ENVIRONMENTAL HAZARDS AND SUSTAINABLE DEVELOPMENT OF ROCK QUARRIES, LOWER BENUE TROUGH NIGERIA

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©Ontario International Development Agency ISSN: 1923-6654 (print)

ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: The increasing number of abortive and abandoned quarry pits, and the several associated geo-environmental hazards have given cause for greater concern. Environmentalists, governments, and the general public now seek innovative ideas, and research collaborations that will reduce incidents of abortive and abandoned quarry pits. Quarry operators may be charged with the responsibility to reclaim quarry pits as soon as their operation is over, or make equivalent cost payment to government agency who will take over the responsibility as soon as mining is over. The goal is to achieve sustainable quarry practice in the Nigeria lower Benue Trough so that future generations may benefit from the igneous intrusive, and still have livable and sustainable environment

This study has found that many quarry operators do not conduct proper intrusive mapping prior to excavation or mining. Blind mining in this way is unsustainable; results in several abortive quarry pits that destroys ecosystem. Environmental impact assessment of such trial pits in the Nigeria lower Benue Trough shows loss of human life and arable land, rock fall, landslides, and health effects. For example, stagnant water in the pits supports daily breeding of mosquito and tsetse fly, causing persistent malaria and sleeping sickness in the area. Spectroscopic analysis of water samples from the abortive quarry pits and domestic water wells show excess of Sulfate (SO_4), Sodium, Total Dissolved Solids (TDS), Total Hardness (as $CaCO_3$), Turbidity, Salinity, and Total suspended solid (TSS). Near surface water table, joints and fractures enhance pit water and groundwater interaction, thereby increasing groundwater pollution. This paper shows how electrical resistivity survey could be used successfully to map intrusive bodies prior to quarry development. The aim is to reduce abortive quarry pits, and the associated hazards. Diabase (the target rock) shows bright spots, with resistivity values in the order of diabase > quartzite > siltstone > sandstone > shale. Overburden thickness to diabase is 2-11 m, confirmed by physical measurements at quarry pits. Result of geo-electric mapping is presented in a quarry concession map as a tool for pit planning and design, and sustainable quarry development rather than blind mining or trial excavation in the study area. This paper calls for collaborative research that could lead to sustainable quarry development.

Keywords: Blind mining, Environmental hazards; Geophysical mapping; Sustainable mining

INTRODUCTION

The concept of hard rock quarry

In archaeological terms, a quarry or mine site is where raw material-stone or metal ore-was mined for use as building material or tool construction. Quarrying is a very old technology, used since the time of the ancient Egyptians for the limestone used in their immense pyramids, temples and monuments. They are interesting to archaeologists, because discovering the sources of raw materials found on archaeological sites tells us how far people in the past could and would go for specific purposes, or what their trade networks might have been like. Evidence at a quarry might also show available technology in the form of tools left behind and cut marks in the walls of the excavation pits. According to Bloxam (2011), the historical value of quarry site is listed as four data elements: the resource itself (that is, the raw material); the production remains (tools, spoil and discarded products); the logistics (what it takes to get the raw material out of the quarry); and the social infrastructure (the organization of people required to use the quarry, make the objects and transport them away). She argues that quarries should be seen as complexes, fitting into a dynamic landscape where tradition, ancestry, memory, symbolism and information about territorial ownership coexist.

Many quarries naturally fill with water after abandonment and become lakes. Others are made into landfills. A further problem is the pollution of the road from trucks when they are leaving the quarries. To control and eliminate the pollution of public roads wheel washing systems are becoming more common. Water-filled quarries can be very deep with water, often 50 feet or more that is often surprisingly cold. Though quarry water is often very clear, submerged quarry stones and abandoned equipment make diving into these quarries extremely dangerous. Several people drown in quarries each year. However, many inactive quarries are converted to swimming pools. Loupasakis and Karfakis (2008) reported how gradual incorporation of the abandoned quarries into the cities of Greece generated the need for change of their usage to be environmentally compatible.

According to Berry and Pistocchi (2003), early response to issues of abandoned quarry pits is to characterize the special features of the effects of blasting and other quarry operations. Efforts will then be made to control these effects when the quarry was still active, than when it becomes inactive and abandoned. For example, both active and abandoned quarry pits should be fenced off or otherwise secured to prevent people from injuring themselves there. However that is not applicable to the abortive quarry pits in the study area. In some cases there may be toxins present at the site, due to the way in which the rock was extracted. In others, as the quarry slowly fills with water, it may be a tempting place to swim. A quarry may pose hazards to swimming through objects in the water, depth, coldness, or toxins which may have leached into the water. In some cases, an inactive quarry may be converted into a swimming area, with modifications made to create a safe swimming and recreation area. A quarry is a profitable operation, which in the Benue Trough is mainly for production of rock aggregates used in all engineering structures: Roads, Buildings, Dams, Bridges, and foundation, etc.

Over the years little advances have been made in our understanding of the environmental hazards associated with abandoned quarry pits. According to Lameed and Ayodele (2010), forest ecosystem of unexploited plot of quarry is seriously a disturbed site due to scanty fauna and flora species impacted by quarry activity. The pits may be used for waste dumping or contain contaminated pool of water, thus becoming source of groundwater pollution and breeding place for mosquitoes. These abandoned mine pits deserved reclamation to account for sustainable mining practice. Most quarry operators in the lower Benue areas do not conduct proper mapping or exploration of the intrusive rock at a proposed site prior to excavation and mining. Trial mining or excavation in this way has resulted in economic waste, and several abortive and abandoned pits that degrade environment, threaten life and ecosystem in the vicinity.

This paper discusses how electrical resistivity survey could be adapted to map intrusive rock bodies in a site at Lekwesi in the Nigeria lower Benue trough. The goal is to make quarry practice more sustainable by reducing abortive to abandoned quarry pits, and their associated hazards in the area. Investors are interested in the economic benefits of producing aggregates from igneous intrusive rock along the Trough, without recognizing the needs for sustainable quarry practice. Blind mining or trial excavation of the intrusive rock classified by Nwachukwu et al. (2010) as Olivine diabase has resulted in several abandoned pits. These abandoned pits can be seen in places like Isiagu, Lokpaukwu, Lekwesi, Lokpanta, Abakaliki, and to upper Benue trough areas. This situation worsens, because many of the quarry operators fail to conduct geophysical and geological exploration of the intrusive body prior to excavation. Some of them are ignorant of the availability of fast geophysical exploration technique application to intrusive mapping. Others are in the habit of trial excavation based on their understanding of surface topography as relating to intrusive body. Few also doubt the availability and reliability of geophysical tools and human resources for the mapping. This has led to blind mining, poor pit development, several abortive to abandoned pits, and geo-environmental hazards in the trough areas. Webmaster (2012) observed that most abandoned quarry pits were operated during the time when environmental concerns and conservation issues were less sensitive and environmental and mining rules and regulations were not as stringent. In the study area, enforcement of mining rules and regulations has never been effective.

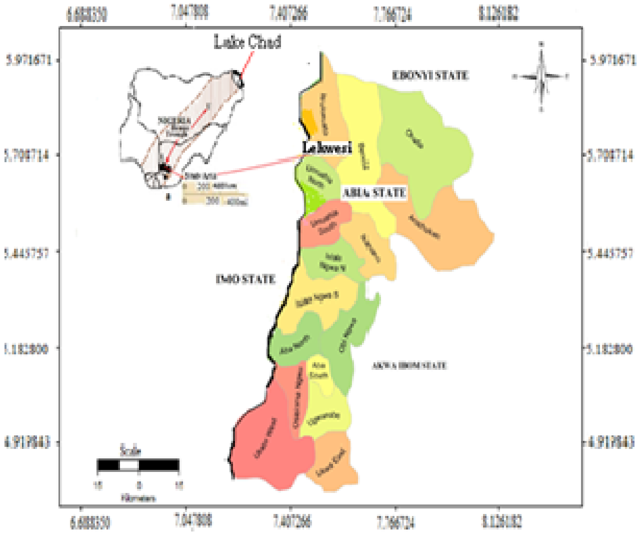


Figure 1: Map of Nigeria showing Abia state fifteen county areas, and the study area-Lekwesi

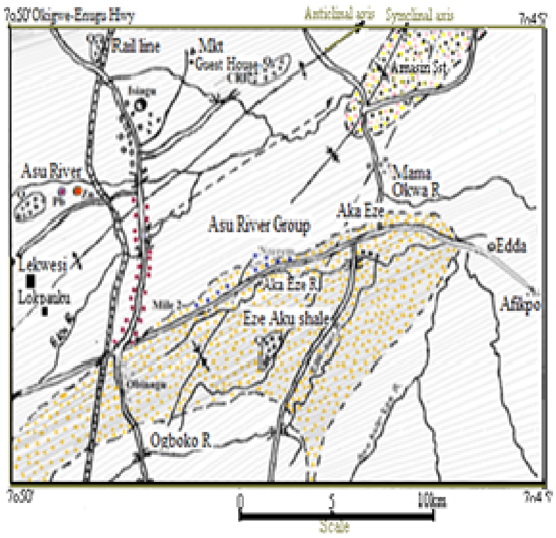


Figure 2: Geologic map of the study area within the lower Benue Trough (After Nwachukwu et al. 2010)

Figure 3a: Abortive quarry pit

Figure 3a: Abandoned trial pit, no pit design.

Figure 4a: Exposed adult human skeleton (AHS) and a decomposing young human body (YHB).

Figure 4b: Pit overburden sliding and rock fall.

Igneous intrusive rocks of lower Benue Trough

The study areas (Lekwesi) lie in the sedimentary basin of Southern Nigeria (Figure 1). The sedimentary units in this area are generally cretaceous in age, and have long been studied by several workers (Reyment, 1965; Kogbe, 1975; Adegoke, 1969). Based on the findings of these workers, the study area is underlain by the Asu-River Group (Albian), and bordered on the south by the Eze- Aku shale (Figure 2). The Asu River group is the lowest (oldest) lithostratigraphic unit of the cretaceous age laid down within the Benue Trough. The Benue Trough originated from early Cretaceous rifling of the central West African basement uplift. It forms a regional structure which is exposed from the northern frame of the Niger Delta and runs northeast for about l000 km to underneath Lake Chad, where it terminates (Figure 1).

Whiteman (1972) showed that the Asu-River Group was intruded by minor basic and intermediate intrusive during the Santonian period which outcrop around Isiagu, Lekwesi, and Lokpa-ukwu. The geologic history of Lekwesi and environs shows that during the Albian stage, majority of the argillaceous sediments in the area were laid down. Then the general topography (landscape) was more or less flat. However, the tectonic activities that occurred during the santonian age deformed these rocks and resulted in considerable folding of the sediments (Kogbe, 1975). There is igneous intrusion within Asu-River Group (Albian age). These intrusions are therefore post Albian events (in accordance with the principle of cross-cutting relationship). The intrusive are widely distributed from Ishiagu to beyond Zurak. But the more notable areas are Ishiagu, Lekwesi, Lokpa in Okigwe area, Abakaliki, Lafia, Egbede Hills and Aghila areas, south of the belt. Etuk et al. (2008) described the Lokpaukwu-Lekwesi–Uturu–Ishiagu magmatic belt of the Lower Benue Trough as an example of structurally controlled igneous intrusion. They believed that heat from the igneous intrusions raised the temperature of the source rocks above the liquid oil window limit, and thus inhibited the preservation of essential constituents of petroleum in the shale of the Lower Benue Trough. The general relief of this study area is characterized by hills and valleys. Majority of the hills and valleys align in the NW-SE direction, and conform to orientation of the folds from the Santonian orogenic deformation.

In the lower Benue Trough, the several unprotected abortive and abandoned quarry pits and trial excavation pits indicate unsustainable mining practice. At the moment, the affected areas are classified as danger zones, where no farming or movement is encouraged. If the habit of not protecting both active and abandoned quarry pits continues in the trough area, future generations of human inhabitants will face danger. Future generations of human and other animal population in the area will face displacement, greater poverty, and hunger due to lack of farm lands. Presently the surface environment is increasingly becoming hostile. The quarry operators are mainly concerned with the economic benefits of producing the rock aggregates but not extending the benefits to reclaiming the abandoned pits for sustainability of land, environmental protection, and safety of ecosystem in the area. Air in the area is continuously polluted by quarry dust, worsened by continuous fleet of haulage trucks plying on unuttered community road. This unuttered road is usually the only community road which the quarry operators extend to their sites. Surface water in the area consisting of natural streams and the stagnant water in the abandoned pits are increasingly polluted.

The characteristic dendritic drainage pattern of the argillaceous and other fine grained sediments is not uncommon with Lekwesi and Lokpa-Ukwu. The Ishiagu and environs are well drained with the general river flow trending NE-SW. Majority of the rivers return in the northern part and merge as tributaries to the Asu-River Group, while those of the south form tributaries to Eze-Aku River (Figure 2). In addition, the general surface water flow pattern conforms to the fold axes. Majority of the rivers in Lekwesi and environs align in this direction with the exception of those in the NW part which tend to flow in northeast-southwest direction. The intrusive area is characterized by thick and dense vegetation typical of the tropical rainforest. The fine-grained soil; mostly clay, shale, silt and mixtures of these and sands support luxuriant plant growth. The presence of abundant trees, shrubs and grasses is responsible for the dense vegetation found in these areas. The vegetation however is denser in the parts directly overlain by the Asu-River Group that is, mainly Ishiagu, Lekwesi and Lokpa). Those in areas with Eze-Aku shale grade after that of the Asu-River Group. The characteristic thick vegetation observed in the areas is typical of area underlain by the Asu River group or close to it. It can be attributed to the closeness of the water table within Asu River group.

METHOD OF INVESTIGATION

Several active and abandoned quarry pits within Lekwesi communities were investigated. Many photographs were taken to explain field potentials for geo-environmental hazards. Community members were interviewed about environmental hazards associated with the abortive and abandoned quarry pits and about their relationship with the quarry operators. Distance of pits to residential areas was estimated using car mileage. Pit dimensions were measured with tape and the depth probed with logging tools. Emphasis was placed on pits located close to residential areas. Water sample was collected from selected pit and shallow domestic hand-dug well, using plastic bottles for stereoscopic analysis using DREL-3 spectrophotometer. Residential areas considered close to quarry pits are those not exceeding 2 km interval. Incidents of death of human beings and domestic animals, and potential for landslide and rock fall were investigated to assess environmental safety within and around the pits. Field observations were recorded also in photographs to ease explanations. Result of water analysis were presented statistically and given specific environmental interpretation.

As a follow-up to traditional geological mapping, a compass survey of the proposed site was conducted in order to define a limit of investigation, and to produce a working base map. The base map will enable calculation of both the entire survey area and defined area of prospect. A temporary bench marks using Melina trees and concrete beacons at locations where Melina tree was not visible. Geophysics technique using electrical resistivity method was applied to assess the potentials of the site for development of commercial intrusive rock quarry. Schlumberger configuration was used for multiple vertical electric sounding (m VES), and Wenner configuration was used for complementary profiling in order to assess lateral extent of any intrusive body encountered. Coordinate and elevation of the eighteen VES stations were established using E-trex GPS. The VES field technique was conducted according to professional guidelines using Allied Geophysics Instrument. All necessary precautions for geo-electric measurement were duly considered. Advanced Geosciences Incorporation (AGI) 1D Software accomplished the data processing. Data analysis was carried out to investigate subsurface lithology at the various locations. The goal was to map out prospective body (s) of intrusive diabase, discriminating such body (s) from the host rock. It is on the bases of the depths of intrusive body (s) so identified that assessment of the site's potential for commercial quarry development would be justified.

For literature demonstrating the field techniques of vertical electric sounding (VES), and electric profiling, we refer readers to Dobrin and Savit (1988), Telford et al. (1990) and USDOT (2004). The apparent resistivity (**Ω**-m) at each measurement point was computed by multiplying the field resistance by a geometric factor (equations (1) and (2)). In the VES, **L** is the current electrode spread (m), and **l** is the potential electrode spread (m). The apparent resistivity values were then applied in the Advanced Geophysics Inc. (AGI) 1D automatic analysis software to obtain the VES curves, with number of layers constrained to the model curve. VES traverses were run east to west in the direction of regional strike, at final AB/2 of 125 m, while profiling measurement interval was constant at 3m.

VES apparent resistivity $(\rho a) = K \times R$ (_/m), (1)

Where K = geometric factor; R = field resistance.

Equation (1) can be expressed as follows:

$$\rho a = \left[\frac{\pi (L/2)^2 - (l/2)^2}{l} R \right] \quad (2)$$

Wenner profiling apparent resistivity (ρα) = 2παR (3)

RESULT OF INVESTIGATION

Environmental hazards of abortive blind mining and trial excavation pits

Community members confirm greater hazards accountable to abortive trial pits than the successful quarry pits. They reported presence of a species of mosquito and tsetse fly bigger in size than the normal. They lament of dust pollution particularly during the dry season (October-March) caused by traffic of trucks hauling rock aggregates from the active quarries. This they complain comes with noise pollution that starts as early as 5.0 am, noting that the communities share elongated settlement along their only main road that becomes the only haulage road. Blind or trial excavated abortive pits are too many than the planned successful quarry pits. As a result, they largely destroy natural landscapes and wildlife habitats. To service quarries, roads must be built and during operations a constant stream of construction and excavation vehicles to and from the site produces noise, dust and pollution. Quarries can be exploited as long as the rock or the economic deposit remains intact. Eventually, they go out of production and become abandoned. Quarries that are no longer in operation pose dangers to man and all animals in the vicinity. Uncontrolled blasting as practiced in the study area, results in a 3-D over-breaking of rock, creating joints and fracture planes. Over-breaking could lead to failure of nearby engineering structures such as buildings, roads, bridges, dams etc. Minor joints and cracks formed by uncontrolled use of explosives blasting become mega with time due to movement of groundwater. The joints and cracks finally become weak planes that could cause failure of overlying engineering structures. Joint and fracture planes enhance interaction of groundwater with contaminated water in the pits increasing groundwater pollution.

Figure 3a is a large abortive trial quarry pit for over ten years. The pit area measures 100 m length, 85 m width, and 5 m average depth located within 500 m to community residential area. This pit was abandoned following absence of massive and continuous intrusive body. Intrusive boulders were rather intercepted in spatial distribution that provided low and uneconomic overburden stripping ratio even at average depth of 20 ft from surface. There was no proper planning or design of the pit. This was traced to blind mining practiced by the operators. They could not conduct proper intrusive mapping, by applying suitable geophysical technique and/or use geologic method of coring. Community members interviewed confirm the pit as the largest mosquito and tsetse fly breeding ground in the neighborhood. They complained of persistent malaria and sleeping sickness, both of which they claim has inflicted laziness and poverty to their people. Some of the community members lamented over the number of domestic animals that have drowned in the pit. They demanded emergency response by government towards fencing off the pit, pending when reclamation activity could commence. At the time of this study, the quarry operators have left the site for over 15 years, leaving behind some of their unserviceable tools.

Figure 3b unlike 3a is not a full established quarry; it is produced by a more local mining method based on continuous trial excavation and selection of boulders, followed by hand breaking of the boulders. These activities have been on in this area for over thirty years. This has resulted in deep excavation pits exceeding 50 ft at some points. In order to disintegrate a boulder, the miners pour used engine oil over the boulder, to penetrate any cracks and joint planes. They cover same with wood, and set fire on the set-up. The set-up is allowed to burn over a night, until the oil is burnt out. This process weakens the boulder which now responds to disintegration by sledge hammer blows. The use of oil and burning respectively are not environmentally friendly. The stagnant pool of water marked as ***P***, provide perennial source of domestic water to the local miners. This site experiences frequent rock fall, often causing injury and death to the operators, and domestic animals.

The environmental responsibility of open pit mining operations is protection of the air, land, and water. Quarries are developed along the lower Benue Trough since mid 19^{th} century with virtually no environmental controls. This is largely attributed to the fact that environmental impact was neglected or not understood. Even when the awareness is created, and regulations put in place, such regulations are never enforced. In addition, the required technology is not usually available during this period to prevent blind mining or control environmental damage. Abortive to abandoned quarry pits have been on the increase, and no consideration is so far made about their reclamations by the operators or the law. Reclamation practices, such as using recovered earth materials and re-vegetation, and employing mitigation measures to offset potential impacts to lives, properties, domestic animals and wildlife is necessary. Dead human bodies, dead wild and domestic animals, as well as skeletons may be found within and around such pits even when isolated from residential areas. Figure 4a shows a complete adult human skeleton (AHS), and a decomposing body of a child of about ten years (YHS) littered at the shallower part of a blind mining trial pit.. This was observed because water in the shallower part of the pit dries up during peak of dry season (December-to February) when this investigation was conducted.

Blind mining trial excavation pits usually have no design of slope, bench height and haulage. Figure 4b; A trial pit overburden material becomes weak due to continuous blasting and excavation. The overburden hanging wall becomes increasingly weak during the peak of rain season (May-August) when surface and subsurface water movement saturate the overburden. As a result, the hanging walls of the overburden continuously get weaker and unstable. Abandoned quarry pit slope instability and increasing weakness of overburden wall causes geo-environmental hazards. There is danger to movement of man and other organisms and unquantifiable threat to ecosystem as long as these pits remain open and unprotected. Major geo-environmental hazards include rock fall and overburden sliding.

Figure 5, **a:** A very deep, poorly planned quarry pit completed and abandoned. Depth estimated to 50 ft, with roughly excavated overburden surface, vegetation, and associated land organisms merged with pit water. Natural environment and ecosystem is in danger. **b.** Evidence of rock over breaking, pit slope (90^{o-}), pit is temporary abandoned after selective mining of near surface diabase intrusive boulders. **c.** Pit water continuously seeps downwards following several cleat joints and fractures of varying magnitude. This is due to over breaking associated with uncontrolled blasting and inappropriate use of explosives. Water in pits 5b and 5c are already maintaining the groundwater table of the locality, confirming continuous pollution of groundwater in the area. Joints and fracture planes extend from the blast rock to lower depths, and to the overburden material, making it incompetent when saturated. Vertical drilling of blast holes causes over breaking of pit walls produces vertical and curved-out pit walls that causes unstable pit slope. Rock fall, overburden sliding, accidents to man and other animals, loss of life, loss of farm land, increasing seismicity, loss of natural ecosystem, are environmental hazards of abandoned quarry pits.

Figure 5: Photograph of abandoned quarry pits in the area, with physically observed rock units corresponding to the electrical resistivity result

Poor design of quarry pits as observed in figures 5 results in greater hazards including ecosystem destruction. Lack of proper bench heights, working platform, and haulage road makes quarry pit appear more hazardous. Before quarry pits become abandoned, working platforms and inner haulage roads are finally blasted and removed, making most of the abandoned quarry pits in lower Benue trough inaccessible. This increases the geo-hazard potentials of abandoned quarry pits in the area.

Statistical analysis of water from abandoned trial pit and a shallow domestic well

Figures 6 and 7 are bar charts showing varying concentration of tested parameters. Figure 6 show concentration of tested parameters in a water sample collected from an abandoned blind quarry pit in Lekwesi, while figure 7 is a bar chart showing levels of concentration of same parameters in a water sample collected from a private hand-dug well in the area. It is expected that concentration of pollutants in other trial pits will be similar, and higher than that obtained from the shallow wells. Similarly the level of pollution of shallow water wells in the area will be similar because of identical environmental conditions. For this, only a representative sample of abandoned trial pit, and a selected public domestic well are investigated.

Environmental implications of the water analysis result

Most people consider water with a TSS less than 20 mg/l to be clear, water with TSS between 40 and 80 mg/l to be cloudy, while water with TSS over 150 mg/l to be dirty. The nature of the particles that comprise the suspended solids may cause these numbers to vary. The shallow domestic wells sampled were neither dirty nor cloudy in appearance, yet the TSS is high.

Both water in the pits and of the shallow domestic wells is hard water that will make washing of cloths difficult. The high sodium content implies high salinity which the community members interviewed specifically lamented of. They described the water as salty, but whereas some declined drinking the water, others felt it could be managed in the absence of alternative. However, the truth remains that drinking the water is not ruled out in poor homes with children.

The high sulfate and sodium both have adverse health implications that cannot be neglected, but the implications and magnitude are not investigated in this study.

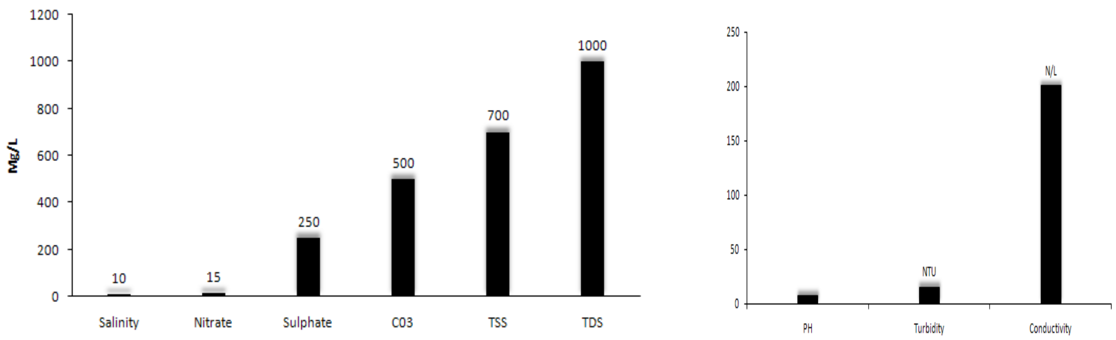


Figure 6: Water sample from selected trial abandoned pit at Lekwesi

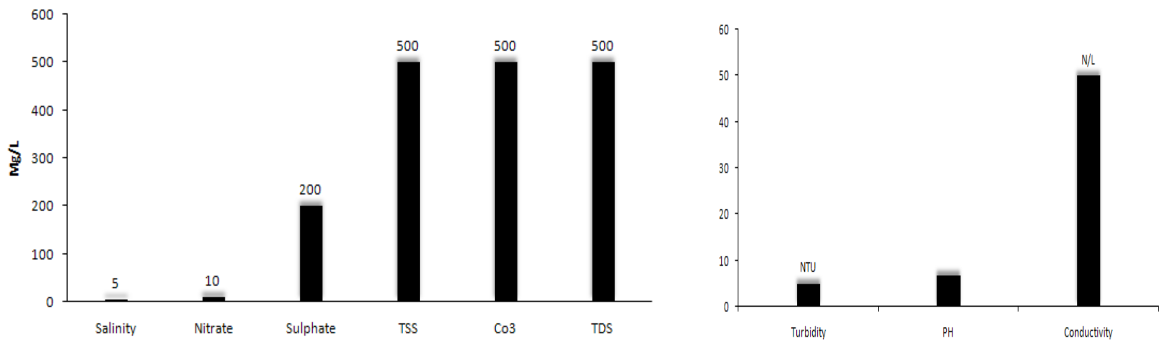


Figure 7: Water sample from selected shallow well at Lekwesi

Result of geo-electric mapping-selected VES models

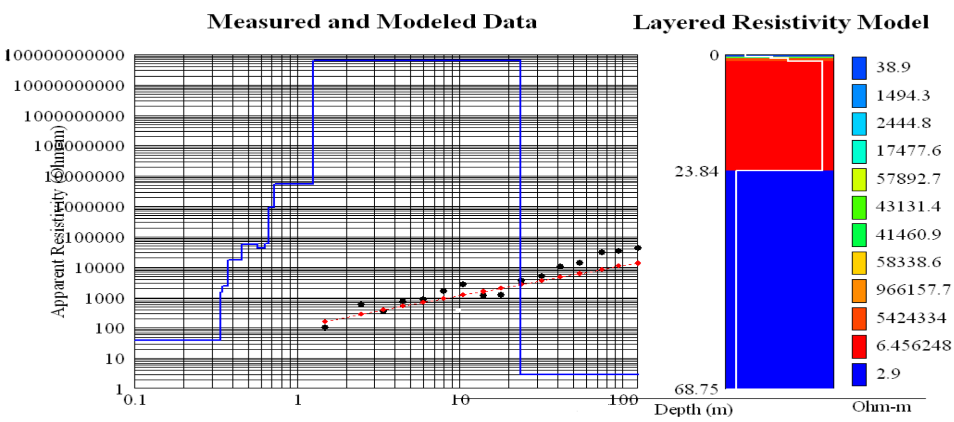


Figure 8: Subsurface inverted model of VES station 2

Table 1: VES 2 TBM 1 – TBM 2 (B); El 339 ft; N05.57.527; E07.29.062

Prospect layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
7	0.14	0.26	0.4	58338	Shale	Yellow
8	0.4	0.5	0.9	966157	Siltstone	Brown
9	1.2	0.9	2.1	5424334	Quartzite	Off-Red
10- 11	21.7	2.1	23.8	6456248	Diabase	Red

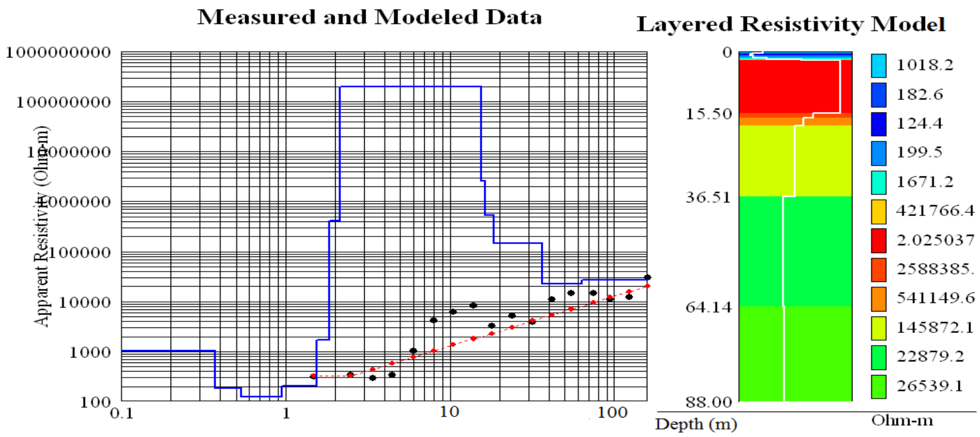


Figure 9: Subsurface inverted model of VES station 3

Table 2: VES 3, TBM 2 – TBM 3 (A); El 324 ft; N05.57.494; E07.29.065

Prospect layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
	1.7	11.5	18.5	431766	Siltstone	Brown
7	2.5	13.2	15.5	2025037	Diabase	Red
8	2.0	15.5	17.5	2588385	Diabase	Red
				541149	Quartzite	Off-Red

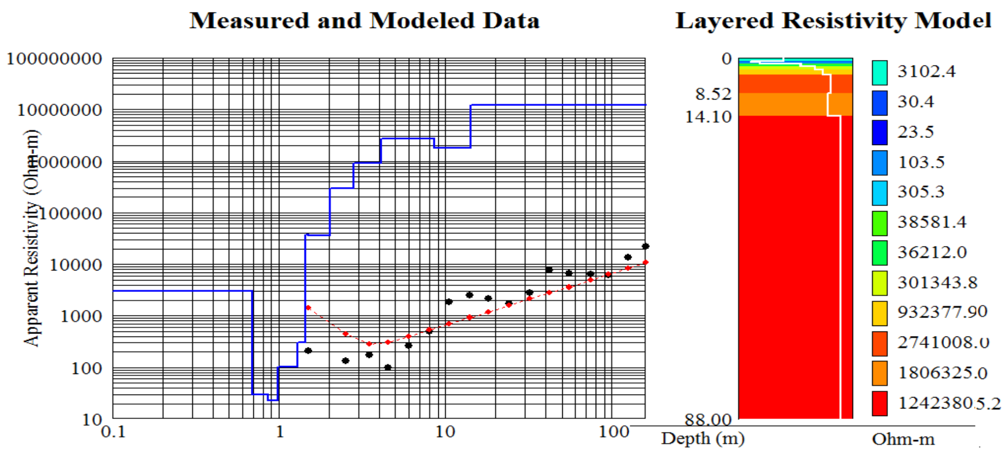


Figure 10: Subsurface inverted model of VES station 7

Table 3: VES 7, TBM 7-TBM 8; El. 202 ft; N05.57.489, E07.29.151

Prospect layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
9	1.5	3.0	4.5	932377	Shale	Yellow
10	4.5	4.0	8.5	2741008	Diabase	Off-Red
11	5.5	8.5	14.1	1806325	Siltstone	Brown
12	---	14.1	>88	12423805	Diabase	Red

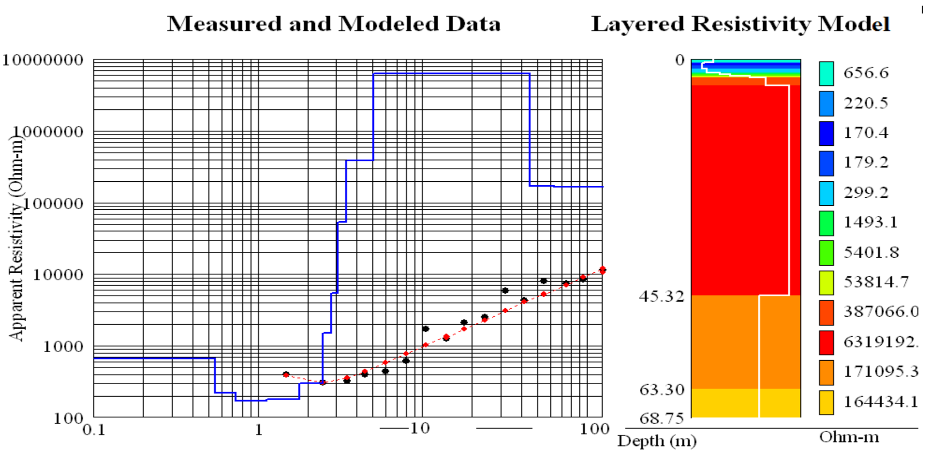


Figure 11: Subsurface inverted model of VES station 12

Table 4: VES 12; TBM 13-TBM 1, El. 319 ft; N05.57.421, E07.29.069

Prospect layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
9	2.0	3.32	5.32	387066	Quartzite	Off-Red
10	40	5.32	45.32	6319192	Diabase	Red
11	20	45	63.3	171095	Siltstone	Brown
12	>4.5	63.3	>68	164434	Shale	Yellow

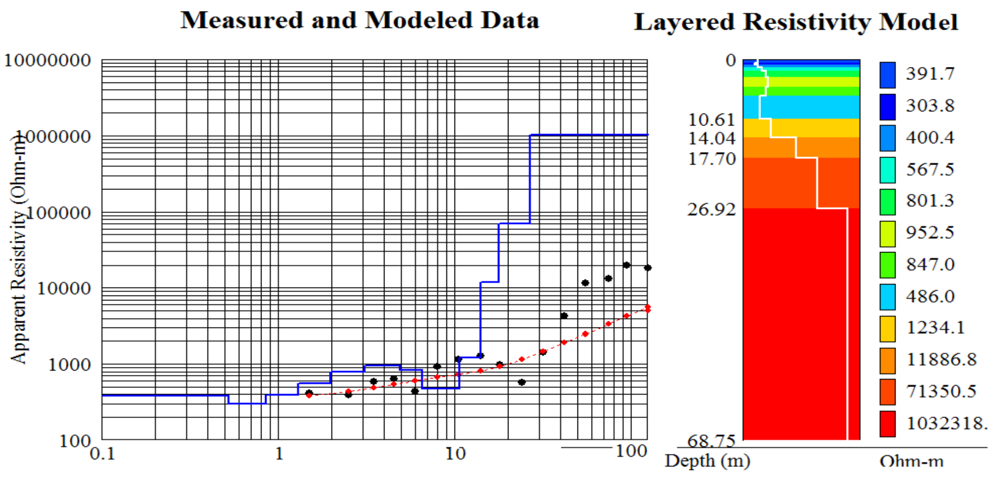


Figure 12: Subsurface inverted model of VES station 2

Table 5: VES 14 TBM 20-TBM 22; El. 299 ft; N05.57.42, E07.29.031 Offset to TBM 14

Prospect layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
	3.4	10.6	14.0	1234	Shale	Yellow
9	3.7	14.0	17.7	11886	Siltstone	Brown
10	9.4	17.7	26.9	71350	Quartzite	Off-Red
11	>41	27	> 68.7	1032318	Diabase	Red

Selected Geo-electric Profile models

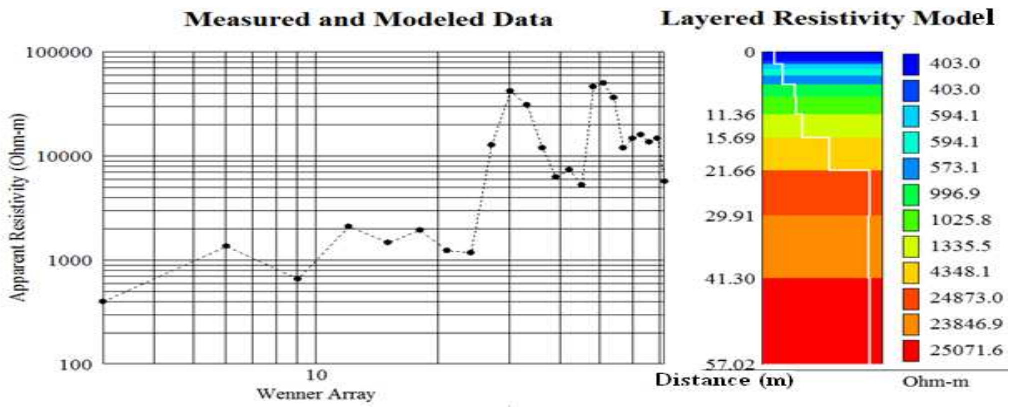


Figure 13: P1 (TBM1-TBM2)

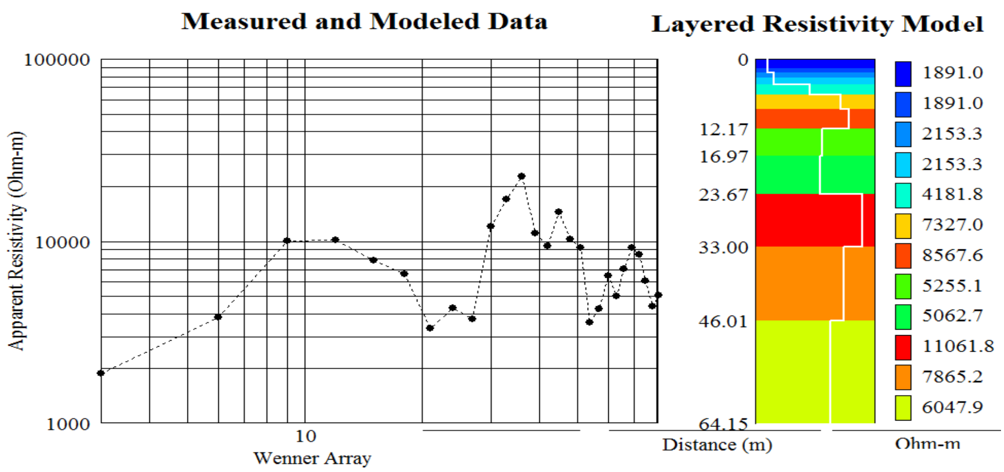


Figure 14: P2 (TBM1-TBM2)

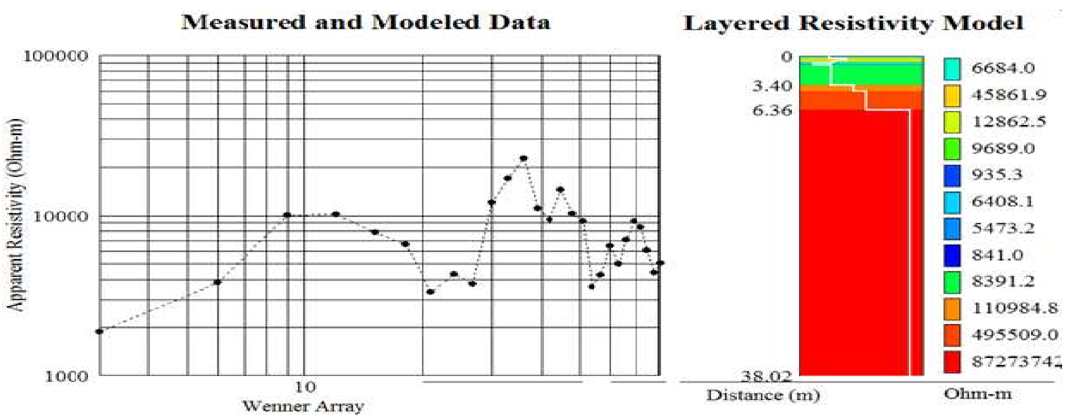


Figure 15: P5 (TBM1-TBM2)

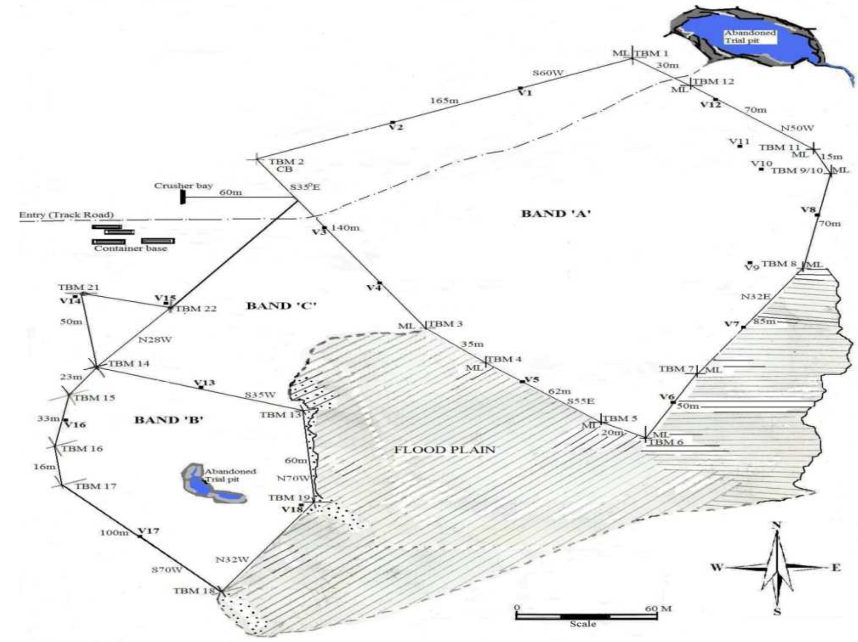


Figure 16: Base map of the proposed quarry site at Lekwesi (Map-1); TBM = Temporary bench mark; ML= Melina tree, CB = Concrete beacon; V1-V18 = VES stations; Flood plain = Swamp = Rice farm

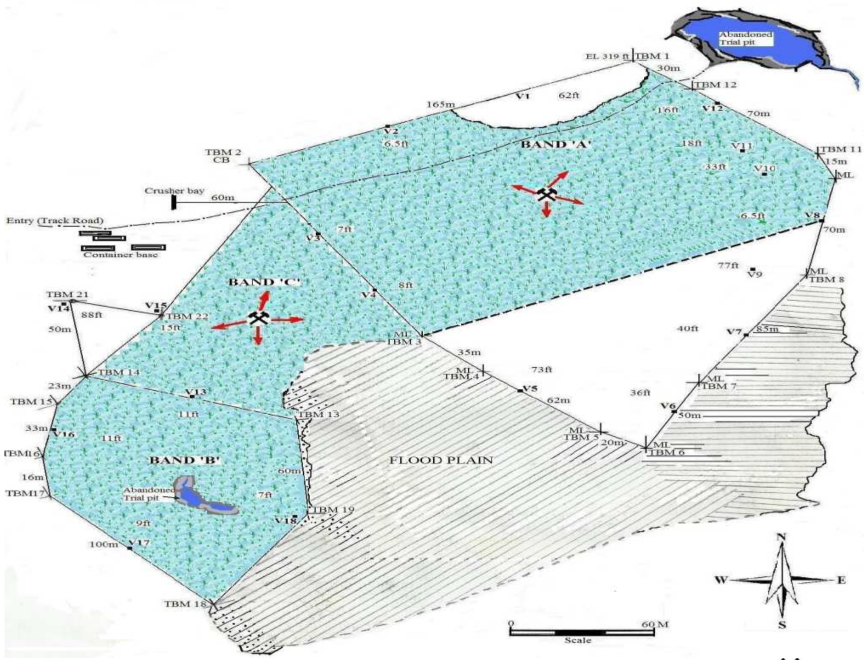


Figure 17: Diabase Quarry concession map-2 of the proposed Lekwesi quarry site. ⚒ = Quarry opening point suggested; Direction of arrows suggests possibility of radial mining.

Analysis of VES response models

Figures 8-12 are selected VES models out of a total of eighteen VES conducted in this study, and figures 13-15 are selected resistivity profiles. The models interpretation (Tables 1-5) emphasize on geo-electric responses over diabase (brilliant red), quartzite (off-red), baked clay-siltstone (brown), and shale (yellow). Clay and clay-shale have shades of blue, while sand and sandstone have orange, and green respectively. The yellow color of shale may vary slightly, depends on hardness and indurations, as a function of water saturation. Resistivity values decrease with water saturation, thereby affecting color codes. As a result, the usual order of resistivity: siltstone > shale > clay-shale. The brilliant red color or bright spot is the target rock (diabase). Its prospect at any VES station depends on the depth of occurrence from surface and the respective thickness. The shallower the depth of occurrence, the greater is the prospect and economic benefit of mining the rock to produce aggregates for building and other engineering structures. This is because shallower depth implies less overburden thickness, which accounts for low stripping ratio and overburden stripping cost.

Tables 1-5 show analysis of the VES result at the selected VES stations. T. Depth or top depth is the depth from surface to the top of intrusive body, and B. Depth is the bottom depth of respective rock body. Geo-electric response by apparent resistivity value is in the order of diabase > quartzite > baked siltstone > sandstone > shale. There is no specific order of occurrence of the associated rocks. Usually, quartzite is observed as overlying the diabase. The clay-siltstone is found usually baked, overlying the quartzite, or below the intrusive body. Occurrence of quartzite directly over the intrusive diabase and the baked clay-siltstone can be described as a result of the high temperature contact metamorphism of the Santonian orogenic episode. Economic depth of diabase in the area ranges from 2-11 m (6.5-36 ft) confirming decrease of quarry prospect with increasing overburden stripping ratio.

The rest of the profiles were run as follows; P3 between TBM 9-TBM 2, P4 between TBM8-TBM 3, P5 between TBM 14- TBM 21, and P6 between TBM 14-TBM21. Results indicated lateral distance of each intrusive body along measured profile. Both the extensive laccoliths and the boulders can be described on the bases of their lateral distance. Three of the six complementary resistivity profiles (P1, P2, and P5) are selected samples presented in this paper. The profiles describe the lateral disposition of the intrusive bodies. The intrusive bodies occur as discontinuous bands of laccoliths to bands of massive boulders aligned in the northeast-southwest. Depth of occurrence, thickness, and lateral distance of diabase at each measurement point showed spatial variation which was used as bases for delineating the intrusive prospect bands suitable for quarry development. Physical measurements at active quarry pits (Figure 5) were used to justify result of the electrical resistivity mapping. Survey result showed overburden thickness to diabase as 2-11 m, confirmed by the physical measurements.

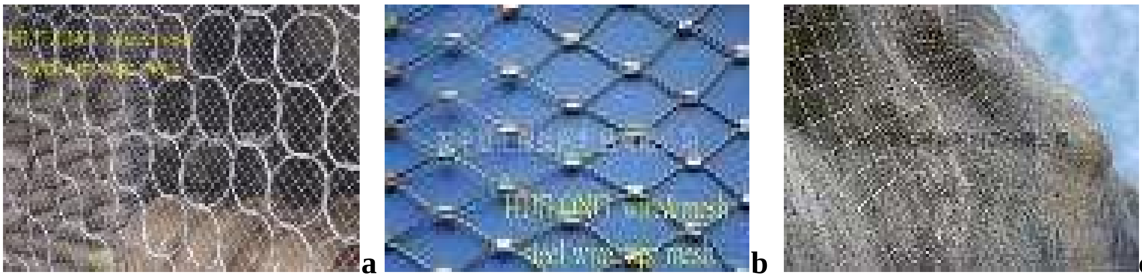
Prospect maps of the investigated intrusive site

VES model responses of the eighteen stations mapped was investigated. A base map (figure 16) of the area was produced from compass survey following the absence of any existing survey map. Geo-electric mapping results were then interpolated on the base map to produce a quarry concession map (figure 17). Depth of occurrence, thickness, and lateral variation of diabase at each measurement point showed spatial variation which was used as bases for delineating quarry prospect bands. Areas of VES 1, 4, 5, 9, and 14 are not prospective due to absence of diabase or deep occurrence exceeding 12 m depth. VES 6, 7, and 10, have low prospect due to diabase occurring at depth between 9-12 m.

Areas of VES 2, 3, 8, 11, 12, 13, 15, 16, 17, and 18 show high intrusive prospect suitable for quarry development. Figure x is the intrusive prospect map of the Lekwesi site showing area suitable for quarry development as band **A,** band **B,** and band **C.**

The positions where mine development symbol is located in band A and band C are suggested points for the mine opening. The diverging arrows suggest possibility of radial mining along the direction of arrow. The two opening points need not be opened at same time. Only one opening point may be used for the mine development. For a better pit design, the most central opening points or that located at band C is recommended. Operators may wish to consider the opening point of band A, if constrained, rather than the former. By triangulation, area of the prospect was calculated as 42700 m^2 being about 50% of the entire base map area. The area comprised respectively Band A = 24500 m^2, Band = 9600 m^2 and Band C = 8600 m^2

A quarry concession map of the type shown in figure 16 is all it takes for proper planning and design of open pit quarries. It is the tool for land and environmental conservation, presenting sustainable quarry practice, rather than blind mining or trial excavation in the study area.



a b c

Figure 18: Samples of quarry pit perimeter fence design; **a**. Steel wire ring, **b**. Steel wire mesh

Figure 19: Samples of warning signs for abandoned quarry pits areas Explanation (a) Danger; Movement Restricted, abandoned quarry pit 100 m ahead (b) Danger; Grazing Restricted, abandoned quarry pits 200 m ahead

The increasing number of abortive and abandoned quarry pits, and the several associated geo-environmental hazards have given cause for greater concern. Environmentalists, governments, and the general public now seek innovative ideas, and research collaborations that will reduce incidents of abortive and abandoned quarry pits. Quarry operators may be charged with the responsibility to reclaim quarry pits as soon as their operation is over, or make equivalent cost payment to government agency who will take over the responsibility as soon as mining is over. The goal is to achieve sustainable quarry practice in the Nigeria lower Benue Trough so that future generations may benefit from the igneous intrusive, and still have livable and sustainable environment.

This implies conservation of igneous intrusive as economic natural resource, conservation of land for agriculture and environmental ecosystem for future generations in the Nigeria lower Benue Trough.

Conclusion And Recommendations

Conclusion

This study has shown how geophysical (Geo-electric) method can be applied in mapping of intrusive, to achieve sustainable quarry practice. It is important for quarry operators to conduct proper mapping or exploration of a proposed quarry site prior to excavation and mining. Trial mining or excavation results in economic wastes and several abandoned pits that destroy life, living environment, arable land and ecosystem in the vicinity. Specifically, there is environmental degradation such as presence of stagnant water in the several abortive and abandoned trial pits that breeds mosquito and tsetse fly, causing persistent malaria and sleeping sickness respectively. Geo-environmental hazards such as rock falls and landslides are common incidents in the area. This paper has shown how multiple vertical electric sounding (mVES), electric profiling, and traditional geologic mapping methods could be integrated to assess a site for successful and sustainable quarry development.

Bright spots are shown in brilliant red color over intrusive diabase (the target rock), and minor over quartzite, sandstone, shale and siltstone. Apparent resistivity value is in the order of diabase > quartzite > clay-siltstone > sandstone > shale. There is no specific order of occurrence of the rocks from surface. Intrusive bodies located between 2-11 m (6.5-36 ft) from surface are only considered as prospective, and confirmed by physical measurements at quarry pits.. Recognizing that quarry prospect or profit decrease with increasing overburden stripping ratio. Three economic bands of diabase were identified. Also identified are two possible mining opening points to be confirmed by test drilling (Coring) rather than excavation. Details of this investigation results are duly presented in a mine concession map. About 50% of the entire area investigated is prospective for diabase quarry.

Recommendations

Affordable safety measures

It is difficult to reach operators of most abandoned quarry pits in the lower Benue Trough after they left the site. The companies make their money, destroy the environment, and quit with little or no compensation to the host communities. Some of the pits were abandoned because of no economic intrusive deposit to sustain mining at a chosen site. Others may be abandoned because continuous mining is no longer economical, as the target rock has become either exhausted or is located at greater depth. Often the quarry operators may be limited by equipment and a poor pit design which may result to abandoned pits. Some of these operators are illegal miners. Absence or lack of enforcement of relevant mining laws has led to quarry operators abandoning quarry pits without giving concern to environmental safety. Abandoned older quarry pits earlier seen as isolated from residential area are now within close proximity with residential areas due to increasing population and development.

Abandoned quarry pits reduce arable land for rural faming and food production, making inhabitants of the area to neglect their traditional farming occupation to casual quarry labor. One major and affordable method to improve environmental safety in the vicinity of abandoned pits is to provide perimeter fencing of each abandoned pit. This will control movement and reduce accidents to human beings and other domestic and wild animals in the pits. Sample of fence design suitable for protection of quarry pits are as shown in figure 18. The need for perimeter fencing of abandoned quarry pits is urgent in the study area, in the absence of pit reclamation. Abandoned quarry pit hanging walls can be protected by use of steel wire mesh to prevent rock fall. When water become very scarce in the heart of dry season, abandoned quarry pits often become sources of domestic water. Cases of injury or death may arise due to frequent rock fall. It is recommended to use wire mesh as shown in figure 18c for rock fall protection.

Warning signs, in form of posters and sign posts should be used in addition to alert the public on the presence and dangers of abandoned pits. Wogalter et al. (2002) stressed the need to enhance the usability of danger or warning sign designs by considering factors internal to the user (e.g., beliefs, perceptions of risk and danger). They also developed an evaluation method that can be used to measure the effectiveness of warnings signs, such as the degree to which warning signs are communicated to recipients and the degree to which they encourage or influence behavioral compliance and safety. Warning signs are to be placed at strategic locations from 500 m, and at regular interval of 100 m to the very location of a quarry pits. This will help to control movement into abandoned pit areas particularly cattle grazing. Figure 19 shows samples of warning signs that may be placed at strategic locations in the vicinity of abandoned quarry pits. Approval of quarry license shall depend on the result of geophysical mapping and economic evaluation of intrusive bodies mapped. This paper calls for solution; collaborative sustainability studies, attention of governments and international agencies for sustainable quarry practice and improvement of environmental quality.

ACKNOWLEDGEMENT

We are particularly grateful to the following staff of GEOPROBE Int'l Consultants Ltd; Mr. Chinedu Ohuawunwa (Geophysicist), Mr. Uche Nnorom (Geologist), Oscar Igbo (Mining Engineer), and Ekene Mbagwu (Metallurgist), for their assistance in the field mapping. Special thanks go to Mrs. Ijeoma Nwachukwu (Mining geologist) for assistance on the data processing. Thanks to GEOPROBE for providing field logistics that enabled this study.

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