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Mineshaft Imaging Using 2D Electrical Resistivity Tomography in a Kaolin Mining Site at Kankara in North Central Nigeria

Daniel Eshimiakhe[1]*, Raimi Jimoh[1], Larry Bagudu[1], Abubakar Hussaini[2] and Matthew Monday Ogwuche[1]

[1]*Department of Physics, Ahmadu Bello University, Zaria, Nigeria*
[2]*Department of Physics, Umaru Musa Yaradua University, Katsina, Nigeria*

Abstract

A Kaolin mining site at Dajin Gwanma in north central Nigeria was investigated to detect subsurface voids created due to mining of kaolin deposit and to perhaps suggest areas prone to subsidence. This study was undertaken on conceptual resistivity model that subsurface voids characterized by higher or lower resistivity than the host, depending on weather the void is in-filled water or not. The data collection was carried out with Terrameter SAS 4000 and ES 464 electrode selector equipment. Dipole-dipole configuration at electrode spacing of 5 m was used to acquire the data along parallel profiles laid at equal interval in the study area. The acquired data along each profile were inverted with 2D algorithm. The results show that the voids are characterized by high resistivity (950 Ωm-2500 Ωm) at depth of between 0-4 m and low resistivity (10 Ωm-100 Ωm) at a depth of 5-30 m indicating both air-filled and water-filled voids respectively. The study shows that the voids increase in dimension with depth in NW-SE direction, suggesting that the voids are trending most probably along vertical bedrock joints. It also suggests that voids may overtime grow large enough that the overlying top soil can no longer bridge it, leading to its collapse.

Introduction

The worldwide need for clay especially in the early nineties, required increase mining of kaolinite. Deposit of this important raw material is widely distributed in Africa, especially Nigeria [1-5]. Large amount of this raw material came from underground mining in areas where surface mining is impracticable or uneconomical. However, the discovery of oil and the subsequent shift from kaoline and other deposits have left some of these areas with abandon mines. The study area and its surrounding are richly mineralized with kaolinite which is *in situ* formed through hydrothermal and or weathering alteration of Feld spathic rocks of granite and arkose [6]. Consequently, a lot of mining activities are still carried out (formal and informal mining). These are done by the miners digging through the subsurface in search for this deposit (kaolin), thus, creating voids (empty space) within the subsurface (Plate 1). These voids might undergo subsurface expansion as water from rainfall can percolate and erode the mud and rocks around the voids. In addition, the expansion can also result from erosion of walls of the voids as a result of the water in them. This action, with time can grow large enough that the overlying soil cannot bridge it, thus leading to collapse of the overlying layer. This could lead to loss of human lives and animals. This tells of how dangerous and risky it is for such local miners to keep on mining and not knowing the damage their activities pose. An incident of such ground collapse at a segment of the study area, leading to the death of one miner. This have prompted the need to investigate the study area using 2D electrical resistivity tomography to detect subsurface cavities in the area and the objectives are to determine the probable lateral extent of cavities and its characteristic resistivity value range. The choice of resistivity method is governed by its success in locating underground openings which exhibits either higher resistivity or lower resistivity than the host rock depending on the weather the opening is in-filled or not. The detection of underground voids in Ohio using resistivity tomography [7], detection of abandoned mine workings at Regency park Subdivision in Pennsylvania [8] and the use of electrical tomography to detect buried cavities in Rome [9], are typical examples.

Plate 1: Shafts being created due to local mining of Kaolin.

Location and Geology of the Study Area

The mining site is situated in Kankara local government area of Katsina state. It is located about 5.6 km from Kankara and 1.4 km from Danmarke village and falls within the latitude 11°53’31.91”N to 11°54’31”N and longitude 7°26’31.23”E to 7°21’00”E.

The entire area is underlain by rocks of the basement complex consisting mainly of migmatites, granites gneiss, biotite gneiss, and metasediments of generally amphibolite facies, metamorphism and granitic rocks of the older granite suite [10]. The geological formation in the vicinity strikes generally east-west and outcrops of the host mica-shist can be found along rivers channels (Figure 1) [11]. The rock *in*

***Corresponding author:** Daniel Eshimiakhe, Department of Physics, Ahmadu Bello University, Zaria, Nigeria, E-mail:eshimiakhedaniel@yahoo.com

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situ occurs as silvery to light grey on the fresh surface, interspersed with injection of quatzo-feldspathic veins along fracture planes. It is generally fissile and readily parts along the cleavage planes. The rock has low south-east angle of dip varying between 22° and 40° [12].

Materials and Methods

Data acquisition and processing

The 2D ERT survey was carried out using the dipole-dipole array configuration. The reason for the choice of this array is that it is the most sensitive to resistivity variations below the electrodes in each dipole pair and is very sensitive to horizontal variations with depth. Thus, it is the most preferred array for mapping vertical structures like dykes and cavities. The choice of direction of the profiles was, on the other hand for continuous direction of the cavity to be mapped and to be able to get the lateral extent of these voids. A total area of 210 m by 20 m was surveyed. The data collection was carried with tetrameter SAS 4000 and ES 464 electrode selector employed. The dipole-dipole electrode configuration with electrode spacing of 5 m was used to acquire the data along 5 parallel profiles laid at interval of 5 m. The profiles were laid with the origin at the West and the end at the East of the study area, covering a lateral length of 210 m. The mine shaft pit entrance was located at a lateral distance of between 140 m to 180 m (Figure 2).

Prior to data inversion, the apparent resistivity data set were inspected in accordance with the suggestion of Loke, [13] for bad datum point and such points were deleted. The 2D ERT of each profile were inverted using the RES2DINV software (Geotomo software), using the smoothness constrain algorithm inversion technique.

Interpretation of Results

Figures 3-7 shows the 2D pseudo-sections for each of the profiles. All the profiles show the inversion result with an absolute error (RMS) of 5.3% for profile 1, 10.5% for profile 2, 4.8% for profile 3, 4.4% for profile 4 and 4.2% for profile 5. Thus indicating that a good fit between the measured and calculated apparent resistivity data has been achieved. Oval shaped features with high and low resistivity zones have been observed near the surface in each of the five profiles which indicates

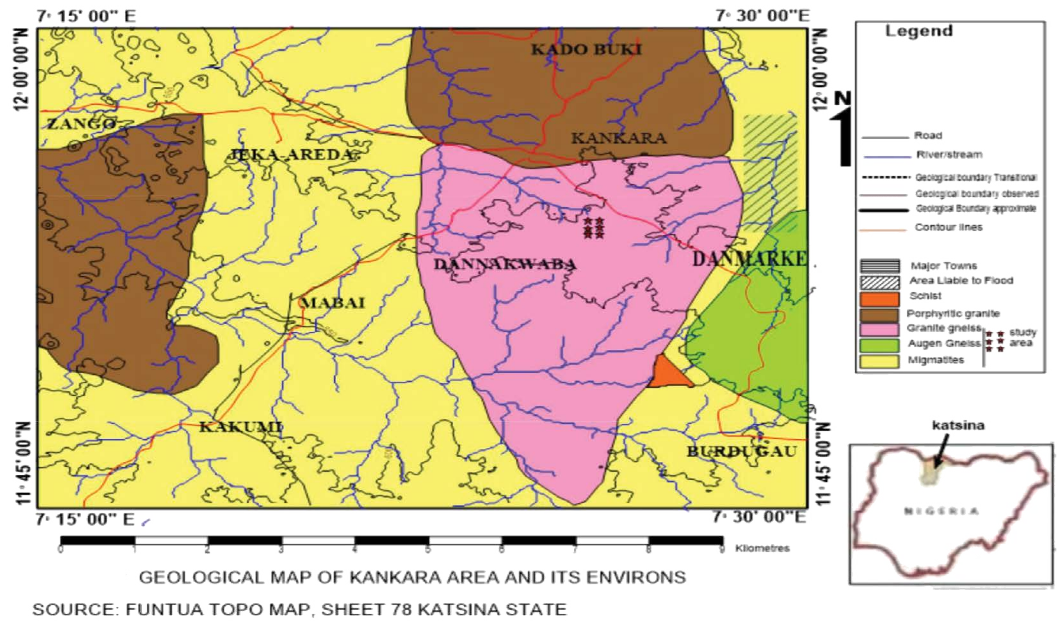

Figure 1: Geological map showing the study area (adapted from Kankara & Farouk).

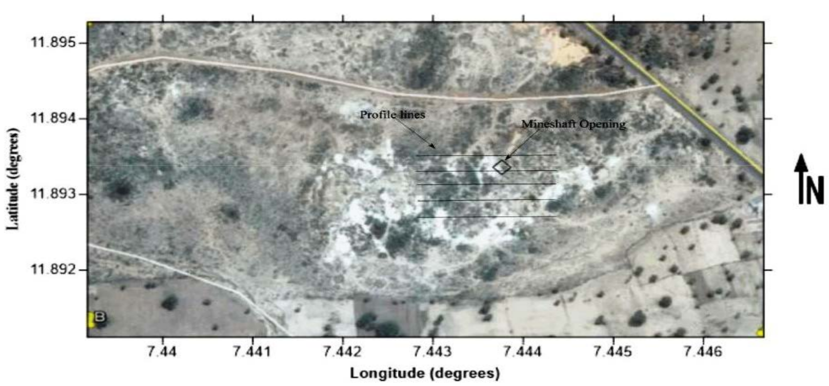

Figure 2: Map showing the Profile lines layout and mineshaft opening.

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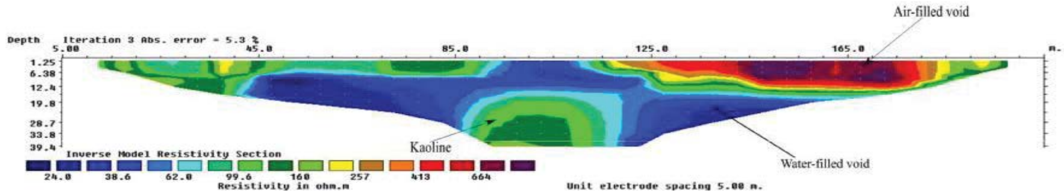

Figure 3: Inverse resistivity model of profile 1.

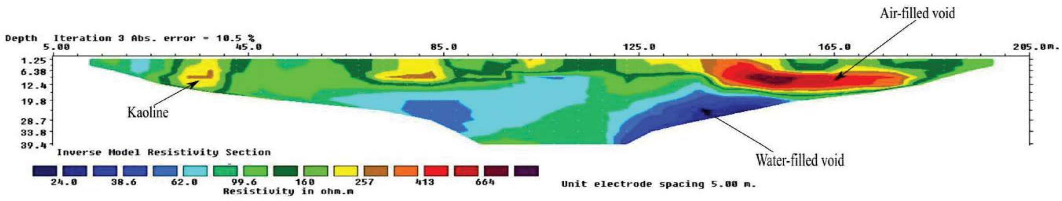

Figure: 4: Inverse resistivity model of profile 2.

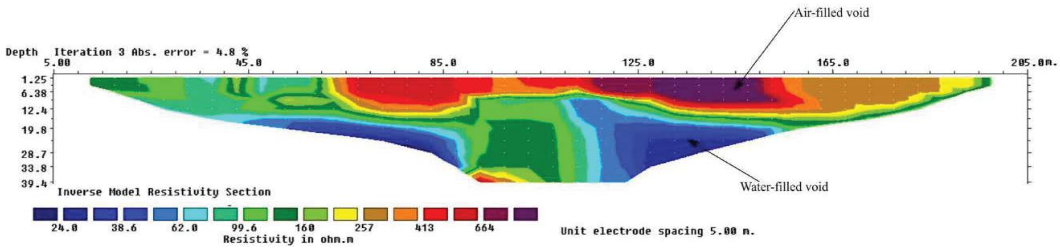

Figure 5: Inverse resistivity model of profile 3.

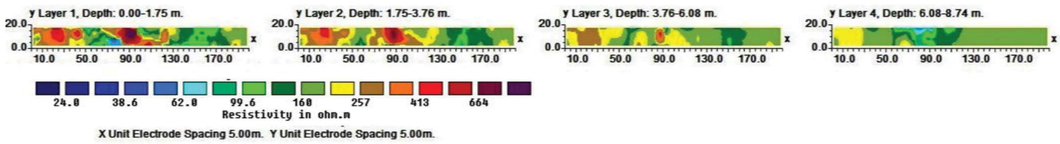

Figure 6: Inverse resistivity model of profile 4.

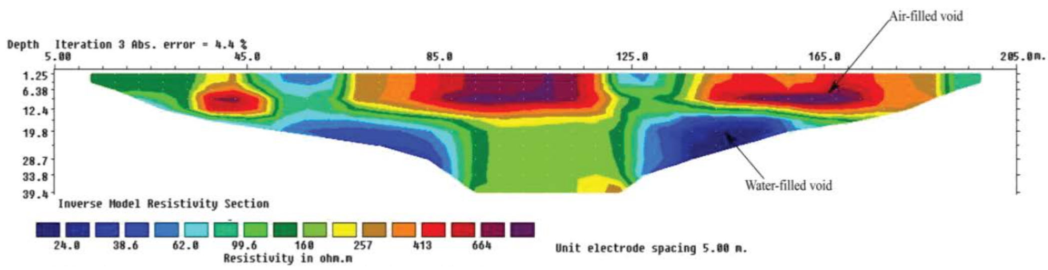

Figure 7: Inverse resistivity model of profile 5.

the presence of cavities. The position of the cavities on the resistivity inversion which is about 140 m to 160 m, tallies with the horizontal position of the mineshaft opening along the profiles. Kaolin minerals can be found along each profile based on the resistivity contrast with the host rock, between 90 Ωm -97 Ωm. Table 1 gives the standard resistivity values of that was used to infer the range of resistivity values encountered in the inversion model of all the profiles.

The five 2D profiles were collated into 3D data set by writing a computer script to give the resistivity slices at various depths (Figure 8). Air filled void can be seen at a shallow depth (slice 1, 2 and 3), while water filled void can be seen to begin at a depth of 6 m.

Discussion and Results

According to previous studies conducted in South-western Missouri, typical resistivity values for subsurface cavities can be characterized on the basis that air-filled cavities show very high

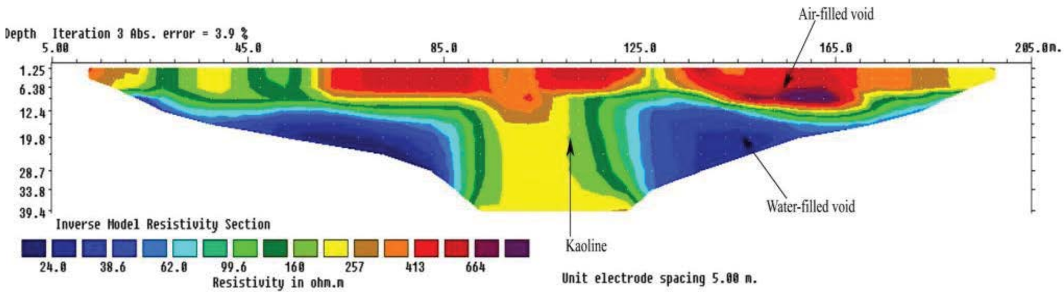

Figure 8: Resistivity slices indicating the depth of the cavity.

Rock types resistivity	(Ωm)
Clay	35–100
Saturated Clay	27–55
Sandy clay	60–210
Saturated sandy clay	50–120
Top soil	250–350
Lateritic clay	110–550
Kaolin	41–97
Soft weathered basement rock	56–1238
Fresh basement rock	200–>5129

Table 1: Range of resistivity values and their Corresponding geologic interpretation derived for this study.

resistivity values usually more than 1000 ohm-m but again are variable depending on the conductivity of the surrounding strata and depth/size/shape of void. Water filled cavities usually show very low resistivity values. Considering the study area, low resistivity value of water can be caused by the inclusion of kaolin mineral with the water. Kaolin minerals in this study area were derived from gneisses and granitoids, both rich in feldspars and micas. The alteration of the parent minerals (Feldspars such as microcline and micas such as muscovite) contained in the gneisses and granitoids eventually lead to the formation of the kaolin. When the clay particles are immersed in water, dielectric properties of the water reduce the coulomb forces holding the positive ions. Some of the counter ions leave the clay surface and move relatively free in the water and contribute to rock conductivity. Even in cases where cavities have been in-filled, a contrast between the resistivity of the cavity and bedrock will often occur due to differences in the packing and composition of the in-fill material. These were used as guide for inferring voids in this study.

Results for the 2D inverse model show evidences of both air-filled cavities and water-filled cavities at horizontal distance of 140 m-160 m. It can be seen that air-filled cavities are found in the top-layers of each profile (ranging from a depth of 0-12 m) having resistivity values ranging from 250 Ωm-1500 Ωm and water-filled cavities are found at much deeper depth, having resistivity values ranging from 10 Ωm-65 Ωm. Also, the size of air-filled cavities is much smaller than the water-filled cavities as the depth of each profile increases. This can be attributed to the fact that water contained in the cavities at deeper depth seem to cause erosional activities and as a result leads to an increase in size of the cavities over time.

Conclusion

The study has shown that the 2D ERT imaging technique is very effective in the detection of cavities in the survey area. It suggests the inferred air-filled cavity is characterized by high resistivity values that range between 950 to 2500 Ωm at depth that range from the surface, 0 to 6 m. The water filled cavity is suggested to be characterized by low resistivity values that range between 10 to 100 Ωm at depth range of 6-30 m. It also shows that the direction of the cavities below the surface of the surveyed area is in the NW-SE direction. Thus suggesting that the cavities trend along bedding planes on vertical bedrock joints.

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Conflicts of Interest

The authors declare no conflict of interest.

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