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Application of Geotechnics in Open Mine Design and Reserve Estimation

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Abstract

The need for a proper understanding of subsurface geology, depositional pattern of the intrusive rock and mining trend at the study area was very imminent. Data for this mining design was then generated through geotechnical subsurface investigation. A total of eleven (11) borings were made to depths of 25 meters into intrusive rock bodies. Drilling is carried out both in the quarry pit and around the surrounding berm. A sampling interval of 1.0 meter was maintained for the cored rock samples from each of the eleven drilled holes. The depth range of the boreholes varies from 15.0 meters to 25.0 meters. Results of analyses showed that the intrusive trends in the east-west orientation. However, north-south trends were also observed at certain sections of the mine/quarry. The values of the plunges of the intrusive were observed to be between 2.00 and 6.00 degrees at the northern segment and 4.00 to 6.00 degrees at the southern segment. The average thickness of the intrusive bodies varies from 11.20 meters for the surrounding bench area to 20.00 meters in the pit. This observed thickness of rock mass covers an area of approximately 81,750 m2, made up of 29,500 m2 for the floor of the quarry and 52,250 m2 for the surrounding bench. Using an average thickness of 16.00m, the rock volume was calculated to be 1,300,000 m3.The rocks has a density of 2.98 mg/m3, which gives us a total reserve tonnage of 3,874,000.

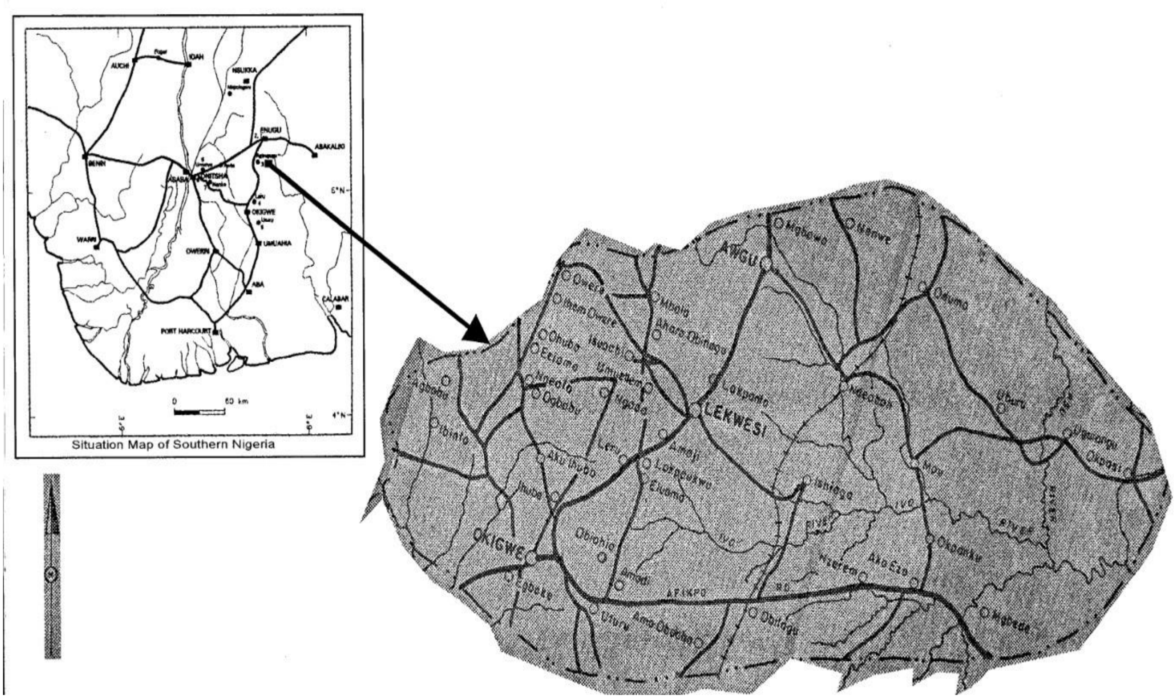
Introduction

Few local quarries owned by the natives are found scattered within Amata-Lekwesi in Awgu Local Government Area of Enugu State, but the most developed are the quarries owned by Crush Rock Industries Nigeria Limited at Isiagu and Crush Stone Industries Nigeria Limited at Amata-Lekwesi. All these quarries adopted the open-pit method of mining, which is always froth with uncertainties because of the subsurface nature of the igneous intrusive in some parts of the area. The need for a proper understanding of the subsurface geology therefore becomes very important to establish the mining trend of any of the quarry deposits that are not exposed at the surface. This research was conducted out of the need to save one of such industries from absolute abandonment due to exhaustion of mineable rocks.

Amata-Lekwesi, in Awgu Local Government Area of Enugu State, is located approximately on latitude 5^0 55′ north of the Equator and longitude 7^0 40′ East of the Greenwich Meridian (fig.1).The area falls within the southern part of the 6000km long belt of the Cretaceous sediment of the Benue Trough (an aulacogen) (Olade, 1976). The land use is mainly farming and few improperly exploited open-pit mines by the natives and the Crush Stone quarry. The place is accessible by road through the Port Harcourt–Aba-Enugu expressway. Settlement pattern is more of dispersed and linear, since the majority of their activities are tied to farming and mining operations.

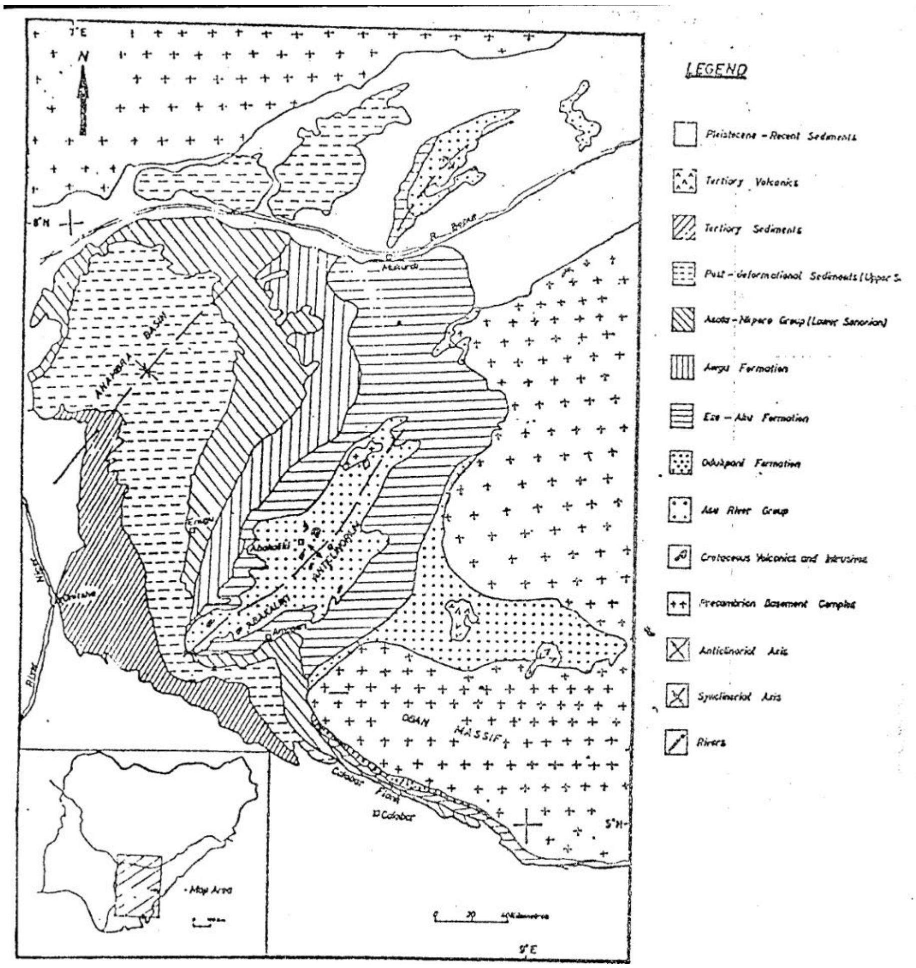
Regional Geologic Setting

During the initial period of rifting and subsequent to the final separation of the south American and African plates, it is believed that sinistral strike-slip movements were continuously generated and transmitted into the continent along the developing transform faults of the Romanche, Chain and Charcot fracture zones.



By early Albian, these transcurrent movements had initiated a series of isolated depositional centres and sub-basins where mostly alluvial fans, braided stream and lacustrine sediments constituted the initial deposits prior to extensive marine incursions. The onset of the earliest eustatic transgressive episode in the mid Albian gave rise to marine sedimentation of the Asu River Group within the Benue Trough. The 2000 meter thick sequence of shales and siltstones with minor pyroclastics belonging to the Albian Asu River Group form the underlying rocks in the southern portion of the aulacogen (figure 2). These rocks grade northwards into shallow marine platform carbonates of the middle Benue (Arufu and Gboko formations) (Reyment, 1970). Stratigraphic equivalents in the upper Benue depression include an unnamed deltaic shale/sanstone sequence in the Makurdi area, and the Bima formation to the northeast (Murat, 1972; Burke *et al,* 1972). An early episode of deformation during the Cenomenian generated a marine regression that confined carbonate sedimentation (Odukpani formation) only to the Calabar flank (Nwachukwu, 1972, 1975).

By Turonian times, the most extensive transgression which connected with the Saharan sea-way (Central West African Basin) had extended marine connections supposedly to North Africa (Petters 1978b; Avbovbo, 1985). A 1000 meter thick unconformable sequence of



argillites and carbonates of the Eze-Aku Formation were deposited. Lateral equivalents of this Formation are unnamed succession of shales and carbonates in the middle Benue, The Turonian Pindiga Formation in the upper Benue, the Ameseri (sandy and calcarious sandstone) and the Awgu shale (Burke *et al,* 1972).

Termination of rifting was associated with compressional events during Santonian to early Campanian times which deformed the Albian and Turonian sediments along north easterly (NE) trending axes, producing numerous gentle folds with north westerly (NW) and northerly trending tensional faults and fractures (Carter *et al*, 1963). The deformation was also accompanied by alkaline magmatism and lead-zinc-copper mineralization during the period. The intrusive dykes resulting from the magmatism are located at various depths, having Eze-Aku shales at the base and the Awgu shales at the top of the intrusive (table 1) and the Mid Senonian lower coal measures overlying the Nkporo shales. Some of these intrusive which appear domal in shape (like those at the Crush Stone Quarry site at Isiagu) are found close to the surface and yet deeper at some parts. The depth variation and domal nature may suggest various levels of magmatic sill structures (Wright, 1968; Murat, 1972).

Table 1: Litho-Stratigraphy of the Study Area

AGE	GROUP/FORMATION	LITHOLOGY
Cretaceous (Mid Senonian)	Lower coal measures	Coal, Sandstone, Shales
Cretaceous (Lower Senonian)	Nkporo Shale Group	Shales, Mudstone
Santonian-Early Campanian	Awgu Shale	Shales and Siltstones
Cretaceous	Intrusives	Intrusives (Quarry rock)
Cretaceous (Turonian)	Eze-Aku Shale Group	Blach Shales, Siltstones
Cretaceous (Albian to Mid Cenomenian)	Asu River Group	Shales, Limestones

Material and Methods

Data for the work was generated through geotechnical subsurface investigation (using Slanzi rotary diamond coring rig) for the purposes of establishing the trend and geotechnical characteristics of the intrusive body, depth of overburden rocks, estimate of the reserves of mineable rock bodies and the overall plan of the quarry site. A total of eleven (11) borings were made to depths of 25 meters into the intrusive rock bodies (Fig.3). Drilling is carried out both in the quarry pit (BH6, BH7, BH8) and around the surrounding berm (BH1, BH2, BH3, BH4, BH5, BH9, BH10, BH11). A sampling interval of 1.0 meter was maintained for the cored rock samples from each of the eleven drilled holes. The depth range of the boreholes varies from 15.0 meters to 25.0 meters (Appendix A). Rock/soil samples obtained from borings were subjected to both visual field examination and laboratory tests/analyses to guide in designing a mine system that is based on the geology and geotechnical properties of the rocks.

Results and Recommendations

Litho-Stratigraphy

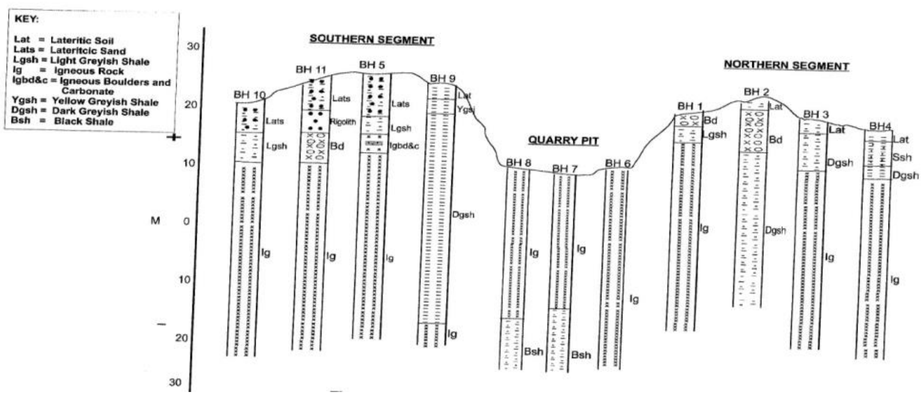
The litho-Stratigraphy of the area is as shown in figure 4. The range of depth of the overburden materials is between 0.00 meter in the quarry pit (BH6, BH7, BH8) to 20.00 meters on the berm (BH9). The overburden materials are mainly shale (light greyish shale, yellow greyish shale, dark greyish and black shale) and lateritic clayey sand. Borehole (BH9), located about 50.00 meters west of BH8 touched the intrusive from 20.00 meter depth. This perhaps indicated a westward dipping trend for the rock.

Again, only a thickness of about 6.5 meters of highly fractured boulders were discovered in BH2, located about 35.00 meters east of BH1. Below these boulders was the dark grey shale down to a depth of 25.00 meters. The absence of any fresh rock body from this borehole down to the final depth of drill (25.00m) could indicate that the intrusive dyke-like structure never extended beyond the region of BH2.

However, apart from BH2, a general trending pattern is seen running from the northern segment (BH1, BH3, BH4) through the quarry pit (BH6, BH7, BH8) to the southern segment (BH10, BH11).

Orientation of the Intrusive Body

The intrusive was observed to trend in the east-west orientation. However, north-south trends were also observed at certain sections of the mine/quarry. The values of the plunges of the intrusive were observed to be between 2.00 and 6.00 degrees at the northern segment and 4.00 to 6.00 degrees at the southern segment. The outline of the observed rock outcrop distribution in and around the quarry is as shown in figure 5. Cross sections AA', BB', CC', DD' and EE' (Figs 5b & 5c) indicate the subsurface orientation of the rock outcrops within the mine area.



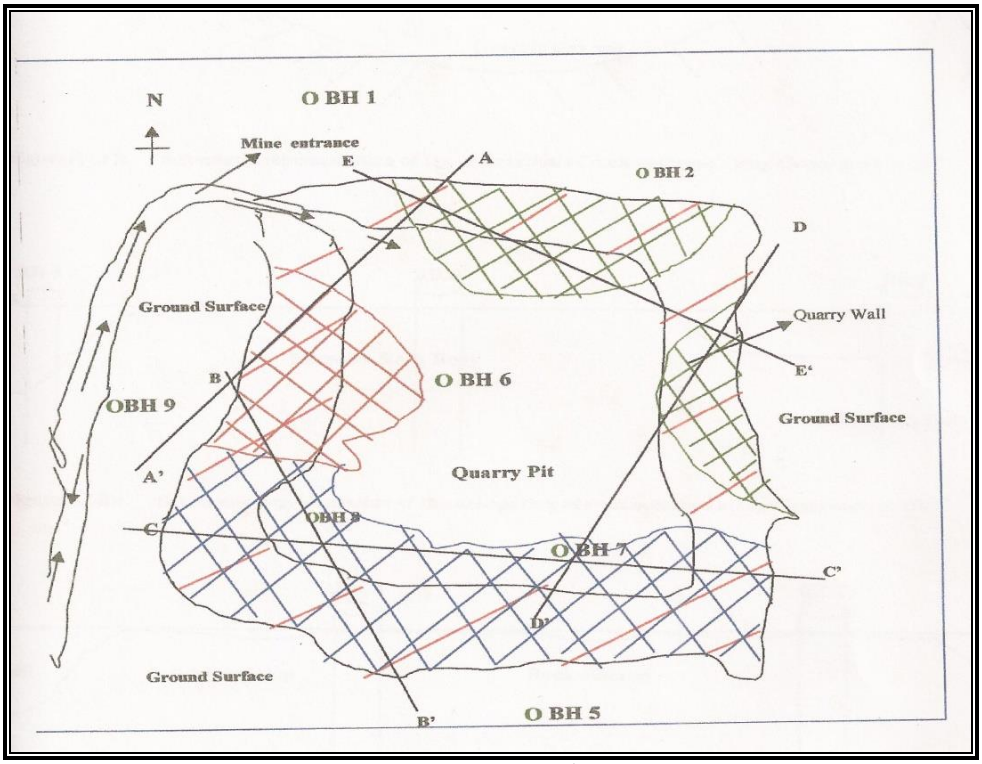
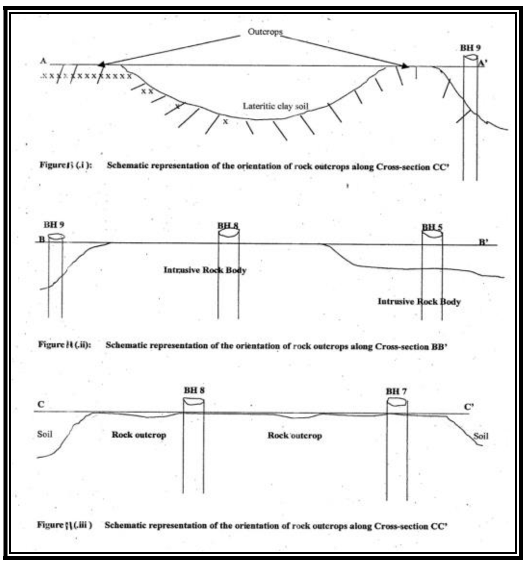


Figure 5a: Schematic Representations of the Distribution and Orientation of Rock Outcrops at the Amata-Lekwesi Quarry



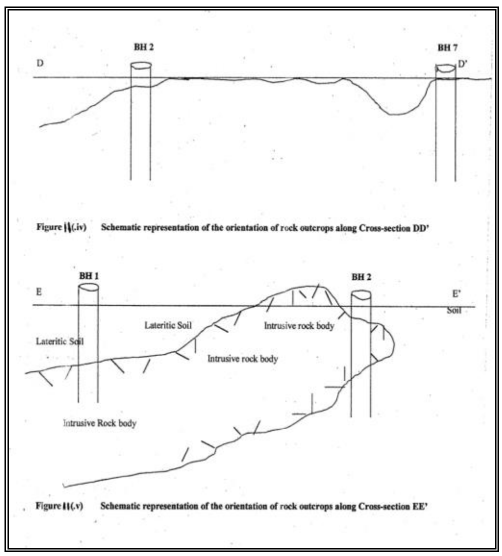


Figure 5b: Cross Sections AA, BB and CC

Figure 5c: Cross Sections DD and EE

Thickness of Intrusive Body

The average thickness of the intrusive bodies varies from 11.20 meters for the surrounding bench area to 20.00 meters in the pit. This observed thickness of rock mass covers an area of approximately 81,750 m^2, made up of 29,500 m^2 for the floor of the quarry and 52,250 m^2 for the surrounding bench (table 2).

Table 2: Estimates of the Intrusive Rock Bodies

PARAMETERS	INTRUSIVE ROCK BODIES										
	BH1	BH2	BH3	BH4	BH9	BH5	BH10	BH11	BH6	BH7	BH8
Depth to top of intrusive rock body (m)	5.9	0.40	5.85	11.60	21.00	7.50	4.50	5.00	0.00	0.00	0.00
Depth to bottom of intrusive rock body (m)	>00.12	7.40	19.85	23.60	>25.00	22.50	>23.50	18.00	23.00	23.00	13.50
Thickness of rock body (m)	>00.51	7.00	14.00	12.00	>4.00	15.00	>19.00	13.00	23.00	23.00	13.50
Average rock thickness (m)	11.20					16.00			20.00		
Area of intrusive rock body (m^2)	37,350					15,000			29,500		
Volume of intrusive rock body (m^3)	417,200					240,000			590,000		
Reserve (tons)	Volume of Rock x Density of Material = 1,722,400 x 2.98 = 5,132,752										

Rock Volume Computation and Life Expectancy of the Mine

The estimated area between the three (3) borings located within the quarry pit, namely BH6, BH7 and BH8 was approximately 29,500m^2. Using an average rock thickness of 20.00m between these three borings, we have a rock volume of approximately 590,000m^3, and with a rock density of 2.98 mg/m^3, we have a unit tonnage of approximately 1,758,200 tons for the quarry pit. The estimated area of the surrounding berm is approximately 52, 250 m^2 while that of the pit floor is 29,500m^2, bringing the total area to 81,250 m^2. Using an average thickness of 16.00m, the rock volume was calculated to be 1,300,000 m^3.The rocks has a density of 2.98 mg/m^3, which gives us a total reserve tonnage of 3,874,000.

Life Expectancy

The life expectancy of a mine or quarry is usually determine by the reserves of the mineable rock materials. The reserves are usually divided by the agreed production quantities per year by the mine operators. Assuming the agreed production quantity of the quarry by the operators is x tons per year, when the proven reserves of the mine is y tons, then, the Life Expectancy of the mine are given as:

LE = y/x (in years) ....equ (1)

If a total of ten trailer loads, each of 30,000 tons of crushed stone are mined per day for a total of six days per week over a period of one year, this will translate into 86,400 tons per year. Based on the above equation, the life expectancy (LE) of the mine is put at 44.8 years. It should be noted however, that the life expectancy of any given mine during the mining operations depends on several factors.

(a) Unplanned changes in the annual production quantities for the mine due to unforeseen reasons such as sudden increase in crushed rock demands.

(b) Short-fall in the availability of rock materials due to lack of investigation to determine the reserves proper orientation.

(c) Failures of operational equipments due to unanticipated breakdowns or lack of replacement of spare parts for effective repair of machines.

(d) Industrial unrest occasioned either by workers' dissatisfaction with conditions of service or grievances occasioned by company policies or other reasons.

Mine Systems Design

The mine systems design proposed for the study area takes into consideration the mine plan, adequate haulage way, mine slope angle (θ), mine wall height (h), excavation plan and mine drainage.

Mine Plan

The existing mine plan as shown in Figure 6a indicates that the major (long) axis is trending north-south with the mine expansion in the north-south direction. However, it was observed from subsurface investigations that the rock bodies are trending in the east-west direction and so the mining should progress in the same direction as the rock trend, which plunges at a value of about 35-40 degree westwards. The mine plan as existing and modified respectively at the study area is shown in Figures 6a.

Mine Haulage Way

The main haulage way for the site is situated along the western segment of the mine layout commencing from the crusher plant and trending north-eastwards along the western edge of the mine to a point where it enters the mine proper close to the northern edge of the mine Figures 6a.

In constructing the haulage ways, attempts should be made to have slopes not steeper than the traction friction angles (θ) of the tires of the mine vehicles. A haulage way slope angle of about 20-25 degree is recommended.

Mine Slope Angle (θ)

The subsurface lithology of the study area indicates that the top 0.5 to 11.0 meters, depending on the holes, is composed of sandy shale and clayey sands which are underlain by intrusive rock bodies. Thus, the stability of the quarry walls will depend to a large extent on the angle of the bedding planes and the stability of the overburden materials. A dangerously unstable condition occurs when the bedding planes slope steeply towards the quarry pit, especially if there is groundwater seepage that helps to lubricate the bedding planes. Stable conditions are assured only when the bedding planes are near horizontal and smaller in size or inclination than the cut slopes or slopes away from the excavation. The shaley and sandy shale materials that form the overburden at the northern segment of the quarry has a steep slope of about 48^0

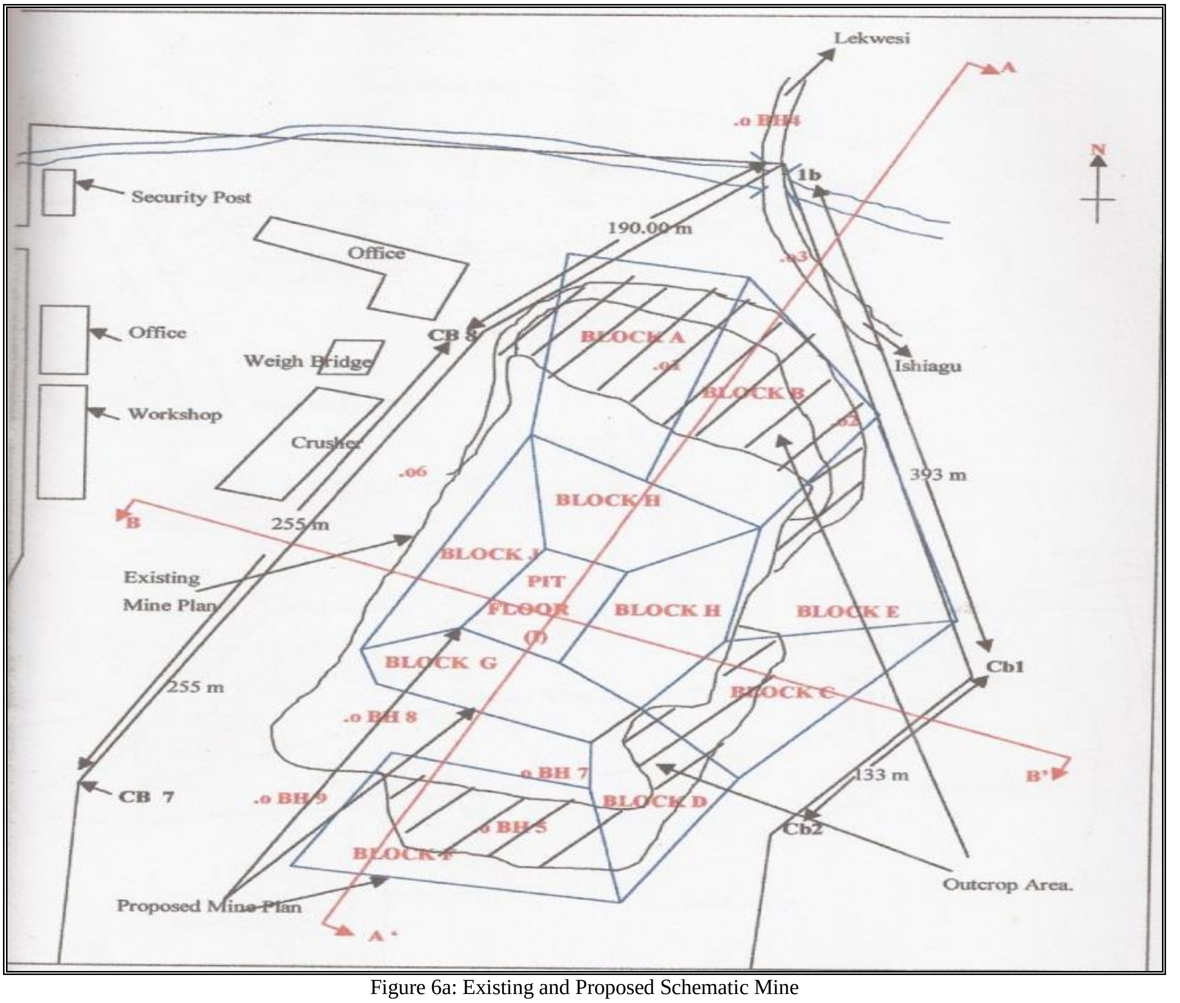


Figure 6a: Existing and Proposed Schematic Mine Plan for Crush Stone Quarry at Amata-Lekwesi

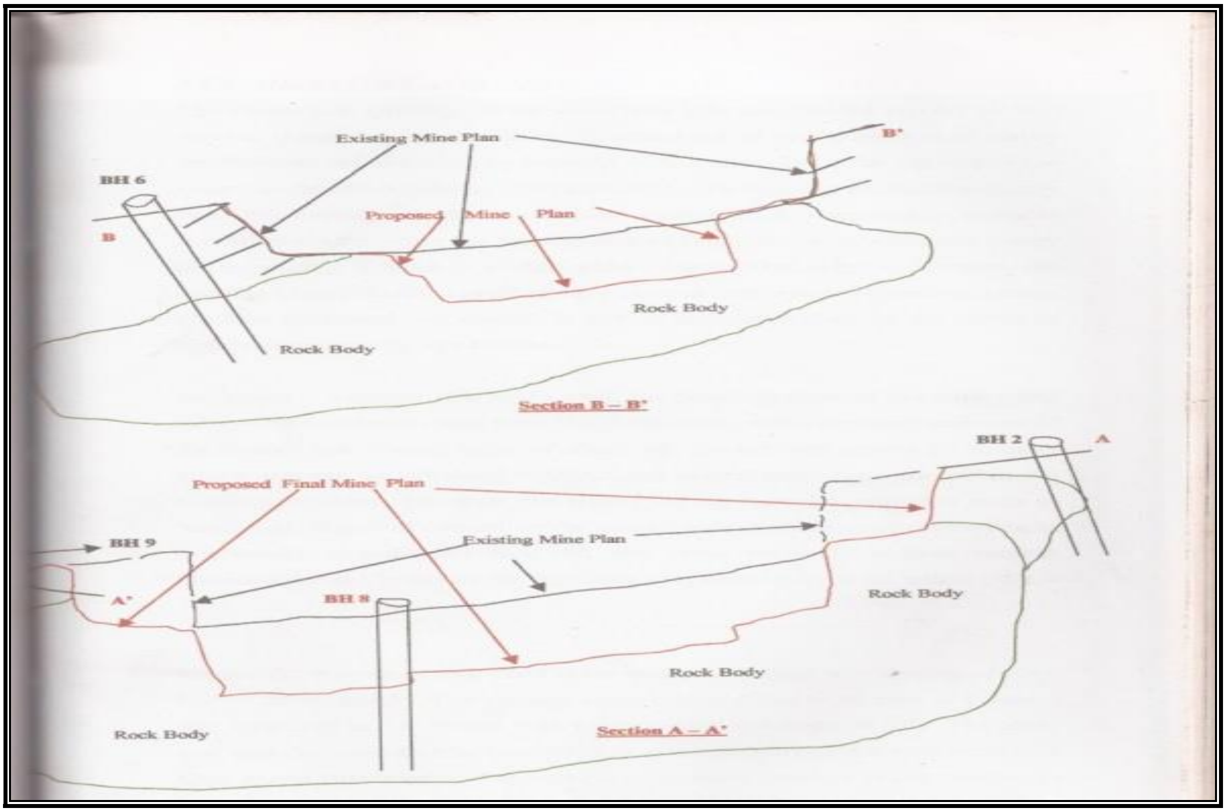


Figure 6b: Cross Sections of Existing and
Proposed Mine Outlines at Amata-Lekwesi Quarry

towards the quarry pit through which seepage was noticed to occur and slopes away from the pit in the southern segment. However, the stability of the material properties tends to insert high degree of control on the overall stability. An open excavation in a normally consolidated clay soil will stand vertically without support provided that the height of the face does not exceed the critical height ***(Hc).***

$$Hc = \frac{4Cu}{\gamma} \quad \text{................................ equa. (2)}$$

Where c_u = average untrained shear strength of clay, γ = density of clay, Hc = critical height. The average slope length of the mine face was measured at 5.0 meters with an average slope angle of 58^0. The shale was also discovered to be fissured; hence the stability of the rock mass to a large extent depended on the negative pore-water pressure in the fissures to keep the mass tightly stable in the undisturbed situation. On removal of this lateral pressure by excavation, a positive pore-pressure is initiated causing some slide of mass fragments along the mine face at places where the 58^0 slope angle was exceeded. The frictional angle (θ) values of sandy shales and clayey sands can be taken to be approximately 48^0-$50^{0.}$ However, based on the heterogeneity of the materials, a steeper slope than those stated here can be adopted. A recommended slope angle (θ) of 50^0 and 60^0 will be adequate based on actual field trials.

The subsurface lithology at the southern segment indicates that the top 5.0 to about 5.6 meters are composed of lateritic sands and medium to coarse grained sands derived from the in-situ regoliths, below which are the intrusive. Thus, the stability of the quarry walls will depend to a large extent on the stability of the overburden materials. The frictional angle (θ) values of lateritic sands and medium to coarse grained sands can be taken approximately between 40^0 and 46^0. However, based on the heterogeneity of the materials, a steeper slope than those stated here can be adopted. So a recommended slope angle (θ) of between 50^0 and 60^0 will be adequate based on the frictional properties of the field materials.

Mine Wall Height (h)

The wall height of a mine or quarry is controlled principally by the position, direction, orientation and volume of the ore body or the mine-able rock as well as the dimensions of the working equipments in the particular mine. The results of field borings revealed that the maximum depth of the rock body at the northern segment is in excess of 23.0 meters below ground level. This depth is more than a normal mine wall value, thus, it will be necessary to have a bench in-between the two expected lifting levels of rock extraction at the quarry. For the southern segment, the maximum depth is in excess of 21.0 meters below the ground surface. This depth again is more than a normal mine wall height, thus, a bench in-between two expected lifting levels of rock extraction will be required for the trenching of the quarry.

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