximum electrical anisotropic effect was detected in the NW-SE direction and this coincided with the regional trend of the study area. Consistent NW-SE orientation of maximum axis of electrical anisotropy and the attitude of the gully eliminated the wide range of other possible causes and suggest that the gully is structurally controlled and may be running along the geologic contact between the Benin and the Ogwashi/Asaba Formations.

Key words: Gully erosion, Geophysical survey, Analysis, characterization, Nigeria, faulting.

INTRODUCTION

Erosion gullies resulting from high rainfall intensity, wind action, slope instability, poor engineering and agricultural practices and other exogenic processes are common features both in the sedimentary formations and the basement areas of Nigeria. One thing common to the known erosion sites in the country is that most of them begin as rills along slopes and develop gradually with time into gullies. The most active erosions are generally found along slopes which represent the flanks of paleo-depressions resulting from endogemic processes. Most of the time the erosions get accelerated through human and other cultural activities which appear to interfere negatively with natural processes and degrade landforms.

The Njaba River gully at Awo-Omamma, Imo State, Southeastern Nigeria has peculiar and very interesting origin and characteristics. Its genesis was spontaneous. A major failure suddenly occurred around the area a few years ago along a linear zone following a heavy rainfall. Slumping and land sliding followed. The impact of the gully on the environment was such that local newspapers reported the event as a volcanic eruption. This incident which has degraded the landform in the vicinity and caused great panic in the neighbourhood has attracted the attention of geologists/earth scientists and various levels of government in Nigeria. There is a speculation that this sudden failure cannot be a chance occurrence. There must have been a pre-existing condition hitherto undetected which acted as a trigger for the spontaneous event that opened up the gully. The first suspicion is the existence of a major fracture in the area whose extent may not be readily known. The favourable property of the soil which makes it susceptible to erosion is its formational stability which in turn is dependent upon factors such as fracturing and faulting, weathering and the resultant petro- physical properties.

Zones of fracturing and areas of weakness usually exhibit anomalous electrical, elastic and clastic properties which can be detected by making surface geophysical measurements. The potentials of geophysical methods in the determination of axes of structural in-homogeneity have been adequately highlighted by several workers (Ako, 1976, Ako and Ajayi, 1976, Taylor and Fleming, 1988, Mann and Ekine 1989, Skjernaa ad Jorgensen, 1994, Olorumfemi and Opadukan 1989, Onu, 1998, etc). Apparent resistivity measurements and the establishment of an anisotropic index provide a useful indication of the presence and localization of cracks on the earth surface (Lataste et al, 2002). Azimuthal resistivity surveying has been adopted (Hagrey, 1994; Watson and Barker, 1999;Ramanujam et al.,2006; Ehirim and Eeocha.,2009) as a technique for determining the principal directions of electrical anisotropy and, hence, hydraulic conductivity using the analogy between Ohm's law and Darcy's law. Typically, any observed change in apparent resistivity with azimuth is interpreted as indicative of anisotropy (generally fracture anisotropy). The objective of this study has been to evaluate the subsurface structure of the gully site and adjacent areas using geophysical techniques and to offer geological/geophysical explanation on the cause of the sudden failure. The geophysical methods employed in the study include the direct current electrical resistivity (ER) vertical and azimuthal sounding techniques and the

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self potential method. Data collected through these methods have been analyzed and interpreted. The results have provided vital clues as to the cause of the observed sudden soil failure in the study area.

Location and Geomorphology of the Study Area:

The study area is the gully erosion site at Awo-Omamma, Imo State Southeastern Nigeria. Awo-Omamma is a small community located about 33km northeast of Owerri. The important settlements/communities near the study area includes Oguta, Izombe, Ogbaku, Eziama Obiato, Otulu and Oteru (fig.i). The study area is made accessible by many major and secondary roads as well as footpaths and these facilitated the survey.The landscape is generally gently undulating with bush clad ridges, which separate the wide and shallow depressions running in the NW-SE direction. The average slope at the gully site is about 0.022 southward. The area lies within the rain forest belt but the vegetation is that of Sudan savannah, the rain forest structures having been almost eliminated by human interference. However a trace of the forest zone can be seen along the banks of the rivers and other water courses. The area is drained by the Njaba and Awbana Rivers which are tributaries of the Orashi River.

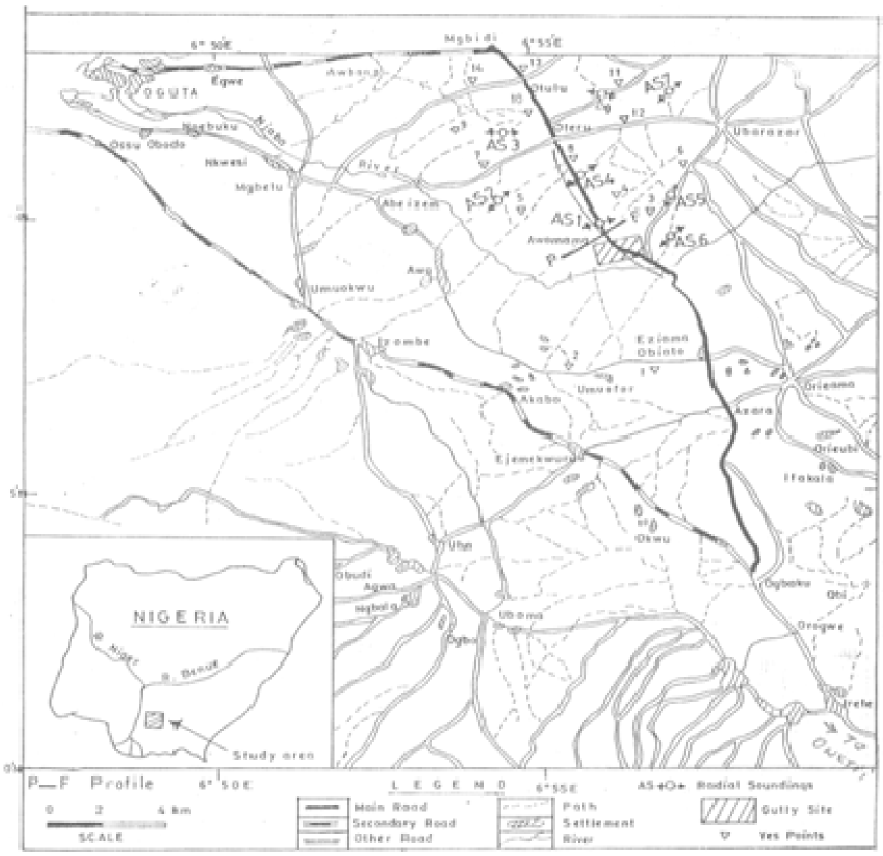

Fig. 1: Map of the study area showing gully site and vertical electrical sounding locations

Background Geology of the Study Area:

Geologically, the study area is underlain by the Coastal plain Sands (Benin Formation) and bits of the Ogwashi /Asaba Formation (fig.2). The opening of the South Atlantic Ocean initiated tectonism in the region of Southern Nigeria and led to the development of the Benue Trough (Wright, 1966; Nyong, 1995). The development of the Benue Trough provided the main structural control and framework for subsequent geologic evolution of Southeastern Nigeria. Three major tectonic cycles could be identified in Southeastern Nigeria (Murat, 1972). The first major tectonic phase (Aptian-early Santonian) directly followed, and was related to, the initial rifting of the Southern Nigeria continental margin and the opening of the Benue Trough. This phase produced two principal sets of faults, trending NE-SW and NW-SE. The NE-SW set of faults bound the Benue Trough; while the NW-SE sets defined the Calabar Flank. The second tectonic phase (Turonian -Santonian) was characterized by compressional movements resulting in the folding of the Abakaliki Anticlinorium and the complementary Afikpo Syncline. The third phase (Late Campanian - Middle Eocene) involved rapid subsidence and uplift in alternation, with subsequent progradation of the Niger delta.

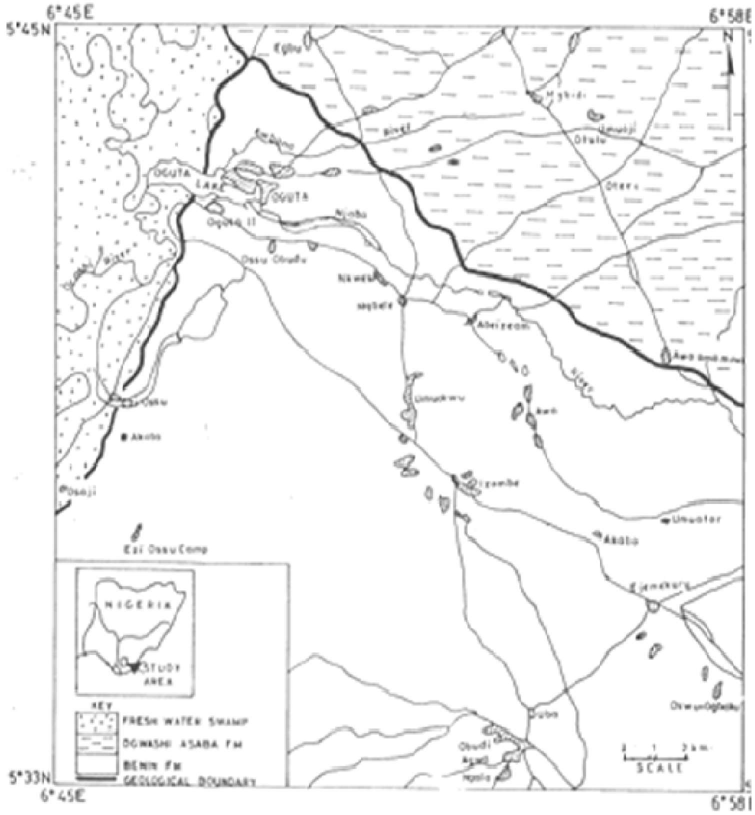

Fig. 2: Geology map of the study area showing the different geological formations

The sedimentary basin of southern Nigeria originated in early cretaceous time as an X-shaped depression oriented NE-SW and NW-SE and defined by a set of mega-tectonic elements, among which are the Benin Flank to the northwest, the Benue Trough to the north and the Calabar Flank to the east (Agagu,1979). The depression was said to be formed in the Basement complex of the African shield. The form of this depression and the rather straight course of long reaches of the Niger and Benue Rivers have led to the speculation that the depression is fault controlled (Short and Stauble, 1967).The depression is genetically related to the Benue Valley; a trough which originated as a drift structure (Cratchley and Jones, 1965). Structural movements in this trough began in the Coniacian time and accumulated in the Santonian. There are three main depositional and tectonic cycles in the southern end of the Benue Trough. The first cycle (Albian - Santonian) was confined in the southern end of the Benue Trough. The second (Campanian-Eocene) filled the Anambra Basin and Afikpo syncline, and the third cycle paved the way for the development of the modern Niger Delta (Mamah and Ekine, 1989; Short and Stauble, 1967) Each cycle was terminated by folding and uplift. There have been continued basement movements, sedimentation and minor faulting along earlier lines of weakness. The Ogwashi/Asaba and Benin Formations represent the Miocene to Recent sediments of the depositional cycle of the Benue Trough, and these gave rise to the modern Niger Delta. The lithostratigraphy of the Benin and Ogwashi/Asaba Formations has been documented by various scholars (Reyment, 1967, Short and Stauble 1967, Kogbe 1976 and Asseez, 1979). The sediments of the Benin Formation are lenticular, unconsolidated, friable and sandy. Clays and sandy clays occur occasionally at deeper levels. The Ogwashi/Asaba Formation is predominantly sandy. The sands alternate with lignite seams and few beds of clay (Reyment, 1965).

Geophysical Field Investigations:

Several geophysical investigations were carried out in the study area which include vertical electrical soundings (VES) at points indicated (figure 1), Azimuthal (radial) soundings at the locations marked AS (fig.ure 2), electrical profiling using Werner array along PF (figure 1),and Self potential measurements.

Twenty (20) vertical electrical sounding positions were occupied using the Schlumberger electrode array. The locations of the sounding points are shown on figure1. Electrical resistivity profiles were aligned along footpaths and open fields providing reasonable profile lengths. It is on account of this that most of the soundings were performed in the northern part of the study area. In the depth sounding mode, a series of measurements were made with increasing electrode separation, to a maximum current electrode spacing (AB) of 1000m. The apparent resistance for each electrode spacing was multiplied by a geometric factor to give the apparent resistivity. The instrument used was the ABEM SAS 4000 Terrameter. Current and potential electrodes were made of non polarisable stainless steel. The observed field data were therefore curves of apparent resistivity against current electrode spacing plotted on log-log papers and constituted the depth sounding curves. Quantitative interpretation was by use of auxiliary diagrams (Zohdy, 1965, 1974) and computer interactive method using a program (OFFIX 3.1). Because of space only one vertical electrical curve is shown (fig.3), which are representative of the geoelectric curves obtained in the study area.

The results of Schlumberger type electrical resistivity sounding were further extended by carrying out Wenner type electrical resistivity (ER) profiling normal to the strike of the gully, using the electrode spacing of 50m. The purpose of the ER profiling was to determine the lateral variation in resistivity. One main traverse was selected on the basis of accessibility along line PF(fig.2).The resistivity profiling data were plotted and shown in fig.4.

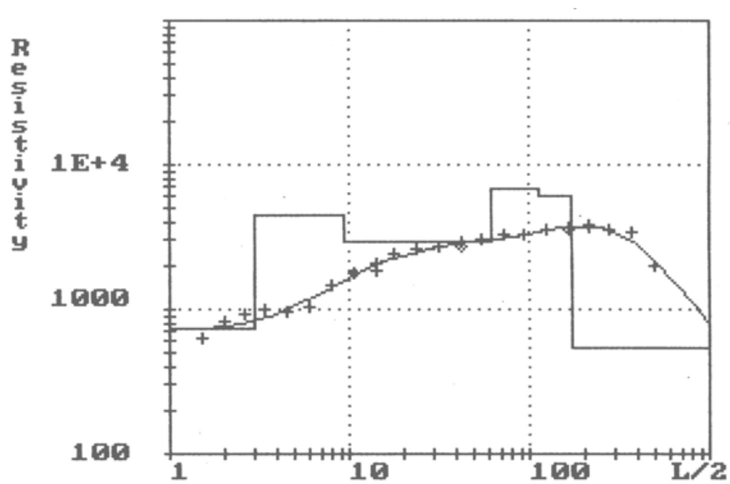

Fig. 3: Electrical resistivity sounding curve (VES 5) representative of the study area indicating the presence of five geo-electric layers

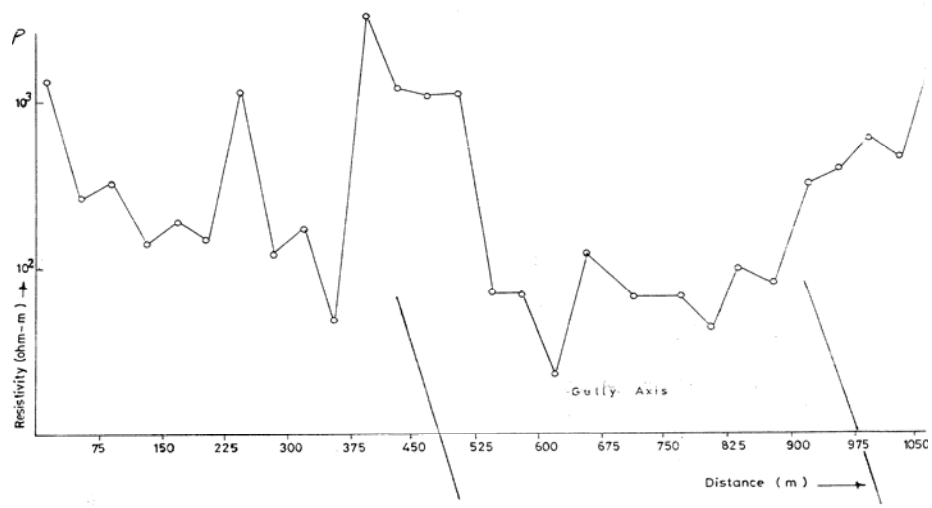

Fig. 4: Electrical resistivity profile across the gully erosion in the study area

Self potential (SP) measurements were also made in a direction normal to the strike of the gully along the same profile used for ER profiling (i.e. profile PF). The instrument used was also ABEM 4000 Terrameter in the SP mode. Non polarizing electrode condition was attained by placing short copper rods in porous pots containing concentrated copper sulphate solution. The non polarisable electrodes were used in order to screen off spurious sources of potential. The observed SP values were displayed as shown in figure5.

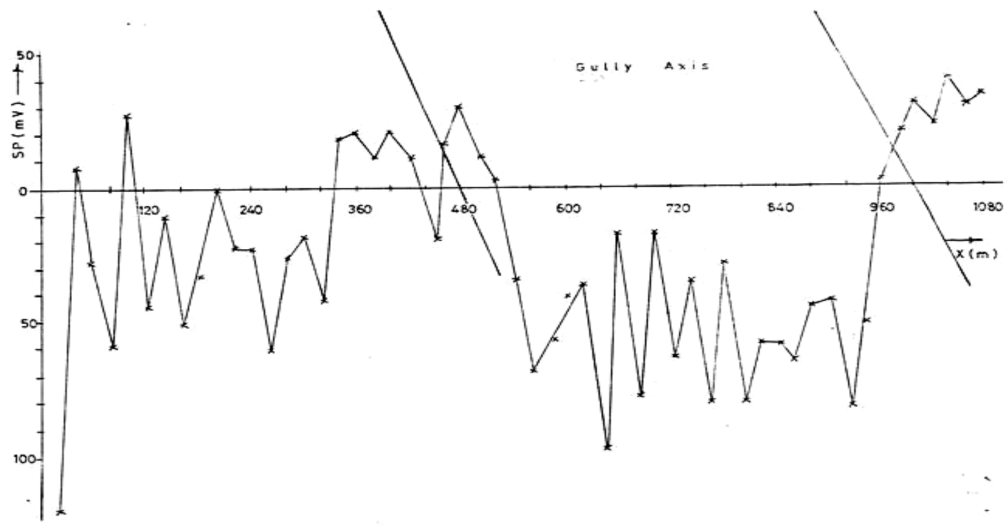

Fig. 5: Spontaneous potential (SP) profile data across the Njaba River Gully.

Six ER radial (azimuthal) sounding positions were occupied at the locations marked AS (fig. 1). The Schlumberger electrode array with constant electrode spacing were rotated 45^o over the span of 360^o to signify readings in N-S, NE-SW, E-W and NW-SE directions i.e. (0^o, 45^o, 90^o, and 135^o). The data for each sounding location were used to produce an anisotropy diagrams (fig.VI).The treatise on azimuthal sounding has been adequately elaborated by several authors (Taylor and Fleming, 1988, Skjernaa and Jorgensen 1999).

RESULTS AND DISCUSSIONS

Most of the depth sounding curves was of the AK and AKQ types with most indicating the presence of 4 to 6 layers with distinct geoelectric characteristics (fig.3). These curves characterize the thick nature of the layers of the sediments.

A combination of the interpreted sounding results together with information from lithological logs of existing boreholes in the study area were used to arrive at the conclusions that the first two geoelectric sections constitute the lateritic overburden. The upper segment of this overburden contains laterite while the lower segment of this overburden is made up of coarse (reddish) sand. The third geoelectric section whose composition according to the lithological logs is mainly medium to coarse grained white sands and gravel with relatively no clay has been identified as a water bearing layer. The resistivity varies from place to place but lies within the range of 685 – 2300 ohm-m. The resistivity would indicate clean non saline groundwater. In the AKQ type curves with six (6) layered geoelectric sections, the third layer consists of highly resistive substratum with resistivity in the range of 4000 – 18000 ohm-m. This is the unsaturated layer consisting of sand and gravels. The fourth and fifth geoelectric layers consist of fine to medium sand saturated with water to varying degrees. Depth sounding curves for the measurements aligned approximately normal to the strike of the gully recorded a continuous increase in apparent resistivity with current electrode spacing (fig 3). Similarly electrical resistivity profiling measurements illustrated in fig. 6 indicated a zone of low resistivity along the strike of the gully within the gully frame. This is expected because zones of fracture constitute a major conduit for water movement (Greenfield and Stoter, 1876). The SP observations (fig. 7) also showed a zone of low Sp values (-50 and -100mV) within the gully axis. Self potential anomalies are usually associated with weathering of mineral bodies, variation of rock properties at geologic contacts or bioelectric activity of organic materials, and in all cases the controlling factor is underground water (Telford et al, 1976).

The anisotropy diagrams obtained in the study area shown in fig. 8 have single peaks showing electrical anisotropy in the NW-SE direction. The E-W and NE–SW fractures sets seem to be weakly developed in these localities as indicated by their anisotropic dimensions. The anisotropy diagrams obtained at the same locality but from surveys with different current electrode spacing were identical or similar with respect to the overall orientation and form but the outlines are smoother for greater current electrode spacing. This probably results from the fact that major fractures contribute to the measured pattern as the current electrode spacing becomes larger than the short wavelength fractures for smaller electrode spacing. Gully erosion follows the axes of structural weakness through the subsurface. These axes of structural weakness are geologically referred to as fault zones and serve as conduits for water saturation. The axis of greater current flow during radial sounding will therefore indicate the direction of anisotropy through the subsurface as water content more than any other factor influences electrical resistivity especially in a locality where the mineralogical symbols are uniform to semi-uniform such as the one obtainable in this locality.

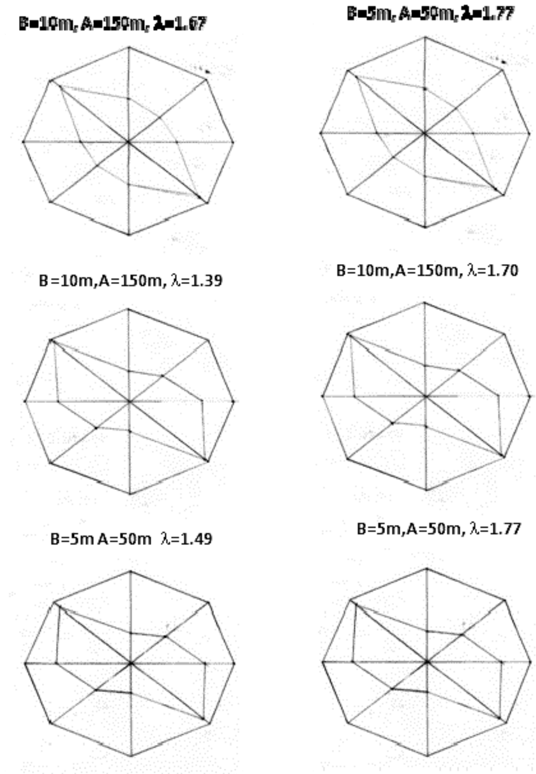

Fig. 6: Electrical resistivity anisotropy diagrams obtained in the study area

According to Habberjam (1975), the length of the major axis of the ellipse is numerically equivalent to the transverse resistance ρ_t while the length of the minor axis is numerically equivalent to the longitudinal resistivity ρ_i. The coefficient of anisotropy, λ is the root of the ratio ρ_t / ρ_i. The coefficient of anisotropy obtained from the survey varies from 1.30 to 1.73, the highest signifying a preferred direction of weakness.

Conclusion:

The azimuths of the major axes of the anisotropy diagrams correlate significantly with the strikes of the geological formations. The coefficient of anisotropy obtained from the survey varies from 1.30 t0 1.70, indicating that structural in-homogeneities exist. The evidence from available geophysical data indicate that the strike of the gully which is oriented in the NW-SE direction is characterized by low SP values ranging from -50 to -100mV; and low electrical resistivity values both flanked by a zone of higher SP and resistivity values. This would suggest a juxtaposition of sediments of different degrees of saturation and resistance to shear and probably separated by a fractured region which may be a fault. The early cretaceous tectonic movement in the sedimentary basin of Southeastern Nigeria guided a major marine transgression across the continent and later determined the course of the Niger and Benue Rivers and probably had tremendous influence on gulling and erosion (Hospers, 1965).Consistent NW-SE orientation of maximum axes of electrical anisotropy and the form of the gully and its orientation which coincides with the regional geologic trend, narrow down wide range of other possible causes and have led to the speculation that the gully is structurally controlled and may indeed be running along the geologic contact between the Benin Formation and the Ogwashi/Asaba Formation. This conclusion however would require supporting evidence from remote sensing data and additional geophysical work in the area and thus this study sets out to narrow exploration target on the causes of the gulling and erosion in this area.

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