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NIGERIAN MINING JOURNAL

INFORMATION FOR AUTHORS

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Unpublished work: Umoru, E.E. (1996) Re-appraisal of mining methods of Ameka Lead/zinc deposit. Unpublished HND project, Kaduna Polytechnic Kaduna, Nigeria.

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Hassan et al (2017) Nigerian Mining Journal, (15) 1 - 4

Determination of specific gravity and Particle Size Distribution Curve for Ngaski Gold Ore Resource

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Abstract

This work presents the determination of specific gravity and particle size distribution curve Ngaski gold ore. The specific gravity was determined by the pycnometer method while the particle size distribution curve was determined by milling four samples of 1Kg each of Ngaski gold ore in a laboratory rod mill for 10, 20, 30 and 40 minutes' time periods and determining the percent passing at 75μm for each product. Results obtained established that Ngaski gold ore has a specific gravity of 2.76 with a particle size distribution curve that fits a linear equation of y=1.988x +14.45. The specific gravity result will facilitate pulp density calculations and gravity concentration considerations, amongst others while the curve will guide in determining the milling time required to produce a required product of specified size fraction.

Key Words: Ngaski gold ore, specific gravity, particle size distribution curve, pulp density

Introduction

Gold along with silver, platinum, palladium, rhodium, iridium, ruthenium and osmium are among the scarcest of metallic elements generally referred to as "precious" or "noble metals". The naturally occurring resources of these metals are mostly associated with large amounts of gangue materials, which influence their beneficiation/extraction processes (Gupta, 2003). Gold occurs naturally as native gold, electrum (gold & silver), calaverite, amongst others as tabulated in Table 1 (Marsden and House, 2009).

Table 1: Properties of Naturally Occurring Gold Minerals

Minerals	Formula	Au Content (%)	Specific Gravity	Mohs Hardness	Colour
Native Gold	Au	>75	16.0 – 19.3	2.5 – 3	Deep yellow
Electrum	(Au, Ag)	45 – 75	13.0 - 16.0	2 – 2.5	Pale yellow
Calaverite	$AuTe_2$	39.2 – 42.8	9.2	2.5 – 3	White or creamy yellow
Sylvanite	$(Au,Ag)_2Te_2$	24.2 – 29.9	8.2	1.5 – 2	Creamy white
Montbrayite	Au_2Te_3	38.6 – 44.3	9.9	2.5	Creamy white
Petzite	Ag_3AuTe_2	19.0 – 25.2	9.1	2.5	Grayish white with violet tint
Hessite	Au_2Te	4.7	8.4	2.5 – 3	Grayish white
Krennerite	AuTe	30.7- 43.9	8.6	2.5	Creamy White
Maldonite	Au_2Bi	64.5-65.1	15.5	1.5-2	Gray-white

Nigerian Gold is naturally found occurring in primary veins, alluvial and eluvial placers in the schist belts of the northwest and southwest of Nigeria. Major known areas where gold occurs in Nigeria include Maru and Anka in Zamfara State, Malele, Tsohon Birnin-Gwari-Kwaga in Kaduna State, Gurmana in Niger State, Birnin Yauri and Fakkai in Kebbi Sate, Okolom- Dogondaji in Kogi State and Iperindo in Osun State (BGS International, 2012, Nigeria Mining Cadastre Office, 2016).

Ngaski gold is associated with quartz mineralization occurring as veins and is yet to be characterized. Processing of this mineral assemblage will require communition to liberate the gold towards facilitating its separation from the waste quartz (Adams, 2005; Mcken and Williams, 2005; Marsden and House, 2009). Ngaski gold ore resource is located in Ngaski Local Government Area of Kebbi State bounded by longitudes 4° 34' 00" and 4° 42' 00" and latitudes 10° 09' 00" and 10° 32' 00". The area is covered by exploration licenses 17868EL and 19647EL but is exploited by artisanal miners.

Production of milled products of specific size fraction will require the knowledge of their milling characteristics determined by the Particle size distribution curve which gives the indication of the milling time required. Specific gravity determination on the other hand will facilitate the assessment of the feasibility of separating mineral assemblage using gravity separation methods as well as computation of mineral processing plant throughputs (Wills and Napier-Munn, 2006).

Specific gravity is mostly determined using the pycnometer method (Jones, 1987 & SGS, 2016). Milling Curve is determined by milling required material in a laboratory rod mill for specified period with percent passing the required size (75μm) determined for each product produced. A graph plot of % passing 75μm versus Milling Time gives the milling curve for milling to 75μm.

Materials and Methods

Materials

Material used comprised Ngaski gold ore sample and water

Equipment

Equipment used were made up of Density bottles, Weighing Scale, Laboratory rod mill; 45μm sieve, 75μm sieve, 106μm sieve, Sieve Shaker, Drying Oven, Drying Plates and Stop Watch.

Experimental Procedures

Specific Gravity

The procedure used to determine the specific gravity of Ngaski gold ore involved grinding 1kg of Ngaski gold ore using a laboratory rod mill, sieving the milled product produced using 45μm and 106μm sieves to produce -45μm +106μm size range material. 50g of the sieved product was then spread on flat drying plates and dried in a drying oven at 110°C for 2 hours. Other procedural steps taken in determining the specific gravity of the Ngaski gold comprise:

a. Weighing the density bottle empty (w);
b. Weighing the density bottle + 4.5g of Ngaski gold ore sample (w1);
c. Weighing the density bottle + 4.5g of Ngaski gold ore sample+ filled with water (w_2);
d. Weighing the empty density bottled filled with water (w_3);

The specific gravity of Ngaski gold ore was thereafter determined using the equation:

$S.G. = (w_1 - w)/[(w_3 - w) - (w_2 - w1)]$ ---- (1)

Milling

The Particle size distribution curve for Ngaski gold ore was determined by grinding 1Kg each of Ngaski gold ore in a laboratory rod mill for 10, 20, 30 and 40 minutes' time periods and percent passing 75μm determined for each of the milled products produced. A graph plot of % passing 75μm versus Milling Time in minutes was then plotted to give the Ngaski gold Ore Milling Curve.

Results

Specific Gravity

Table 2: Specific Gravity Determination Data for Ngaski Gold Ore

Parameters	Test A (g)	Test B (g)
W_t of empty density bottle (w)	7.1	8.2
W_t of empty density bottle + sample (w_1)	11.6	12.8
W_t of empty density bottle + sample + water (w_2)	67.9	57.9
W_t of density bottle + water (w_3)	65.0	55.0

Using equation (1), The specific gravity was established as follows:

S.G (A) = (11.6 – 7.1)/[(65.0 - 7.1)-(67.9-11.6)] =2.8125
S.G (B) = (12.8-8.2)/[(55.0 - 8.2)-(57.9 - 12.8) = 2.7059
Average S.G. = (2.8125 + 2.7059)/2 = 2.76

Curve

Table 3: Curve Determination Data for Ngaski Gold Ore

Time (Minutes)	% Passing 75µm
10	31.5
20	58.1
30	74.8
40	92.2

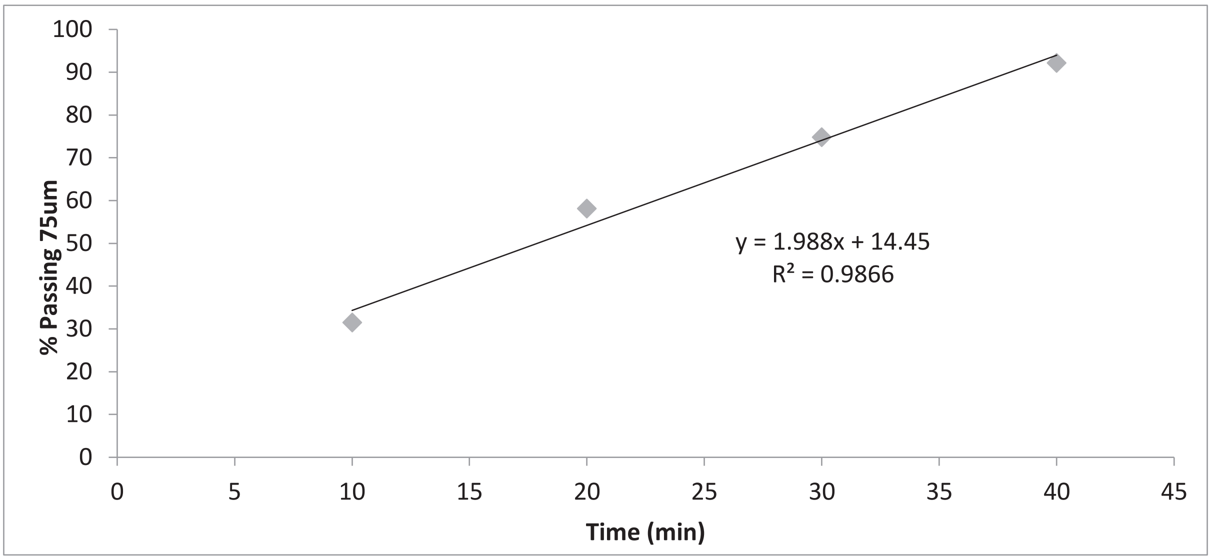

Figure 1: Graph of % Passing 75µm Versus Milling Time in minutes

Discussion of Results

Specific Gravity of Ngaski Gold Ore

The results of table 2 and the calculations for specific gravity that followed showed that sample 'A' indicated that Ngaski gold ore has a specific gravity (SG) of about 2.81 while Sample 'B' indicated that it has an SG of 2.71 giving an average value of 2.76. The figure of 2.81 SG fits the value reported by www.911metallurgistst.com while the average figure indicates a lower gold content, which is still exploitable. The higher the gold content, the higher the SG value arising from the fact that quartz and gold that form the predominant mineral assemblage respectively have SGs of 2.65 and 16.0 - 19.3 as reported by Marsden and House, 2009.

Curve

The plot of the data generated from the milling of 1kg of Ngaski gold ore produced a milling curve that fitted a linear equation: y=1.988x +14.45

which describes a linear curve with a gradient of 1.988, a variance of 0.986 and an intercept of 14.45% passing 75µm. This indicates that the original sample had about 14.45% passing 75µm before milling and that Ngaski gold ore will contain 80% material that passes 75µm sieve after milling it for about 33minutes.

Conclusion

The study established that Ngaski gold has a specific gravity of about 2.76 that falls within the established range for exploited gold ores as reported by Weiss, 1985 and a milling curve that fitted a linear equation of y=1.988x +14.45. The specific gravity result so determined will facilitate pulp density calculations and gravity concentration considerations in Flowsheet design while the milling curve will guide in determining the milling time required to produce a required product of specified size fraction milled to 75µm. The same procedure can be used to determine the milling curve for milling the ore to any desired size fraction.

References

Adams, M. D., (2005): Advances in Gold OreProcessing, Published by Elsevier

BGS International, (2012). Solid mineral occurrences and mineral potential of Nigeria

Gupta C. K. (2003): Chemical metallurgy, principles and practice, willey-VCH Verlag Gmbh & Co, KGaA, ISBN 3-572-30376-6, pp 479 – 484, 500 - 516

Marsden, J.O. and House, C.I., (2009). The chemistry of gold extraction, second edition, published by the society of Mining, Metallurgy and Exploration, Inc.

Mcken A. and Williams S. (2005): An overview of the small scale tests available to characterize ore grindability for design purposes, SGS Minerals Technical Buletin 2005 -06

Nigeria Mining Cadastre Office (2016): Mineral Title Directory

SGS (2016): Proposal to carry out Simulated Heap Leach and Mineralogical Test Work (16/076 Rev1)

Wills B. A., Napier-Munn T. J., (2006): Wills' Mineral Processing Technology, An Introduction to the Practical Aspect of Ore Treatment and Mineral Recovery by Elsevier Science & Technology Books, pp 64 – 75, 225

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Salati et al (2017) Nigerian Mining Journal, (15) 5 - 18

Artisanal and Small-scale Gold Mining in Nigeria: A Case for Review in Line with Policies of Selected Developing Countries

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Abstract
Artisanal and Small-scale Gold Mining (ASGM) in Nigeria is characterised by indiscriminate mining activities and severe environmental problems amidst low compliance with government policies. This paper reviews the government policies on ASGM in Nigeria and compares them with policies in selected developing countries with a view to identifying challenges and proffering solutions. As a result of the overview of government policies on ASGM in Nigeria and a comparative study of global ASGM policies, defective structural definition of the ASGM status and centralisation of licencing system are identified as the major contributory factors to the underdevelopment of the country's ASGM sector. Suggestions proffered for possible reversal of the current situation include the review of legislative and regulatory lapses and decentralisation of the licencing and registration procedures to the State and Local Government levels.
Keywords: Artisanal and small-scale gold mining; government policies; decentralisation.

1. Introduction
Prior to the review of the Nigerian Minerals and Mining Act No 34 of 1999 and promulgation of the 2007 Act, the only existing regulation on ASGM had been the Gold Trading and the Goldsmiths' Act No. 18 of 1935 which was used to regulate gold trading activities in the country (Anon, 1990). There are currently no separate enactments on Artisanal and Small-scale Gold Mining (ASGM) in Nigeria as ASGM activities in the country are governed by the general policies of Artisanal and Small-scale Mining (ASM) contained in the Minerals and Mining Act of 2007 (Anon, 2007). Therefore, ASGM in the country is regarded as a typical activity in the ASM sector.

However, in recognition of the importance of gold mining to the economy, and the attention generated by haphazard gold mining activities across the country for decades, the Minerals and Metal Policy of 2008 includes gold as one of the 'noble metals' that need policy attention. Thus, the policy on gold mining is captured under the noble metals sub-sector and steel industry (Anon, 2008). As part of government efforts to develop the ASM sector in the country, general guidelines on the practice of ASM and manuals for training of local miners have been developed for the artisans in the sector (Tychsen et al., 2011; Jorgensen et al., 2011).

Currently, the legitimacy or otherwise of any ASGM activities in Nigeria is determined by Section 46 (c) of the Nigerian Minerals and Mining Act 20 of 2007, which though is entitled 'Small-scale Mining Lease', also regulates ASGM (Anon, 2007). Therefore, ASGM activities carried out without compliance with this section are illegal, and are punishable under Section 133 of the Act. The Small-scale Mining Lease gives the licence holder the right to conduct artisanal mining operations (including gold mining) which do not include the use of extensive explosives, toxic chemicals or agents (Anon, 2007). An applicant holding an exploration licence may also apply for a small-scale mining lease or make a fresh application for issue of same. Small scale mining lease is granted for a period of 5 years and may be renewed upon application for another term of 5 years. Under the Minerals and Mining Act, the ASGM licence holder has equal chance to apply for mineral titles at the Mining Cadastral Agency (MCA).

The Minerals and Mining Act empowers the ASM Department to oversee and supervise the activities of the ASGM sector, ensuring that such mining activities are restricted to the established zones of mineralisation. The Ministry of Mines and Steel Development (MMSD) has also been mandated to provide various extension services to duly registered, and operating mining co-operatives in the sector (Anon, 2007). As part of efforts to ensure compliance of miners with rules and regulations, and formalisation of the ASGM sector, the ASM Department has been strengthened to perform the specific functions of organising miners into cooperatives, and providing them with the required training and supports (Anon, 2008).

This paper reviews the government legislative frameworks and enforcement strategies on ASGM in Nigeria and compares them with similar policies elsewhere in a global perspective. The aim is to identify the direction of government's policy thrust and its impacts on ASGM control with a view to proffering suggestions on effective regulation of ASGM activities in the country.

1. Challenges of Government Policies on ASGM

A number of factors have been identified as obstacles to effective regulation of ASGM activities in Nigeria. These challenges have resulted in an uncoordinated and chaotic ASGM environment with loss of huge revenue to the government. The following have been identified:

i. Centralised licencing system;
ii. Regulatory lapses;
iii. Obsolete environmental laws; and
iv. Overlapping regulatory functions.

Centralised Licencing System

The centralisation of the Cadastral operations and cumbersome application procedures have continuously militated against effective management and administration of mining titles' in the Nigerian ASGM sector (Salati et al., 2012). As a result, most miners in the sector have been discouraged from joining cooperative groups, and have remained outside the formal mining sector operating illegally.

Regulatory Lapses

There is lack of emphasis on the integration of the informal mining activities into the formal mining sector in the current Minerals and Mining Act of 2007 as far as ASGM development is concerned. There is also no distinct regulatory organ to enforce ASGM rules in the country as the supposed department is already subsumed under the existing ASM Department within the MMSD, giving rise to sporadic ASGM activities in the minefields (Salati, et al., 2014). Thus, the regulatory flaws in the legal framework of the Nigerian mining laws have combined effects of ineffective enforcement and increased illegality in the minefields.

Obsolete Environmental Laws

Previous mining and environmental laws in Nigeria did not take specific cognisance of mercury emissions, apart from the National Effluent Limitation Regulations and other related environmental laws in the country. The National Environment Standards and Regulation Enforcement

Agency (NESREA) Act of 2007 replaced the Federal Environmental Protection Agency (FEPA) Act of 1988, and is administered by the Ministry of Environment. It represents a body of laws and regulations meant for the protection and sustainable development of the environment and its natural resources (Anon, 2011a).

Overlapping Regulatory Functions

To complement obsolete environmental laws, problems in the Nigerian mining regulatory structure is further compounded by overlapping of responsibilities on environmental matters between government agencies which often create bureaucratic bottlenecks and inefficiency in environmental regulation in the mining industry. These lapses are noticeable in Anon.(1995)and Anon.(2011a).The overlapping functions usually occur between the Ministry of Mines and Steel Development (MMSD) and Ministry of Environment (MOE)especially concerning environmental issues in mining areas. Although synergy between the two agencies is crucial for effective environmental regulation in the Nigerian mining industry, the effect of their overlapping functions seems to be eroding such benefit.

2. **Global Comparison of Government Policies on ASGM**

ASGM Policies in Ghana

The Small-scale Gold Mining Laws (PNDCL 217 and 218 of 1989)had been promulgated to curb illegal gold mining in Ghana known as 'galamsey', meaning 'gather and sell', regulating their purchase and handling of mercury, specifying their mining areas and restricting them from the use of explosives (Amankwah and Anim-Sackey, 2003;Eshun and Mireku-Gyimah, 2002; Mireku-Gyimah et al., 1996).This legalisation, however, appeared to have escalated ASGM activities indiscriminately across the country (Donkor et al., 2006). To control this situation, District Small-scale Mining Centres were established to provide technical advice and assistance to small-scale gold miners, while the precious Minerals Marketing Corporation (PMMC) was also instituted to oversee the marketing of gold produced by the small-scale miners (Eshun and Mireku-Gyimah, 2002). This policy change resulted in Ghana's gold output of 93 % growth within seven years of the policy commencement; employment of thousands of people who otherwise would have been unemployed; opening up of remote areas where the small-scale gold mines are located; and raising the social status of the host communities and surrounding villages (Mireku-Gyimah et al., 1996; Mireku-Gyimah and Suglo, 1993).

Although the previous laws on ASGM have been repealed and replaced recently by the Minerals and Mining Act of 2006, Nyame (2010) argues that only one section (i.e. Section 96) mentions the purchase of mercury leaving out any penalty for defaulting miners. The effect of this brevity concerning the use of mercury in the new law appears to have contributed to poor policy implementation regarding its purchase, handling and disposal by local miners. However, the Minerals and Mining Act (2006), in agreement with the previous laws, allows Ghanaian citizens of eighteen years and above or a cooperative group consisting of ten or more persons to apply for ASGM licence to mine on a maximum of 10 hectares (25 acres) land in areas designated for small scale mining (Eshun, 2005; Macdonald et al., 2014). The prohibition of foreign nationals from owning small scale mining concessions and the constitution of National Task Force on Illegal

Small-Scale Mining have also encouraged the establishment of the National Association of Small-Scale Miners in the country.

ASGM Policies in Mali

The regulation of the ASGM sector in Mali, through Ordinance No. 90-09/P-RM and Enforcement Decree No. 90-186/P-RM of 1990, legalises gold-washing activities and small-scale gold mining thereby differentiating between traditional and mechanised gold washing (Keita, 2001). The possession of a gold washer's card allows miners access to traditional gold washing. Similarly, small-scale gold mining and mechanised gold washing are secured with the acquisition of small-scale mining development licence.

The Malian labour law prohibits children from shaft digging, cutting and carrying of wood for underground shafts, transport of rock from the shafts, crushing, grinding, panning in water, and the use of explosives, mercury and cyanide (Anon, 2011b). The law also stipulates how much weight children are allowed to carry, according to their age, gender and mode of transport.

However, the policy could not be implemented because the gold washer's card is beyond the reach of miners in the traditional gold washing sector (Keita, 2001). The licencing agency lacks the required logistics to enforce the law. In addition, application procedures are too complex for the large and small scale gold mining companies, thereby discouraging many of them from applying.

ASGM Policies in Burkina Faso

Like in other African countries, ASGM is an emerging sector in Burkina Faso in view of its huge gold deposits, coupled with sporadic gold mining activities in different parts of the country. The political will to develop the entire mining sector by the Burkina authorities is reflected in the Mining Code of 1995 and its application decrees of 1997 (Jaques et al., 2006). Some aspects of the Mining Code specifically cover the ASM sector, under which ASGM operates, making a distinction between small-scale and artisanal mines. In Burkina Faso, a prospective small scale entrepreneur can only be permitted to operate by assuming the status of an artisanal gold miner. This is because, contrary to a small-scale gold miner, an artisanal gold miner has no obligation to hold an exploration or mining licence (Jaques et al., 2006). A gold purchase licence allows entrepreneurs in Burkina Faso to purchase gold extracted by small-scale miners and trade in precious metals; to do this legally, a trading post needs to be mounted, which requires an artisanal mining permit (Megret, 2011).

In order to encourage the transformation of the ASGM sector to a full-fledged people-oriented and private sector-driven mining industry, the Burkina Faso government proposed a new Mining Code, which is expected to boost investment from global companies, while ensuring the continued existence of the traditional gold mining sector. The policy change is targeted at making the mining industry double its contribution (12.7 %) to the country's Gross Domestic Product (Kabore, 2012). Some of the amendments in the proposed Mining Code are also geared towards proper development and integration of the ASGM sector in the country. Such proposed incentives include preference to local gold businesses and recruitment, preference for local residents, especially for work that does not require qualification, and creation of a Mining Fund for local development (Howard and Bahamin, 2012).

However, environmental challenges such as land degradation and use of mercury in gold mining, frequent disputes between artisanal, small-scale, and large scale gold miners, and other social hazards associated with the ASGM sector remain a big task for the Burkina Faso government to handle. This requires the enactment of implementable mining policy that can effectively regulate the ASGM sector and facilitate its integration into formal mining.

ASGM Policies in Uganda

The Mineral Policy of 2001 mandates the Department of Geological Survey and Mines (DGSM) to carry out the following functions with respect to ASGM activities in Uganda (Anon., 2011c; Data, 2013):

i. Regularisation and improvement of ASGM through light-handed application of regulations;
ii. Provision of information on production and marketing;
iii. Provision of extension services through gold miners association; and
iv. Implementation of awareness campaigns targeting artisanal and small-scale gold miners.

Also, Part IV of the Mining Act (2003) and Part VI of the Mining Regulations (2004) refer to aspects of licencing and maintenance of location licences for ASGM operations in the country. Although Ugandan legislation does not distinguish between artisanal and small-scale gold mining, ASGM licence is acquired in respect of small-scale gold operations, prospecting or gold mining operations with limited capital and basic technology (Anon., 2011c). The licence is exclusive, granted for a two-year period, and renewable in two years. Although mining policy and legislation provide overall framework for the management of ASGM in Uganda, control of the sector falls within the various sectorial laws and regulations, including those derived from national fiscal, environmental and labour policies, requiring miners' compliance in the sector. However, most miners engaged in ASGM are largely unaware of these legislations (Anon, 2011c).

ASGM Policies in Tanzania

The Tanzanian mining policies of 1970s and 1980s in which the ASGM operators are granted concessions for gold mining in designated areas require only minimal capital and the use of basic equipment (Anon., 2011d). The 1983 Small-scale Mining Policy particularly allows low income citizens of the country to partake in ASGM activities; thus, paving way for the liberalisation of the sector in the late 1980s (Fisher, 2008; Mwaipopo et al., 2004); and initiating the formalisation and legalisation of the sector which culminated in the passage of a new mining law in 2010 (Anon, 2011d). The major policy thrusts of the ASGM formalisation process in Tanzania include concession allocation, decentralisation of the licencing procedures, micro financing and capacity building for miners in the sector.

Ownership of Primary Mining Licence (PML) which is specifically meant for ASGM business entities exclusively favours the citizens of Tanzania more than other nationals (Anon, 2011d). Environmental and safety guidelines are also streamlined for miners in the ASGM sector only unlike large gold mining companies that have to go through complete procedures of environmental impact assessments (EIAs).

ASGM Policies in Mongolia

Although proposals for the regulation and legalisation of the ASGM sector in

Mongolia started in 2002, the most significant milestone in the development of the sector was a road map projection on artisanal mining from 2008 to 2015 (Anon., 2012). This regulation is the foundation upon which future ASGM policies in the country are expected to be laid. This temporary regulation allows the ASGM operators access to land and promotes the middlemen in the gold business channels, though the miners are restricted from the tailings of the large companies, processing plants and use of explosives in primary mining.

However, the regulation does not provide incentives for formalisation but only stipulates the control and supervision of ASGM activities without any legitimacy to directly allocate concession to miners. Major limitations of the current policies of ASGM in Mongolia include the following (Singo, 2012):

i. Inability of the ASGM to evolve into other entities, such as private companies, or cooperatives within the existing legal framework due to law restriction;

ii. There is restriction on the size of equipment used by the ASGM operators (500 cm^3 engine capacity) which slows down development through low and unsafe production;

iii. Bureaucracy in the commissioning and running of processing plants allows clandestine activities and proliferation of illegal mercury plants; and

iv. Underground mining in the ASGM sector is only permitted under tri-partite agreements with large gold mining companies, which in reality is not feasible.

ASGM Policies in Philippines

The development of ASGM sector in the Philippines is hinged on two mining policies namely the Executive Order (EO) No. 79 and the People's Small-scale Mining Act of 1991, which amended the policy direction of the former (Artajo, 2012).

The government policies are meant to address the challenges facing the gold mining industry in the country such as environmental degradation, displacement of indigenous peoples from their ancestral domains, lack of transparency and revenue-sharing issues. Other problems in the ASGM sector include lack of safety in the mines, low ore recovery, mercury emissions and pollution, and inappropriate technology, among others (Gutierrez, 2013). The policies are also geared towards creating employment in the ASGM sector which is largely informal in the Philippines especially among the rural poor whose means of livelihood mainly depends on gold mining.

However, one major limitation of this mining policyin Philippines is the alienation of ASGM operators in favour of large-scale gold miners (Artajo, 2012). Under the policy, the large scale gold mining operators are given the legitimacy and possession of gold concessions thereby leaving out the artisans and often blaming them for illegality and negative impacts on the environment. This situation has created disharmony between the ASGM operators and large scale gold miners with attendant socio-economic problems.

ASGM Policies in Papua New Guinea

The mining sector in Papua New Guinea (PNG) is governed by two main legislations namely the 1992 Mining Act and Mining Safety Act. The major components of the former include Alluvial Mining Lease (AML) and Mining Lease (ML) which are applicable to ASGM (Mek, 2011; Susapu and Crispin, 2001). The five-year (1989 – 1993) development plan of PNG focuses on citizens' participation in the ASGM sector which is recognised as a viable economic industry for the people to contribute their quota to the development of the country.

Since ASGM is regarded as a legitimate cash-earning activity in PNG, donor funds from international organisations are used to complement government's efforts to support educational and microfinance projects in the country. The policy thrusts of PNG's ASGM policies include the provision of technical extension services; review of the difficult sections of the Mining Act of 1992 to accommodate small tenements applicants; encouragement of foreign investors to participate in the development of ASGM on contract basis using their finance and expertise; and streamlining of the ASGM sector in the country for national development (Susapu and Crispin, 2001). The government's objective in this regard is to improve miners' efficiency, while reducing the social and environmental effects of ASGM.

However, limitations associated with the implementation of the Mining Act of 1992 include the following (Susapu and Crispin, 2001):

i. There are contradictions on the participation in mechanised gold mining and Alluvial Mining Lease (AML), with some sections of the Act exempting it and others allowing it on joint-foreign investment venture basis;
ii. There are anomalies in the cadastral survey lease maps, thereby making policy implementation on concession acquisition difficult; and
iii. Weak institutional capacity of the government agency does not adequately match the potential of the ASGM, thereby slowing down policy implementation and blocking avenues for funds from donor agencies.

ASGM Policies in Peru

ASGM policies in Peru are similar to those in other Latin American countries. The General Mining Law of 1992 does not recognise the existence of the ASGM sector but only makes all the existing provisions in relation to large and medium scale gold mining (Chilmaza and Rivas, 2009). The implication of such provisions is that ASGM entities need to fulfil the same formalisation requirements as large scale gold mining companies. However, following the amendment to the General Mining Law of 1992 through Law 27651, promulgated in 2002, known as the Law of Formalisation and Promotion of Small-scale Mining and Artisanal Mining, specific provisions have been made for the development of ASGM sector (Anon., 2011e). This amendment distinguishes between small gold producers and artisanal gold producers. ASGM in Peru is structured in the following categories (Zevallos and Chilma, 2012):

i. A fully-formalised and independently managed modern ASGM with full professional and technical support, using environmental and labour compliant clean processing technologies; and
ii. An ASGM entity going through negotiations for formalisation process with title holders.

ASGM policy in Peru is hinged on Law 27651 of 2002 whose provisions centre on the integration of cyanide leaching technologies in gold processing. The major provisions of the law include the recognition of the ASGM sector and economic empowerment of gold mining families; clear cut criteria and guidelines for concession acquisition for miners; training programmes for gold miners; awareness programmes on environmental safety and responsibilities; tax incentives; code of conducts for ASGM practices; audit system for ASGM and rights and freedom of miners in the ASGM sector to petition (Chilmaza and Rivas, 2009). However, conditions attached to the ranking of small and artisanal mining gold producers in the Peruvian ASGM sector limit the chances of smooth implementation of the formalisation process. It raises production benchmark which is not attainable by miners and creates bottlenecks in the miners' registration processes.

ASGM Policies in Ecuador

ASGM activities in Ecuador are controlled and regulated under the Mining Law of 2009 and General Regulations of 2009. Provisions of both Acts together with Decree 120 of the same year are specifically targeted at miners in the ASGM sector. They include financial and technical assistance to miners, as well as support and guidelines for environmental protection and boost in production (Anon., 2011f). The laws are emphatic about the granting of ASGM concessions which is done by a bidding process through public mining auctions and tenders. However, centralisation of the bidding process in the urban cities for large ASGM operations; costly and cumbersome bid proposal procedures; and large number of bidders in the system are issues of concern to the government (Anon., 2011f; Barreto, 2012).

The ASGM policies favour Ecuadorian citizens more as artisanal gold mining permits are granted only to them. They are, however, encouraged to be organised into low income family and independent gold mining groups. The policies also favour the granting of mining rights to genuine gold mining cooperative groups and similar entities within the ASGM sector (Anon, 2011f; Barreto, 2012). Transfer of rights and mining title upgrade, negotiations and consultation with host communities and labour conditions and profit sharing are the major issues in the Ecuadorian ASGM framework. The environmental regulations on ASGM also comprise comprehensive guidelines on mercury use, its handling, storage, prohibition and technologies. However, inadequate capital and lack of expertise of the small-scale gold operators seem to limit their chances of meeting mine sites rehabilitation requirements as ASGM operators in the country must obtain water authorisation like other mining operators before they are granted permission to commence operations (Barreto, 2012).
Challenges associated with government policies on ASGM in Ecuador which constitute bottlenecks to effective regulation and control of the sector include lack of an economic policy and incentives to comply with laws, and weak enforcement capacity leading to policy ineffectiveness (Lovitz, 2006). Thus, decision making process takes longer time and incurs more expenses in the long run.

3. Findings and Discussions

The following findings are drawn from the study:

I. Conceptual analysis of government policies on ASGM in Nigeria as illustrated by Salati et al.(2014) shows that government policies are found to be currently defined and structured along the administrative and regulatory functions of the MMSD which are delegated through the Mines Inspectorate (MI) and Artisanal and Small-scale Mining (ASM) Departments. Fig. 1 shows the conceptual definition of the government policies on ASGM in Nigeria. The legislative definitions in the Minerals and Mining Act of 2007 (e.g. section 49) and other legislations emphasise more on small-scale mining contrary to massive ASGM activities in the minefields across the country without any conceptual or structural provision for ASGM in its entirety.

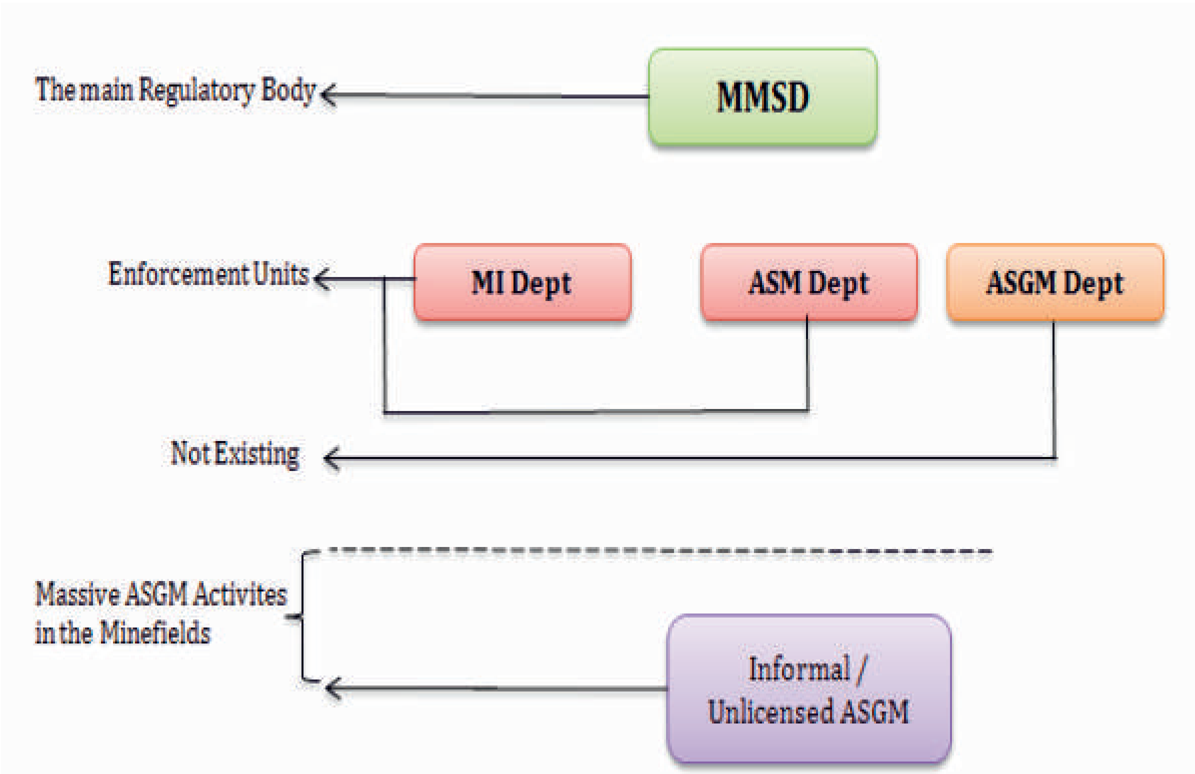

Fig. 1 Conceptual Definition of Government Policies of ASGM in Nigeria

ii The comparison of ASM/ASGM policies of countries such as Ghana, Tanzania, Uganda, Peru and Ecuador is done in this study with a view to identifying organisational features that can improve Nigeria's mining sector. As shown in Table 1, the level of centralisation/decentralisation of licencing system seems to drive the contribution of ASGM to national contribution in some of the countries under review, including Nigeria. This factor is also found to be influential to impressive policies of the countries and the level of policy compliance achieved in the countries' regulation of ASGM. Comparatively, the Nigerian cadastral system is centralised thereby reflecting the low contribution of the ASGM sector to the country's economy, chaotic mining sector and low policy compliance level.

Table 1 Comparison of Government Policies in Selected Countries

Country	Sectorial Status	Type of Cadastral System	Estimated Contribution to National Economy	Areas to be Improved Upon	Areas of Impressive Policies	Policy Compliance Level
Ecuador	ASGM	Decentralised	65 - 75 % (2002 - 2005)	Large scale mining sector.	Formalisation; mercury reduction.	Growing and encouraging.
Ghana	ASGM	Semi-centralised	28 % (2011)	Environmental challenge.	Decentralisation drive; mineral buying centres.	Gradual and encouraging.
Uganda	ASM	Semi-centralised	Low < 5 %	Socio-environmental issues.	Legalisation drive.	Low but growing.
Peru	ASGM	Decentralised	12.63 % (2000)	Mercury-induced pollution.	Formalisation; cleaner processing technologies.	Growing and encouraging.
Tanzania	ASGM	Decentralised	10 % (2011)	Environmental issues.	Formalisation; miner education and empowerment.	Growing and encouraging.
Nigeria	ASM	Centralised	Low < 5 %	Entire mining sector.	Private investment drive; computerised mine cadastral.	Low and discouraging.

(Source: Salati et al, 2015)

1. Conclusions and Recommendations

This study has reviewed the government policies on ASGM in Nigeria, having identified the challenges militating against their effective implementation and compared them with global policies. The study has shown that the government legislative structure on ASGM in Nigeria is ineffective which contributes to poor implementation of government policies in the mining industry. The review of global government policies on ASGM in comparison with those of Nigeria has also shown that decentralisation of licencing system in the ASGM sector has direct positive socio-economic and environmental impacts. It can, therefore, be concluded that ASGM in Nigeria is yet to attain the desired sectorial status due to defective regulatory structure, poor implementation and chaotic ASGM activities as the country.

In view of the identified challenges facing the ASGM sector in Nigeria, the following suggestions are proffered for effective policy implementation and overall development of the sector:

i. The structure of the legislative instrument of the Nigerian mining industry should be redefined through the review of the current legislation with a view to creating a separate structural regulatory platform for ASGM development in the country.

ii. The cadastral system of the entire mining industry in Nigeria should be decentralised to the State and Local Government levels to ease procedures for mining titles application and licencing and make the registration of local miners into cooperative groups accessible and easier.

References

Amankwah, R. K. and Anim-Sackey, C. (2003), "Strategies for Sustainable Development of the Small-scale Gold and Diamond Mining Industry of Ghana", *Resources Policy*, 29, pp. 131 – 138.

Anon. (2012), "Analysis of Formalisation Approaches in the Artisanal and Small Scale Gold Mining based on Experiences in Ecuador, Mongolia, Peru, Tanzania and Uganda", *United Nations Environment Programme*, Geneva, Switzerland, 15 pp.

Anon. (2011a), "A Synopsis of Laws and Regulations on the Environment in Nigeria", *Environmental Law Research Institute*, Abuja, 10 pp.

Anon. (2011b), "A Poisonous Mix- Child Labour, Mercury and Artisanal Gold Mining in Mali", *Human Rights Watch*, *www.hrw.org.* Accessed: November 20, 2013.

Anon. (2011c), "Analysis for Stakeholders on Formalisation in the Artisanal and Small-scale Gold Mining Sector based on Experiences in Latin America, Africa, and Asia- Uganda Case Study", *Alliance for Responsible Mining*, Available online at: www.community.org. Accessed: May 25, 2013.

Anon. (2011d), "Analysis for Stakeholders on Formalisation in the Artisanal and Small-scale Gold Mining Sector based on Experiences in Latin America, Africa, and Asia- Tanzania Case Study", *Alliance for Responsible Mining*, Available online at: www.community.org. Accessed: May 25, 2013.

Anon. (2011c), "SDC Experiences with Formalisation and Responsible Environmental Practices in Artisanal and Small-scale Gold Mining in Latin America and Asia (Mongolia)", *Federal Department of Foreign Affairs (FDFA)*, Available online at: www.sdc.admin.ch/publications. Accessed: June 12, 2013.

Anon. (2011e), "Analysis for Stakeholders on Formalisation in the Artisanal and Small-scale Gold Mining Sector based on Experiences in Latin America, Africa, and Asia- Peru Case Study", *Alliance for Responsible Mining*, Available online at: www.community.org. Accessed: May 25, 2013.

Anon. (2011f), "Analysis for Stakeholders on Formalisation in the Artisanal and Small-scale Gold Mining Sector based on Experiences in Latin America, Africa, and Asia- Ecuador Case Study",*Alliance for Responsible Mining*, Available online at: www.community.org. Accessed: May 25, 2013.

Anon. (2008), "National Minerals and Metals Policy", *Ministry of Mines and Steel Development*, Abuja, 59 pp.

Anon. (2007), "Nigerian Minerals and Mining Act, No. 20, 2007", Ministry of Mines and Steel Development, Abuja, 62 pp.

Anon. (1995), "Environmental Impact Assessment- Procedural Guidelines", *Federal Environmental Protection Agency*, Nigeria, 19 pp.

Anon. (1990), "Gold Trading Act, No.18 of 1935, Chapter 163", *Laws of the*

Federation of Nigeria (1990 revised edition), Vol. 9, pp. 6282 - 6291.

Artajo, M. I. D. (2012), "Enhancing Decent Work Outcomes in Small Scale Gold Mining", Working Papers Series 2012, *Institute for Labour Studies*, Philippines, 20 pp.

Barreto, L. (2012), "A Compendium of Case Studies- Summary of Ecuador Case Study", In *Analysis of Formalisation Approaches in the Artisanal and Small-scale Gold Mining Sector Based on Experiences in Ecuador, Mongolia, Peru, Tanzania and Uganda,* United Nations Environment Programme, pp. 11 – 20.

Chilmaza, F. G. and Rivas, M. R. (2009), "Public Policies for Small Scale Mining: Peru Case", *Alliance for Responsible Mining*, Lima, 12 pp.

Data, G. (2013), "Artisanal and Small Scale Mining (ASM) in Uganda", *Department of Geological Survey and Mines, Ministry of Energy and Mineral Development*, Uganda, 10 pp.

Donkor, A. K., Nartey, V. K., Bonzongo, J. C. and Adotey, D. K. (2006), "Artisanal Mining of Gold with Mercury in Ghana", *West Africa Journal of Applied Ecology (WAJAE)*, Vol. 6, pp. 1- 8.

Eshun, P. A. (2005), "Sustainable Small-Scale Gold Mining in Ghana: Setting and Strategies for Sustainability", *Sustainable Minerals Operations in the Developing World*, Geological Society Special Publication 250, Marker, B. R., Petterson, M. G., McEvoy, F. and Stephenson, M. H. (eds.), pp. 61 – 72.

Eshun, P. A. and Mireku-Gyimah, D. (2002), "Small Scale Mining in the Tarkwa District: A Review of its Impacts", *SWEMP 2002, 7th International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production*,Sardinia, Italy, Italy, pp. 877 – 884.

Fisher, E. (2008), "Artisanal Gold Mining at the Margins of Mineral Resource Governance: A Case from Tanzania", *Development Southern Africa*, Vol. 25, No. 2, pp. 200 – 213.

Gutierrez, R. C. (2013), "Current Experience on the Mercury-Free Transition in Artisanal and Small-Scale Gold Mining in the Philippines, *Presentation at the Asia-Pacific Regional Conference on Artisanal and Small Scale Mining*, Ulaanbaatar, Mongolia, 36 pp.

Howard, J. and Bahamin, P. (2012), "Amendments to the Mining Code", *Mining Journal Special Publication-Burkina Faso*, pp. 11 – 12.

Jaques, E., Zida, B., Billa, M., Greffe, C. and Thormassin, J. F. (2006), "Artisanal and Small Scale Gold Mines in Burkina Faso: Today and Tomorrow', In Hilson, G.M. (Ed.): *Small-scale Mining, Rural Subsistence and Poverty in West Africa*, Practical Action Publishing, UK, pp.113–134.

Jorgensen, T., Tychsen, J., Appel, P.W.U., and Hassan, U.A. (2011), *Improving ASM Operations in Nigeria – Trainers Guide*, Geological Survey of Denmark and Greenland (GEUS), Copenhagen, 21 pp.

Kabore, S. (2012), "A Good Place to do Business", *Mining Journal Special Publication- Burkina Faso*, pp. 3 – 4.

Keita, S. (2001), "Study on Artisanal and Small-Scale Mining in Mali", *International Institute for Environment* *and Development*, England, 32 pp.

Lovitz, S. B. (2006), "Scales of Responsible Gold Mining: Overcoming Barriers to Cleaner Artisanal Mining in Southern Ecuador", *Unpublished MSc Thesis*, University of Vermont, Ecuador, 137 pp.

Macdonald, F. K. F., Lund, M., Blanchette, M. and McCullough, C. (2014), "Regulation of Artisanal Small Scale Gold Mining (ASGM) in Ghana and Indonesia as Currently Implemented Fails to Adequately Protect Aquatic Ecosystems", *An Interdisciplinary Response to Mine Water Challenges*, China University of Mining and Technology Press, Sui, Sun and Wang (eds.), pp. 401 – 405.

Megret, Q. (2011), "Gaining Access to a Globally Coveted Mining Resource: A Case Study in Burkina Faso", *ISSJ UNESCO*, Blackwell Publishing Ltd., Oxford, 397 pp.

Mek, B. (2011), "Artisanal Small-scale Alluvial Gold Mining in Papua New Guinea: Meriyaka Alluvial Gold Mining – A Case Study", *Papua New Guinea Journal of Science, Technology and Engineering*, Vol. 2, No. 1, pp. 1 – 10.

Mireku-Gyimah, D., Opare-Baidoo, S. and Cobblah, A. (1996), "Small-scale Gold Mining and its Impact on the Economy of Ghana", *Surface Mining 1996,South African Institute of Mining and Metallurgy*, Johannesburg, pp. 13 – 16.

Mireku-Gyimah, D. and Suglo, R. S. (1993), "The State of Gold Mining in Ghana", *Trans. Instn. Min. Metall. (Sec. A: Mining Industry),* Vol. 102, pp. 21 – 26.

Mwaipopo, R., Mutagwaba, W., Nyange, D. and Fisher, E. (2004), "Increasing the Contribution of Artisanal and Small Scale Mining to Poverty Reduction in Tanzania – Based on Analysis of Mining Livelihoods in Misungwi and Geita Districts, Mwanza Region", *A Report Prepared for the Department of International Development*, UK, 119 pp.

Nyame, F. K. (2010), "Policy Challenges on Mercury Use in Ghana's Artisanal and Small-scale Mining Sector", *International Journal of Environment and Pollution*, Vol. 41, Nos. 3/4, pp. 202 – 213.

Salati, L. K. (2015), "Development of an Integrated Management Model for Artisanal and Small – scale Gold Mining in Northern Nigeria", *Unpublished PhD Thesis*, University of Mines and Technology, Tarkwa, 172 pp.

Salati, L. K., Mireku-Gyimah, D. and Eshun, P. A. (2014), "Evaluation of Stakeholders' Roles in the Management of Artisanal and Small-scale Gold Mining in Anka, Zamfara State, Nigeria", *Developing Country Studies*, Vol. 4, No. 19, pp. 150 – 161.

Salati, L. K., Bida, A. D. and Ganiyu, I. A. (2012), "Environmental Safety and Health Challenges of Artisanal Mining in Nigeria: Review of Regulatory Strategies", *Nigerian Mining Journal*, Vol. 9, No. 1, pp. 17 – 28.

Singo, P. (2012), "A Compendium of Case Studies- Summary of Mongolia Case Study", In:*Analysis of Formalisation Approaches in the Artisanal and Small-scale Gold Mining Sector Based on Experiences in Ecuador, Mongolia, Peru, Tanzania and Uganda*, United Nations Environment Programme, pp. 47 – 52.

Susapu, B. and Crispin, G. (2001), "Report on Small-scale Mining in Papua New Guinea", *International Institute for Environment and Development*, No. 81, Great Britain, 27 pp.

Tychsen, J., Appel, P. W. U., Hassan, U. A., Jorgensen, T., and Azubike, O. C. (2011), *ASM Handbook for Nigeria*, Geological Survey of Denmark and Greenland (GEUS), Copenhagen, 176 pp.

Zevallos, O. O. and Chilmaza, F. C. G. (2012), "A Compendium of Case Studies- Summary of Peru Case Study", In: *Analysis of Formalization Approaches in the Artisanal and Small-scale Gold Mining Sector Based on Experiences in Ecuador, Mongolia, Peru, Tanzania and Uganda,* United Nations Environment Programme, pp. 21 – 26.

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Geotechnical and Petrographic Assessment of Supare Rocks as Dimension Stone, Ondo State, Southwestern Nigeria

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Abstract

A study of the geology and the geotechnical properties of rocks in Supare, part of Owo sheet 265 NW, Ondo State South Western Nigeria was carried out to identify rocks as dimension stone. The suitability of different rocks types assessed was based on the physical and the mechanical properties of the outcrops. A total of ten rock samples were analysed for physical and mechanical properties. The samples examined showed good compressive and tensile strength properties suitable for block production in accordance with standard specification. The compressive strength ranges between 149.71 N/M^2 and130.51 N/M^2. The high values of water absorption (1.27%) and porosity (0.88%) for L3 reduces its quality and suitability for use as dimension stone production. The examination carried out to determine the mineralogical composition of the rock samples which also provided information on weathering condition shows that all sampled rocks are free of flaws and deleterious minerals. The major minerals in the rocks are quartz, feldspar and mica.

Keywords: Dimension stone, geotechnical properties, petrography, and mineral composition, physical and mechanical properties.

Introduction

Dimension stone is any hard rock or natural stone specially cut, trimmed to a specification and polished. This term applies to natural rock quarried or cut for the purpose of block or slab that meet dimension in term of size and shape. The term Natural stone includes rocks having fine colour and pattern, having the required strength and weathering resistance such as granite, marble, sandstone, slate, quartzite, limestone, granodiorite, dolomite, serpentinite, gabbro, gneiss, etc. It is however worthy of note that not all natural facing rocks are suitable for dimension stone production (Lapedes, 1978). Among the target features of any dimension stone, mechanical and the physical properties are of tremendous relevance. The major yardstick for the geotechnical assessment or evaluation of dimension stone include compressive strength, tensile strength, porosity and water absorption. The aim of this work is to study selected outcrops in Supare, Ondo State which are typical of certain lithologies and have the potential for use as dimension stone. Exterior cladding must be free of deleterious minerals which are subject to chemical and or physical weathering. Sulphide tends to oxidize, leaving streak and stain on the surface. Soft minerals such as olivine and pyroxene, formed at great depth and temperature, are unstable under conditions found on the earth's surface. They erode and leave a pitted surface. Other minerals such as epidote, were created during alteration or metamorphism and occur as softer inclusion in the rock.

In dimension stone production, flaws refer to the assemblage, pattern and distribution of joints fractures, faults and microcracks. Although, flaws are not desirable in dimension stone products, parallel joints which intersect at right angles and that are not closely spaced may aid dimension block mining (Selonen, 2000). Therefore any rock for dimension stone application must be free of flaws and deleterious minerals for marketability of the products (Loudes, 2000).

Geology of the Study Area

The study area lies between latitude 7°27' – 7°29' N and longitude 5°40' – 5°42' E on Owo sheet 265NW on a scale of 1:12500. It covers an estimate of area of about

13.4km^2. Supare Akoko lies within the undifferentiated migmatite-gneiss complex of Nigeria Basement rock as classified by Rahaman (1973) and these account for over 99% of the basement rock in the terrain The rock under study are located in Northern district of Ondo State as shown in Fig 1. This area is dominated by three rock type: granite-gneiss followed by granite and migmatite. The geological map of the area of study is represented in Fig 2.

According to Kogbe (1979), the basement complex rocks of Nigeria are composed predominantly of magmatic and granitic gneiss, quartzite, slightly migmatised to unmigmatised metasedimentary schists and metaigneous rocks, charnockitic, gabbroic and dioritic rocks and the member of the Older Granite, granodiorite and syenite. Migmatite are found to be abundant in southwestern Nigeria. Supare granite outcrop is described as granite gneiss, where the granitic material takes the form of indefinite impregnation.

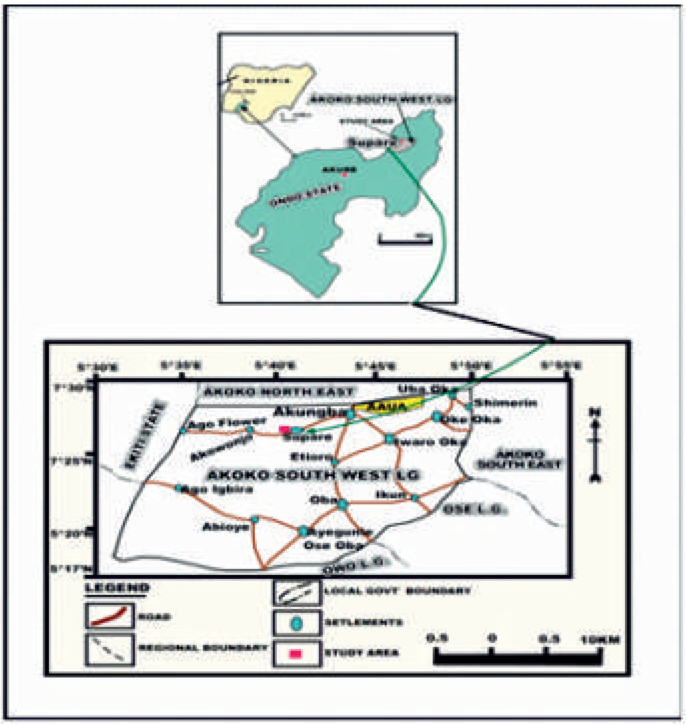


Figure 1: Location map of the study area (Department of Earth Sciences, Adekunle Ajasin University, Ondo State.).

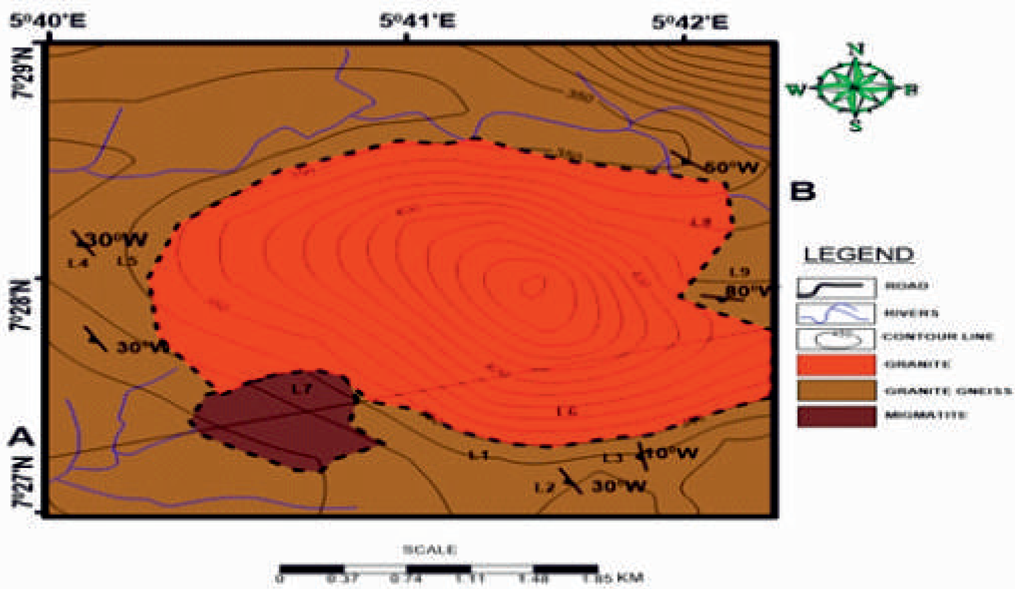


Figure 2: Geological map of the area of study

Material and Methods

The research was conducted through field work and laboratory analyses of samples collected from nine outcrops and additional samples from SUTOL Crushed Rock (an existing dimension stone industry) as control sample. Global Positioning System (GPS) was used to locate the coordinate of the study area. Sample preparation which involved rock coring and machining for mechanical and cutting to sizes for physical properties in accordance with the procedure given in International Society of Rock Mechanics, 1981 was strictly adhered. Parameters determined include; porosity. Unconfined (uniaxial) Compressive Strength, Tensile Strength, Water Absorption and Thin Section

Porosity

Three specimen of irregular form from a representative sample rock was prepared. The specimen mass was 50g and labelled A. The volume (V) was calculated from the average value of several caliper reading, the specimen was saturated by immersion for a period of an hour in a vacuum of less than 800pa. The specimen was removed and surface dried using moistens cloth with caution to ensure no fragments were lost. The mass of specimen plus container (B) was determined with an accuracy of 0.01g; the specimen was dried in an oven to constant mass at temperature of 105°C. After closure of container and cooling in a desiccator for 30 minutes, the mass (C) of the dry sample with container and lid was determined with an accuracy of 0.01g. The container with the 1.0g was cleared and dried and its mass (A) was determined with accuracy of 0.01g.

The porosity was calculated as follows:

Dry mass of saturated surface

M_{sat}= B-A

Mass of dry specimen

Ms= C-A

Volume of the pores, Vv =

Msat- Ms

Density of water

Therefore, Porosity = n= Vv/VX 100%

Where V=Specimen bulk volume; Msat= Saturated mass; Ms= Saturated submerge mass;

A= Mass of sample only; B= Mass of sample plus container and C=Mass of dry sample plus container.

Unconfined (uniaxial) Compressive Strength

The test was carried out by loading a right spherical cylinder with the ratio of height diameter 2.5 and a diameter of approximately 50mm axially until the specimen fails. The cylinder sides was smooth end and freed of irregularities and straight end to 0.5mm over the full length of the specimen, the specimen diameter and the height of the cylinder was established to approximately 0.1mm. Specimen was tested at their natural water content and the maximum load of the specimen was in accuracy of 1% recorded in Newton.

The strength of the rock specimen is given by International standard of rock mechanics as uniaxial compressive strength (U.C.S)

$$= \frac{P\ max}{\pi * (\frac{D}{2})2}$$

where P_{max} is equal to the peak load on specimen (in N)

$$\pi * (\frac{D}{2})2$$

where D is the diameter of the average specimen (in m), the U.C.S is given in Mpa; while = Sectional area of specimen(m^2).

Tensile Strength of Rock Material

Specimen of cylindrical form was made from a representative rock sample with end faces at the right angle to the axis. The specimen diameter was at minimum 10 times the average grain size, the load on the specimen was applied at a regular rate

until failure occurs.
Splitting tensile strength is given by the formula

$$t_s = 2p/\pi LD \text{ in (mpa)},$$

where t_s = (indirect) tensile strength in mpa; P equals the maximum load at the point of failure expressed in (KN); L is the specimen length represented in (m) and D is the diameter in (m) of the specimen.

Water Absorption
The specimen was dried in an oven (in the open container) at temperature of 105^{0}C for twenty four (24hr) hours, after cooling and closure of the materials in a desiccator for half an hour.The mass (c) of the only sample with the container was calculated with an accuracy and precision of 0.01g. The specimen was saturated by in water (water immersion) in a vacuum of lesser in amount than 800pa for a duration of at least 24hours and weighed.

The water absorption is given / calculated as the percentage tape of dry mass as follow:

$$\text{Water Absorption} = \frac{Msat - ms}{Ms} \times 100\%$$

where M_{sat} is saturated mass and M_s is dry mass .

Thin Section and petrography
The procedures involve cutting, lapping, frosting, mounting, trimming and thinning. Rock chips were prepared using dynamo cutter or slab diamond saw to cut into uniform dimensional sizes from the rock specimen. The rock was trimmed to a specific shape by trimming machine to reduce the size considerably from size obtained from the diamond trim saw. Following the trimming process is the lapping process. It involves obtaining a flatten and smoothen surfaces of the rock samples attached to the glass through grinding. In this section, three phases were mandated. The phases entail rubbing the surfaces with different specification of caborundum 400,600 and 1000 respectively until a very fine rock sample was obtained. Frosting as a process involve grinding of the glass slide for surface roughen or flatten it out and roughen the surface for proper binding by Canada balsam.
At this stage the specimen was fixed on slab of the glass, prior to this the slab was also rubbed with 1000 caborundum and later canalda basalm (alradite) ensuring the removal of all air bubble. The mounted specimen and the slab were warmed and later allow to cool. The slide was further grinded again mildly to correct thickness of about 0.003mm. With care the slide is grinded with addition of ater and continuous viewing under microscope to ensure desired section. At the achievement of 0.003mm, excess gum and abrasive were removed via blade and thorough washing.
Clarity of the slide was increased under the petrographic microscope with addition of a glass cover slip to keep the thin section from damage. The thin sections were subjected under two lighting conditions using a petrographic microscope. These are crossed polarizers and plane polarized light. Plane polarized is a restricted light to a simple plane. With crossed polar, properties like twinning, isomorphism, extinction angle, zoning, isomorphism and dispersion were sorted for.

Results and Discussion.
Field Observation
Structural investigation of the study area was undertaken to select outcrops suitable for dimension stone production. In the study area, granite gneiss, granite and migmatite were mapped. Table 1 shows the locations, rock type, and elevation with their respective orientation. Sutol Crushed Rock Limited is an existing dimension stone industries where control sample was obtained for analysis.
Mechanical and Physical Properties of

Selected Rocks
Table 2 shows the results of the mean value obtained for physical and mechanical properties of the selected outcrops.

Table 1: Average Physical and Mechanical properties of Selected Rocks

Sample Rock type	Sample location	Porosity, n (%)	Uniaxial Compressive strength (Mpa)	Tensile Strength (Mpa)	Bulk Density, Q^B (kg/m^3)	Water Absorption, wa,(%)
1 .Granite gneiss	L2	0.64	149.71	14.99	2683.0	0.84
2. Granite gneiss	L3	0.88	131.53	15.33	2702.5	1.27
3. Granite gneiss	L6	0.54	136.32	16.46	2697.5	0.77
4. Granite gneiss	L1	0.56	140.10	14.18	2665.5	1.01
5. Granite gneiss	L9	0.73	145.55	15.56	2684.5	0.94
6. Granite	L8	0.72	142.82	16.91	2732.0	0.93
7. Migmatite	L7	0.73	137.38	14.20	2707.0	0.97
8. Granite	L5	0.66	130.51	14.65	2698.0	0.88
9. Granite gneiss	L4	0.73	139.30	16.23	2678.5	0.91
10. Control sample (Sutol quarry)		0.71	138.63	15.56	2686.0	0.93

Uniaxial Compressive strength (U.C.S)
Table 2 shows results obtained from laboratory for U.C.S and presented graphically in Figure 3. All sampled rocks from the nine outcrops examined and a sample control obtained from Sutol Crushed Rock (an existing dimension stone quarry, near the study area) showed a reasonable U.C.S in comparison to generalized properties of rock used as building stone, proposed by Winkler (1973). Winkler suggested value range for granitic rocks to be 96-310MN/m^2, which is in agreement with results obtained from laboratory. According to descriptive term from Geological Society Engineering group working party (1977), very strong rocks are classified between 100-200MN/m^2 .Therefore all rock samples under consideration are very strong and suitable for dimension stone.

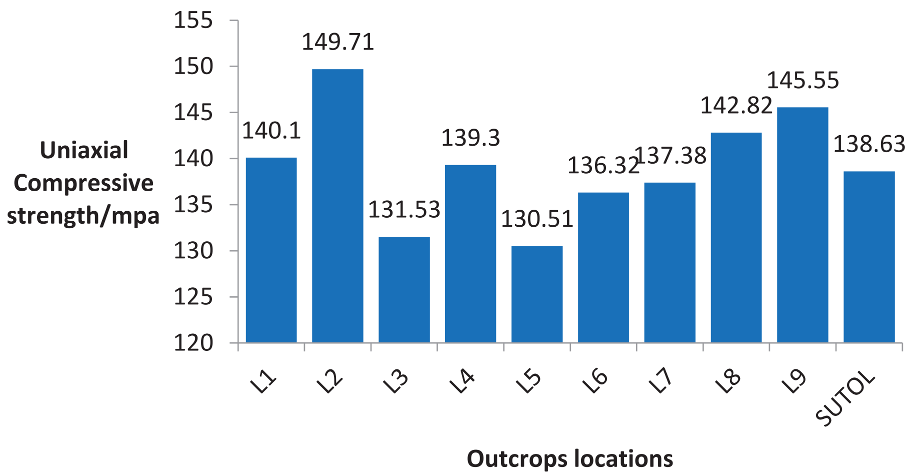


Figure 3: Uniaxial compressive strength per outcrop

The results also indicated L2 as the strongest rock type in the study area with UCA of 149.71N/M^2 follow by L9 with UCA 145.55 N/M^2 and L5 with 131.51N/M^2 as the least.

Tensile strength

The test is aimed at determining the splitting strength of rock materials. The tensile strength of rock samples examined exhibited reasonable result in agreement with ASTM specification standard for dimension stone and generalized properties of rocks used as building stone suggested by Farmer (1968). The result obtained correlated with Farmer suggested value range of 5-20MN/m^2, as outlined in Table 2 and represented graphically in Figure 4

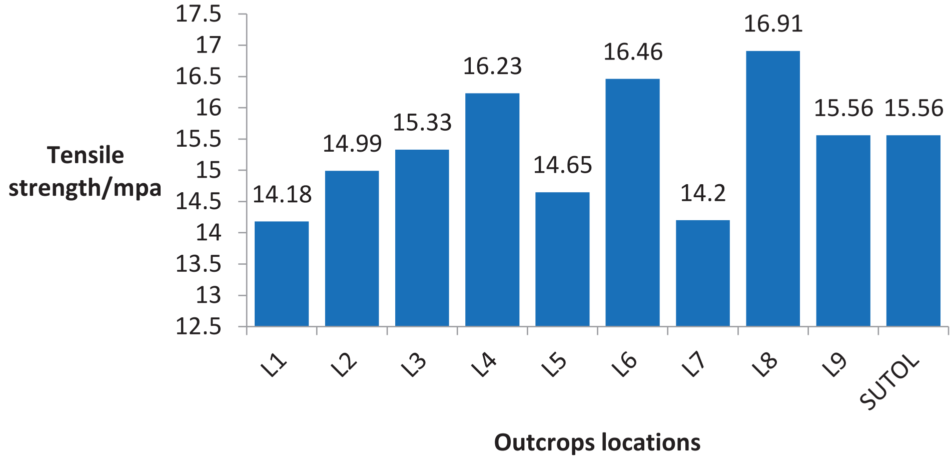


Figure 4: Tensile strength of selected rock samples

Porosity, Density and Water Absorption

The Water content or absorption shows an idea of strength of aggregates. It is the quantity of water stone can absorb under specific immersion condition. Stone aggregates with higher water absorption are tend to be more porous in nature and therefore generally considered not suitable except found acceptable on a pedestal of strength and hardness test. The flow of water would be less to penetrate non-porous stone type and therefore unable to cause significant damage (Sobhi, 2015). Porosity or low water absorption values generally exhibits rocks that are strong and durable. Water is one of the main agents of weathering. High absorption indicates more permeability which reduces dimension stone strength.

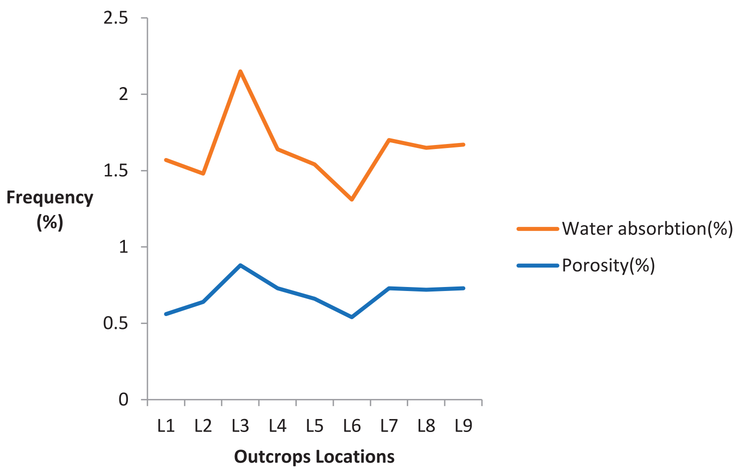


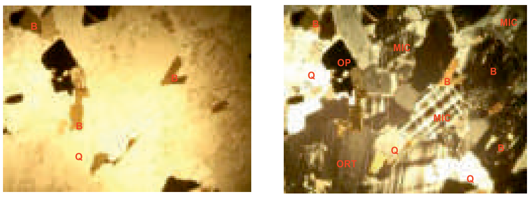
Figure 5: Water absorption and Porosity of selected rock samples

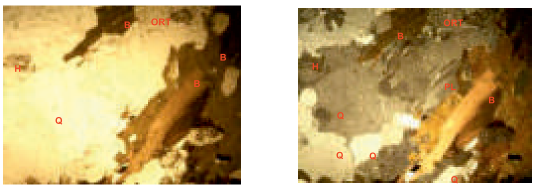
Figure 5 indicates that for the selected rock samples, water absorption is directly proportional to porosity. L3 exhibited highest water absorption of 1.27% and Porosity of 0.88% while L6 recorded the lowest of 0.77% and 0.54% respectively. The high values of water absorption and porosity of L3 makes it unsuitable for dimension stone. The bulk density (mass per unit volume) is a function of porosity and also mineral density of its composition or components. The determination of bulk density is needful to calculate the weight of the stone in wall or constructional element. As a standard, lower density with higher porosity and water absorption, the stone is likely to be less in durable for dimension stone production. and less stain resistant, and more prone to frost and salt attack.

Table 2: Estimated Modal Composition

Minerals	L2	L3	L6	L1 L1	L9	L8	L7	L5 L5	L4 L4	Sutol
	1	2	3	4	5	6	7	8	9	10
Quartz	39%	38%	32%	99%	38%	32%	36%	34%	38%	37%
Microcline	38%	-	31%	-	28%	7%	3%	29%	31%	33%
Orthoclase	12%	16%	9%	-	6%	11%	6%	29%	6%	8%
Plagioclase	-	25%	12%	-	11%	25%	29%	19%	10%	9%
Opaque Mineral	3%	2%	4%	1%	3%	3%	3%	4%	3%	2%
Hornblende	-	1%	3%	-	2%	8%	4%	3%	1%	1%
Biotite	8%	18%	9%	-	12%	14%	19%	11%	11%	10%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Photographic Micrograph of Selected Rocks

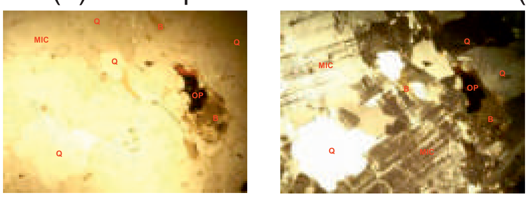


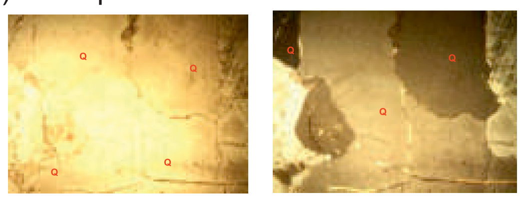


(a) (b) (a) b)

Plate I: Photomicrograph of L2 **Plate II: Photomicrograph of L3**

(a) Plane polar (b) cross polar

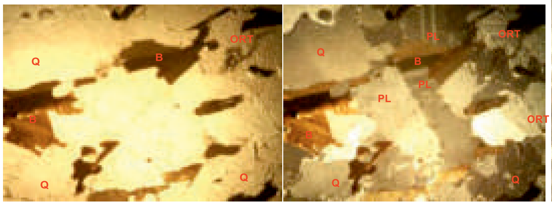




(a) (b) (a) (b)

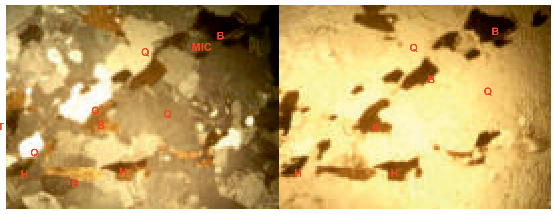
Plate III: Photomicrograph L6 **Plate IV: Photomicrograph L1**

(a) Plane polar (b) cross polar



(a) (b)

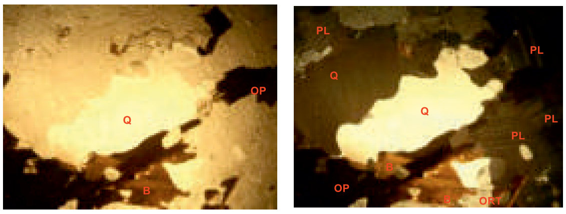
Plate V: Photomicrograph of L9



(a) (b)

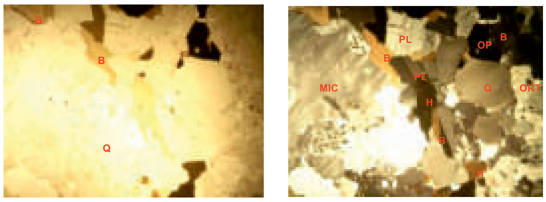
Plate VI: Photomicrograph of L8

(a) plane polar (b) cross polar



(a) (b)

Plate VII: Photomicrograph of L7



(a) (b)

Plate VII: Photomicrograph of L5

(a) Plane polar (b) cross polar

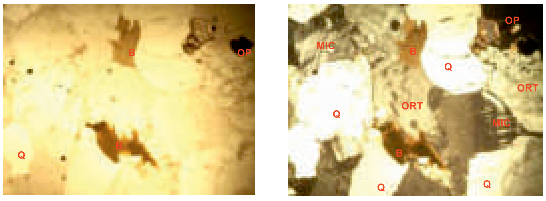


Plate IX Photomicrograph L4

(a) (b)

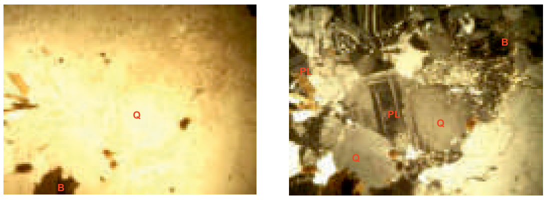


Plate X Photomicrograph Sutol sample

(a) (b)

(a) Plane polar (b) cross polar

Note: B = Biotite, Q = Quartz, MIC = Microcline, OP = Opaque Mineral, H = Hornblende, ORT = Orthoclase, PL = Plagioclase.

Petrography

In assessing of a rock for use as a dimension stone, following the fracture characterization the next requirement is petrographic study to identify its mineralogy, grain size, texture, fabric and weathering states. All these processes are in turn determined by the geological processes which formed the rock. A good understanding of these processes and its corresponding effects will enable one to determine a rock's suitability, availability and consistent production. The petrography study showed that all the sampled rocks of interest (granite, granite gneiss and migmatite) revealed absence flaws and irregularities. In dimension stone production, flaws refers to the distribution of joints, microcracks, pattern and assemblage while irregularities (deleterious minerals) like mica, iron and sulphide inclusion will oxidize leaving stain on the surface. Soft minerals like pyroxene and olivine will erode and leave pitted surface. It is therefore imperative that any materials for dimension stone application must be free from flaws and irregularities for best marketability of finished product.

Conclusion

Dimension stone forms an attractive range of unique natural products that vary in their inherent characteristics. Mechanical and physical properties are noted to be key controlling factors in the dimension stone selection. Field observation and laboratory analysis conducted revealed that the area explored is dominated by medium to coarse grained granite, granite-gneiss and migmatite with granite-gneiss dominating the study area. An examination carried out to determine the mineralogical composition of rock sample which also provided information on weathering conditions and to determine micro-cracks and deleterious minerals in all rock samples indicated that they are void of flaws and irregularities. The summary of the physical and mechanical properties indicates that not all sampled outcrops are suitable for dimension stone production. The compressive strength and the tensile strength of sampled rock are relatively good according to standard specification from International Society of Rock Mechanics. Granite gneiss exhibited highest compressive strength, follow by granite and migmatite respectively. The granite gneiss exhibits better physical, mechanical and geological properties than the migmatite and granite. The observed high porosity and water absorption in L3 granite-gneiss will enhance permeability which will eventually reduce the strength of the dimension stone and make it incompetent for dimension stone production.

References

Department of Earth Sciences, Adekunle Ajasin University (AAU), (2016). Drainage Map of Supare Part of Owo Sheet 265 NW, Southwestern, Nigeria..

Farmer, I. W. (1968). *Engineering Properties of Rocks. E & FN Spon Ltd*. London..

Geological Society of Engineering Working Party, (1977). The Description of Rock Mass for Engineering Purposes. *Quarterly Journal of Engineering Geology* .10, 355-388..

Kogbe, C.A. (1979). *Geology of Nigeria*. Elizabeth and publishing house Lagos, Nigeria.

Lapedes, D.N. (1978). *Mc-Graw-Hill encyclopedia of the geological sciences*. McGraw-Hill.

Loudes, H. S, Selonen, O., & Ehlers. C. (2000). *Evaluation of Dimension Stone in Gneissic Rock-a Case History from Southern Finland*. *Engineering Geology* 58(2), 209-223.

Sobhi, N (2015). Geotechnical Assessment of Dimension stone Resources in Oman *International Journal of Chemical, Environmental and Biological Sciences,* Vol.3(6), 2320-2340.

Winkler, E. M. (1973). *Stone: Properties, Durability in Man's Environment*. *Springer,* Vienna.

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Important Technical Considerations in the Development of Bankable Documents for Quarry Operations

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Abstract
Today's quarry operations are characterised by high capital expenditure, low product price and high operating costs including energy costs (diesel cost). Consequently, when deciding on quarry investment, there is little room for inefficiency in quarry design and production scheduling and, consequently, in the estimates of the quarry project's value. A doubtful and badly implemented quarry evaluation process could wrongly classify a non-profitable venture as being profitable with appreciable probability, and vice versa. And the consequence of a badly implemented quarry investment evaluation process has economic implications to both the promoters and stake holders of the project with financial institution (BOI[1]) inclusive. Many quarries financed by Nigerian banks record poor performances due to the technical flaws inherent in the so called Bankable Feasibility study reports submitted during the loan Application process. This paper suggests the need to engage competent hands (Mining Engineers /Mining Consultants) to carry out technical due diligence on every mining project funding or loan applications to guarantee effective and efficient funding of mining projects and justify BOI's contribution to nation's minerals industry. Also, engage team of engineers to monitor the performance of the quarry throughout the loan period. So as to ensure that the quarry run optimally to guarantee quick pay back and return on investment.
Key words: Bankable document, Technical flaw, Risk, Payback

1.0 Introduction

When an opportunity for opening/developing a quarry or acquiring an existing quarry opens, the promoter or the stakeholders of the quarry need to know the value of the quarry project and the cash flow that the quarry is going to generate over its useful life span. These are the basic determinant factors that can inform the decision to either proceed or not.

Mining projects, quarries inclusive are complex businesses that demand constant SWOT analysis influenced by many underlying economic and physical uncertainties, such as product prices, costs, schedules, capacities and environmental issues among others which are dicey. Hence, quarries present considerable challenge in effective assessments of capital expenditure, to those saddled with the responsibility of taking investment decisions such as Bank of Industry (BOI) and other investors alike.

To estimate the quarry project's value, the valuers will need to use sophisticated valuation techniques to assess, quantify and analyse existing risk and uncertainties involved in the project investment. Results of the evaluation processes guide the owners or stakeholders whether to start or abandon the quarry project. The result will also assist mine planners and quarry engineers to plan and design the quarry operation.

[1]*Bank of Industry*

The task of estimating the mine project's value is not so easy; a typical quarry project will depend on the characteristics of the deposit /reserve, product economics and operating costs of the quarry throughout its life span. Unfortunately, at the beginning of the project, enough information as to the nature and characteristics of the deposit is not usually available and product price behaviour and operating costs are based on historical data, which in most cases is not a good forecast of the future. This lack of information generates uncertainty about the values of the different underlying variables that take part in the evaluation process and consequently, the value of the quarry project.

1.1 Main sources of uncertainty in Granite Quarry projects

1.1.1 Uncertainty in Granite deposits:

One of the most critical sources of technical risk in granite quarry project lies in the quality of the rock to meet Engineering construction requirements and the tonnage of the deposit that will justify the proposed investment. Hence, reserve statement should not be an estimate of what is in-situ, but a prediction of what will be processed in the crushing plant. In the pre-feasibility study, the report is usually an information obtained from a skeletal exploration activity which is usually not a true representative of the entire property. It is then right to state that, if a deposit is yet to be mined, the knowledge of its geological characteristics, including quality and tonnage is limited and could lead to misclassification of resources. To minimise the misclassification, estimation techniques based on stochastic models are commonly used to estimate the geological information at non-sampled location. This is done by interpolating the data from few exploration samples (SME, 2011).

1.1.2 Uncertainty in product prizes and costs:

Another important source of uncertainty that has critical impact on quarry project evaluation is that associated with economic environment where the quarry is located. Within the environment, future prices and costs are the chief sources of uncertainty.

(a) Product prices: Any variation from the expected price (overestimation or underestimation) will modify the results of the entire project evaluation.

(b) Costs: Costs are usually classified as Capital costs, which refers to the investment required for the quarry's upstream and downstream equipment. Operating costs, which refers to the costs incurred in the production activities such as drilling and blasting, loading, haulage, equipment maintenance costs, and administrative costs which refers to the costs incurred in administration and other related activities in the quarry (Camus, 2002). The costs that are independent of the production level are regarded as fixed costs, while the costs that depend directly on the production level are regarded as variable costs. Since estimation of capital and operating costs are an important requirement for quarry evaluation, uncertainty in costs arises due to lack of engineering or economic information at the beginning of the quarry project. It is worthnoting to say that quarries do not know with absolute certainty today how much they will need to spend tomorrow, let alone next month or next year.

1.1.3 Uncertainty and risk is quarry planning and design:

The objective of quarry (pit geometry) design is to determine the projected final pit limits of granite deposit and its tonnage in order to maximize the economic value of the quarry while satisfying operational constraints such as crushing plant capacity and slope angles (Hustrulid and Kuchta, 1995; Dowd and Onur, 1993). The complete process of designing a quarry consists of two principal stages: pit geometry design where the ultimate pit limits are established and contoured; and production scheduling where the sequence of quarrying is planned over time.

The ultimate pit limit is the widest possible boundaries within which all subsequent quarrying operations are performed while maximizing Net Present Value (NPV). Production scheduling is the development of a sequence of extraction schedules from the initial state of the deposit to the ultimate pit limits. According to the tenure of scheduling, the production scheduling can be classified into long-term or short-term scheduling. Long-term is the schedule based on cash flow analysis and provides a guide to a more detailed quarry design and development. Short-term is the development of a sequence of extraction schedules on a daily, weekly or monthly basis within the layout of the quarry. Short-term scheduling ensures the achievement of production targets established in the long-term. Since both the ultimate pit limit and production scheduling depend directly on the granite deposit, future product prices and costs, uncertainty and risk in quarry planning and design arise due to the uncertain nature of the underlying variables that take part in the designing and planning process. It then implies that allocation of the physical limits of both the ultimate pit and long term production forecast turns into a complex and uncertain process since it depends on both the uncertainty of future product prices and false reserve estimation.

1.1.4 Uncertainty and risk in Quarry project operation and management: "*Statement of the problem*"

From the previous sections, the evaluation of a quarry project is a complex process. It involves not only the economic uncertainty of future product prices and costs, but also the technical uncertainties in which both the geological characteristics of the deposit and the designing and planning of the quarry pit geometry are considered. Furthermore, the evaluation of a quarry also involves the different operational strategies that are adopted throughout the operating life of the quarry to enhance the reliability of the quarry process for optimal production.

Quarry industry has received a great number of funding from BOI and other banks, though the quarries created thousands of jobs resulting in significant reduction in unemployment in the minerals industry, as well as projected increase in

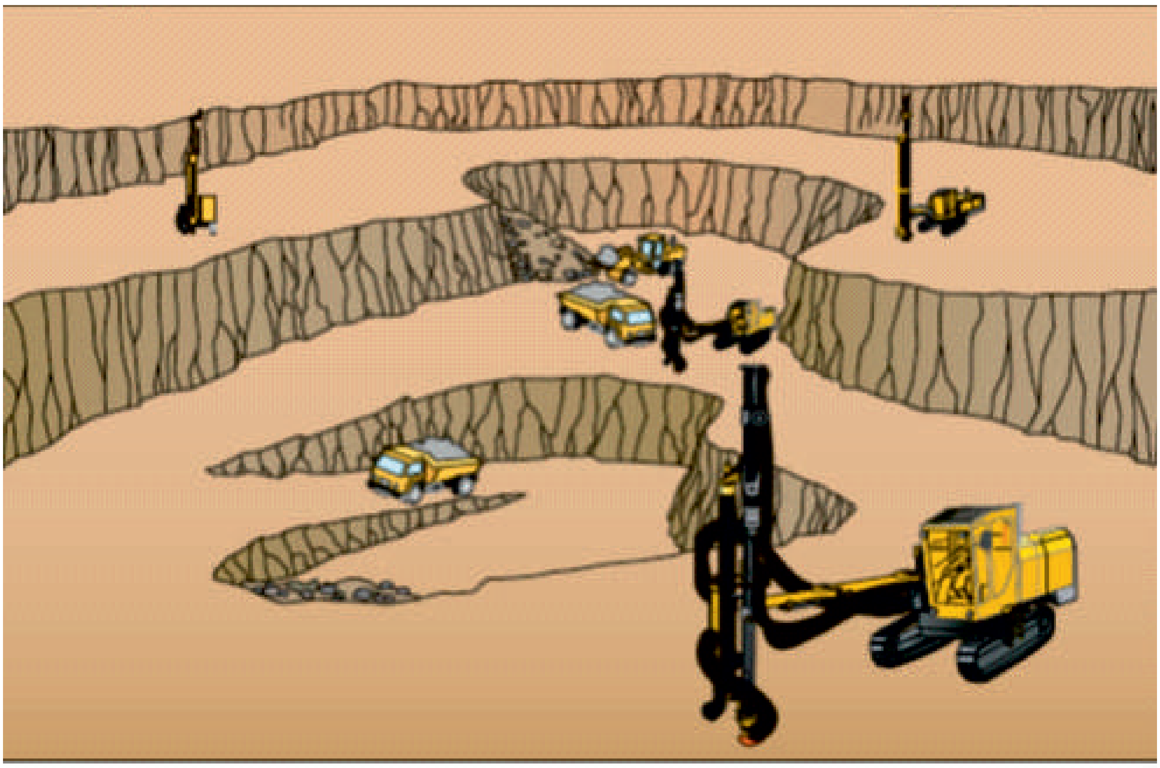

Figure 1: A Typical Pit- type quarry layout (Source: Atlas Copco, 2008)

the wealth and growth of the nation's economy, they bear a high risk in achieving their forecast profitability through maintaining budgeted costs. Most of the problems encountered in the quarries stem from lack of proper evaluation of the quarry design integrity (Abdulraman, 2016). Investigations revealed that most of the quarries have either exceeded their budgeted establishment costs or have experienced operational costs far in excess of what was originally estimated in their feasibility study reports. These lead to the quarries not able to run optimally resulting in elongated pay back and poor return on investment.

This paper provides an overview of quarry management as a guide for financial experts to be acquainted with the operational factors that are capable of elongating the payback period or could lead to premature abandonment of a quarry project.

2.0 Typical Aggregate Quarry Process

A quarry can simply be defined as a factory where solid bed rock is converted to dimensioned / crushed stones. A quarry can either be mountainous (Hill side) or pit type. The pit type quarry is opened up below the level of surrounding terrain and accessed by means of ramps. The excavated rock is crushed, screened and sometimes washed into different size fractions for subsequent sales and use.

Research have shown that pit type quarries record more development and operating costs than the hill side type except, where in-pit crushing is adopted (Eloranta, 2006). A typical aggregate quarry process is a batch process of drilling, blasting, loading, haulage, crushing, screening, stockpiling and material handling (Figure 2). These processes can be classified into upstream and downstream sections. As such, low productivity in upstream will filter through to downstream.

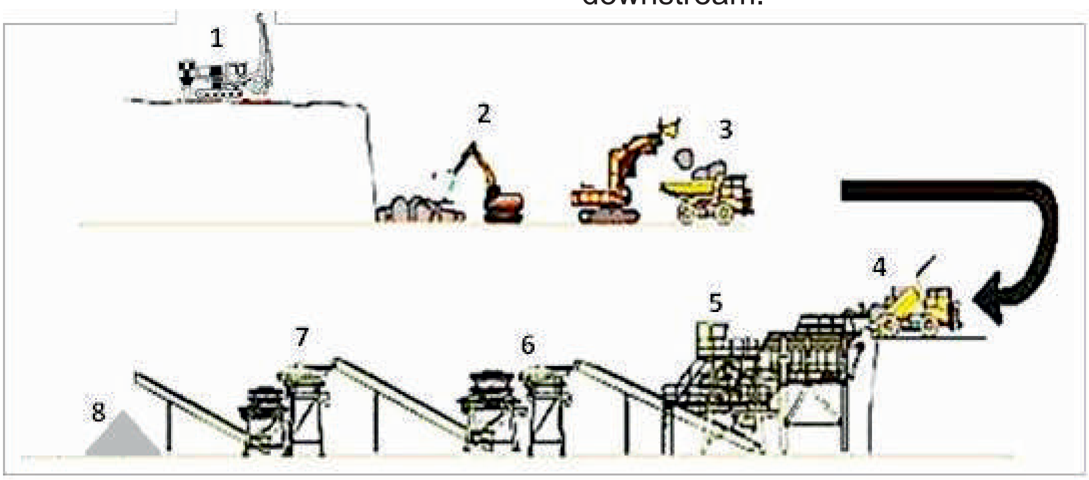

Figure 2:Aggregate Quarry Processes (Source: Abdulraman, 2016)

1 - Drilling; 2 - Mechanical Breaking; 3 - Loading and Haulage; 4 - Dumping and Feeding; 5 - Primary Crushing; 6 - Secondary Crushing; 7 - Screening and Classification; 8 - Storage/ stockpile.

2.1 Critical factors for the realization of the goal of quarry investment

2.1.1 Upstream Operations:

(a) Quarry pit optimization

Appropriate pit geometry design will enhance operational flow and consequently lead to optimum production.

(b) Extraction methodology

Drilling and Blasting design should ensure maximum production at reasonable cost. The drilling facility must be reliable, if the drilling rig is not performing optimally, it will affect the blasting schedule and post a challenge to the quarry in achieving optimal productivity. Blasting operation should provide material with good fragmentation. Blast problem can add 10 - 25% to downstream cost (PwC, 2012) through damages to equipment fleet, granite deposit, mine plan; inefficient processing at the crushing plant; and wastage of explosive for rework (Secondary blasting).

(c) Fleet productivity and fit

The selection and acquisition of loading and haulage facilities must be based on engineering analyses and not the purchase price. Inefficient loading can increase the quarry operating cost as a result of delay in deliveries to the crushing plant; inefficient loading will also lead to ineffective cycle time and utilization of that fleet. Haulage facility is a critical success factor to aggregate quarry process. For operational effectiveness, haulage facility size must match loading facility size; fleet disposition should match mine plan, avoiding queuing at the loading or dumping point, avoiding double dipping from inefficient loading practices, reducing tyre impacts from road conditions and ensuring reliable scheduling and plan compliance.

2.1.2 **Down Stream Operation**:

Just like in the upstream section, downstream activity is a system made of subsystems linked serially such that when there is a stoppage in one of the subsystems, the entire subsystem comes to a hurt. In an aggregate quarry, the layout of the crushing plants and ancillary equipment and structures is a critical factor in meeting production target/requirements while keeping capital and operating cost to a minimum. Crushing plant optimization begins with appropriate design of flow line whose installation meets the required production output, operates at competitive cost, complies with today's tough environmental regulations and can be built at a reasonable price despite the rising costs of equipment, energy and construction labour. There are three steps in designing a good crushing plant: process design; equipment selection; and layout. The first two are dictated by production requirements and design parameters, but the layout can affect the reliability and maintainability of the process with resultant plant optimizations. Running a plant optimally require keeping records of operation for Pareto analysis of failure occurrences. This will identify the critical subsystems that require improvement through appropriate maintenance policies to enhance productivity. A typical cost distribution at quarries is reported by Atlas Copco (2008) as stated below:

Crushing, Screening and Storage – 50%

Loading and Haulage – 25%

Blasting – 16.25%

Drilling – 7%

Drill string – 1.75%

3.0 **Conclusion and Recommendation**

It is very clear that evaluating a quarry project is complex with numerous uncertainties and risks that need to be evaluated, from which decision can be taken whether to proceed or not with the quarry investment. Most of the determinant factors are more of technical issues beyond the understanding of an investment officer of any bank. It is pertinent here that, banks with interest and mandate in mining investment to engage the services of experienced and competent mining consultants as lender's engineer for their portfolio of quarry projects for a thorough technical due diligence, which could guarantee a hitch free pay back of the quarry investment, thereby encouraging more public funds into the industry.

References

Abdulraman, S. O. (2016): Quarry Finance and Management, In Proceedings of Nigerian Society of Mining Engineers' (NSME, Kaduna chapter) National Workshop with the theme “Modern Trends in Quarry Operations”, pp. 10-18.

Atlascopco (2008): “Quarrying for Profit”, Surface Drilling Reference Book, www.atlascopco.com/rock, p. 260

Camus, J. P. (2002): Management of mineral resources - Creating value in mining business, Society for Mining, Metallurgy, and Exploration Inc., p. 107

Dowd, P. A. and Onur, A. H. (1993): Open-pit optimization (part 1), Open- pit design, Transactions of Institute of Mining and Metallurgy, pp. 95- 104

Eloranta, J. (2006): Minimizing Quarrying Costs by Correct Shotrock Fragmentation and In- pit Crushing, p. 42

Franz, W. (2012): Productivity and Cost Management, Asia School of Mines, PricewaterhouseCoopers, www.pwc.com.au, P. 28

Hustrulid, W. and Kuchta, M. (1995): Open pit mine planning and design, A.A.BALkema (Rotterdam) p. 636.

SME Mining Engineering Handbook (2011): Mineral Resource Estimation, 3rd ed. Vol. 1, Pp. 203.

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Evaluation of Engineering Properties of Kanawa Shales of Pindiga Formation in North Eastern Nigeria using Chemical Stabilizers

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Abstract
This study focused on determining the effect of cement, ash and lime on the engineering performance of shales from Kanawa Member of Pindiga formation, North Eastern Nigeria. Twenty-four samples of Black Cotton Soil from this formation were collected 2 kilometers east of Kanawa along Gombe – Biu road. These shaley soils were subjected to stabilization with varying amount of lime, cement, fly ash and their admixtures in order to estimate the best stabilizing agent and its effective quantity. Results shows that Kanawa shales attain minimum plasticity between 5 to 8 % cement stabilizer. Hence, cement proved to be the most effective stabilizer for the Kanawa black shaley soil. It was recommended that a defined pedological map of Nigeria be produced to serve as a guide to engineers in road construction.
Keywords: Shales, Basin, Black Cotton Soil, Stabilizing agents, Liquid Limit, Plastic Limit and Plasticity Index.

Introduction

Expansive soils are soils that swell when water is added, and shrink when they dry out. This continuous change in soil volume can cause structure built on this soil to move unevenly and crack. Each year in the world expansive soil cause more than 2.3 billion dollars' damage to houses, other buildings, roads, pipelines, rails and other structures. This is more than twice the damage from floods, earthquakes, hurricanes and tornadoes combined (Chairman, 1998).
Until recently very little work has been done to study the extent of expansive soils in Nigeria. Although there have been instances in Kebbi, Zamfara, Sokoto axes, Borno-Bauchi Yobe-Gombe-Adamawa axes, South-South and Southwest where concrete work have fractured and even displaced. Historical accounts of actual damaging events caused by expansive soils have been difficult to documented even though damaging effect occur wherever these "black cotton soils" are found, and little is known about Pedological map of Nigeria.

The problem may be overcome by proper structural design but it equally needs the expected stresses in the component and subsequently designing it. The best option is to improve the engineering properties of these soils by using suitable stabilizing techniques. The geotechnical engineer find the most suitable and efficient stabilizing method considering the environment, type of structure and establish the degree of treatment needed for the structure to be stable under varying soil moisture conditions.

This work deals with laboratory treatment on the black cotton soil of Kanawa village in Gombe State Northeast Nigeria so as to arrive at a suitable solution in terms of stabilization. Unpublished work of Bassey et al (2011) on some expansive soil belonging to the Ezeaku formation along Enugu-OKigwe express road concluded that the optimum amount was 3% Cement and 5% lime stabilizer. Other literatures mostly unpublished students' projects from Department of Civil Engineering and Department of Mineral and Petroleum Resources Engineering shows the effective amount of lime, ash and cement stabilizers fall between 3 and 6 %.

Geology of the Study Area

Figure 1 is the geological map of the part of the Gongola Basin including the "studied soil" of the Kanawa Member of the Pindiga Formation. This unit is underlain by the transitional Yolde Formation comprising of siltstones, sandstones and mudstones that are calcareous in nature, and is overlained by a mainly sandstone (Deba Fulani) member (Zaborski et al, 1998). The Kanawa member is made up of mainly black colored shales that look purple-blue in their fresh form with occasional limestone horizons and laminations of gypsum. The limestones are highly fossiliferous with mostly early to middle Turonian ammonites (Reyment, 1955). From the geological map it is obvious that almost all the settlement are on the Deba Fulani member owing to the nature of the Kanawa shales.

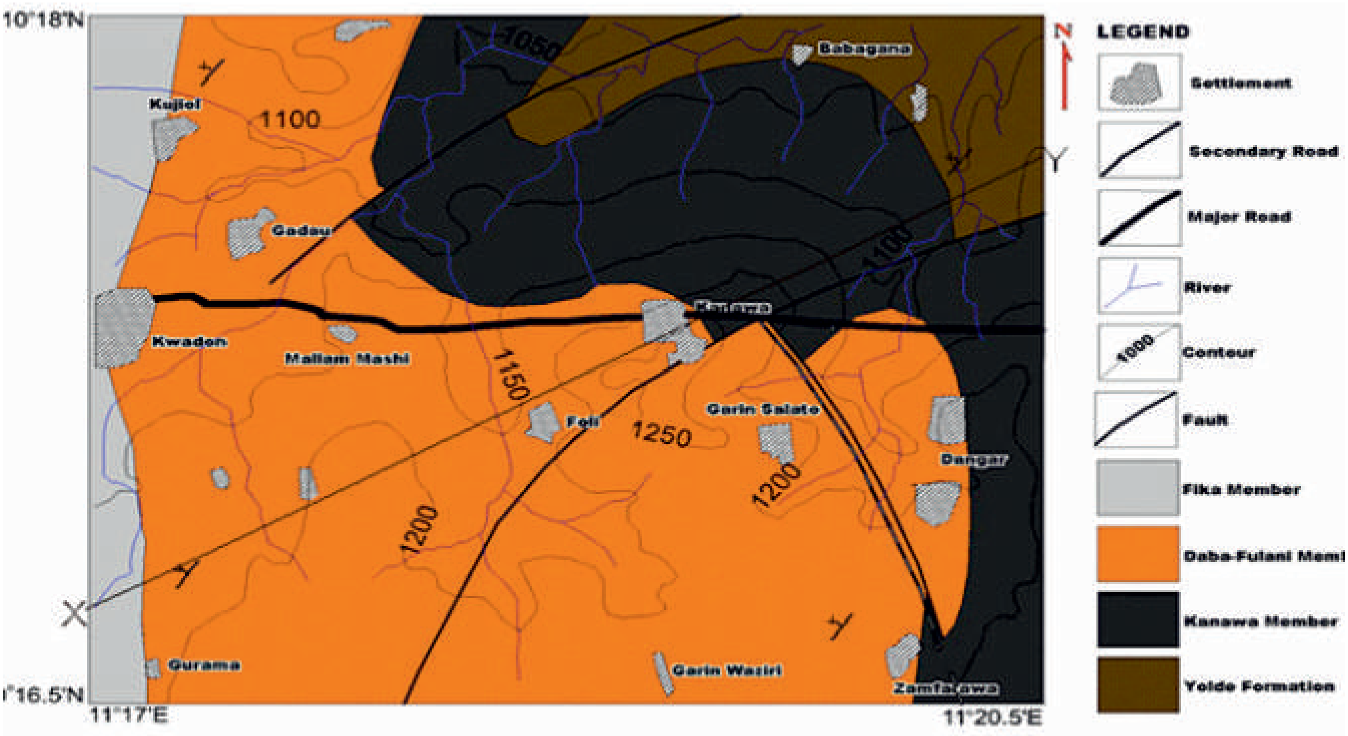

Figure 1. Geological map of the study area. (after Wudda, 2014)

Fig. 1. Geological Map of Kwodon-Kanawa Area after Wudda 2014 (modified from Zaborski et al 1998)

The major road that link Gombe town and Biu is almost always damage between Kanawa village to Dadin Kowa due to the expansive character of the Kanawa shales. Twenty-four soil samples of the Kanawa Member of the Pindiga formation were taken 2km east of Kanawa village along the Gombe - Biu major road in attempt to observe the effect of lime, cement and ash and their admixtures as stabilizer in improving their engineering strengths in terms of liquid limit, plastic limit and plasticity index. The Ashaka Cement Company (Lafarge-based cement) was used along with locally available lime in stores with relative density of 2.3 and pH 11-12 was used while the fly ash was obtained from Ashaka Cement Company Thermal Power section. Engineering properties (Liquid Limit, Plastic Limit and Plasticity Index) were determined from natural untreated soil and were compared to varying admixtures of the stabilizers.

Results and Discussion

Figs 2, 3 and 4 show graphs of effect of the various proportions of the admixtures on the engineering properties of the soil with respect to untreated soil plotted from Table 1. Liquid limit gently increases with increase in the various stabilizers and their admixtures, except fly ash that increases to 55% and decrease sharply to 50% (Fig. 2).

Fig. 3 shows the effect of admixture on plastic limit of the soil. The plastic limit steadily increase with increase lime, cement, lime + ash, cement + lime but sharply decreases above 2% of fly ash and fly ash + cement.

Plasticity index is the range of water content within which the soil exhibit plastic properties. It is the numerical difference between liquid limit and plastic limit. The plasticity index of the unstabilized soil is slightly above 12.0% and it continually increases to 20% at 10% fly ash content. Plasticity index of soil when lime is used increases from 4.5% to 7.5% for 2% to 10% increase of lime content. At 10% of lime content, plasticity index of the soil decreases from 3.3% to 1.9% for 2-8% increase in cement content. Plasticity index for cement + lime admixture increases and become 2.5% at 10% of their content. Plasticity index for fly ash + cement as an admixture decreases for 2-5% of their content and changes from 7.0% to 9.5% between 8% and 10.0% of their content.

Table 1: Average Atterberg Limits with Percentage Admixture

ADMIXTURE %		0	2	5	8	10
LIME	LL	36.5	37	39.5	46	50
	PL	25	32.5	34.5	37	42.5
	PI	11.5	4.5	5	9.0	7.5
CEMENT	LL	37	44.5	44	45	47
	PL	25	41.5	42	42.5	44.5
	PI	12.0	3.0	2	3.5	2.5
FLY ASH	LL	36.5	43.5	44	45	50
	PL	25	41.0	37	33	30
	PI	11.5	2.5	7.5	12	20
LIME FLY ASH	LL	37.5	46	48	49	50
	PL	25	40	42	46	46.5
	PI	12.5	6.0	6.5	3.0	3.5
CEMENT + LIME	LL	37.5	43	46	44.5	47
	PL	25.5	38	40.5	42	43
	PI	12.0	5.0	6.5	2.5	4.5
FLY ASH + CEMENT	LL	37.5	57.5	49	48	48.0
	PL	25.0	48	44.5	41	36.5
	PI	12.5	7.5	5.5	7	9.5

Liquid limit of soil is 36.5% and it continuously increases when lime, fly ash, lime + fly ash and cement + lime are used as admixture. The liquid limit of the soil increased at 2% cement content and reaches 47% at 10% of cement content. The liquid limit of soil for fly ash + cement increases from 37 to 52% at 2% admixture and then decreases with further quantity of admixture.

Plastic limit of soil continuously increase with increasing percentages of the admixtures. However, in the case of fly ash and fly ash + cement, there is regular decrease to about 42 and 48% at 2% admixture respectively. The plastic index of the soil is 12%. Fig. 4 shows the effect of admixture on plasticity index of the soil. Plasticity index of soil for fly ash continue to decrease to 2% at 2% fly ash. It then sharply increases to 21% between 2 and 10% fly ash. At 5% fly ash + cement admixture, the plasticity index increases from 5 to 12% at 10% fly ash + cement admixture.

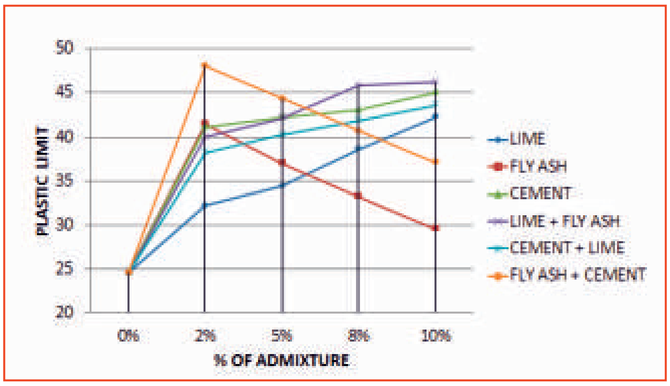

Fig. 2: Effect of Admixture on Plastic Limit of Soil

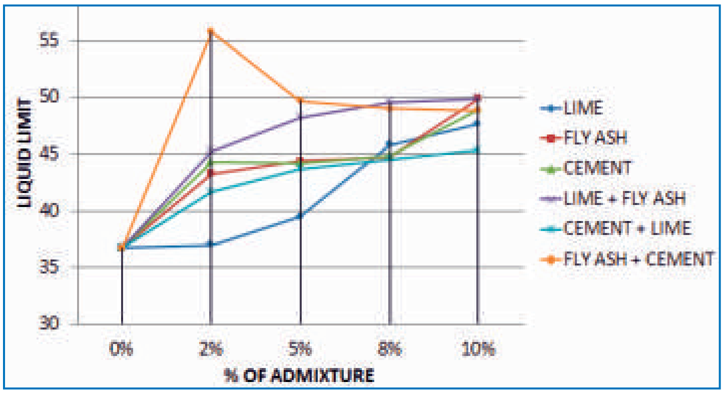

Fig. 3: Effect of Admixture on Liquid Limit of the Soil.

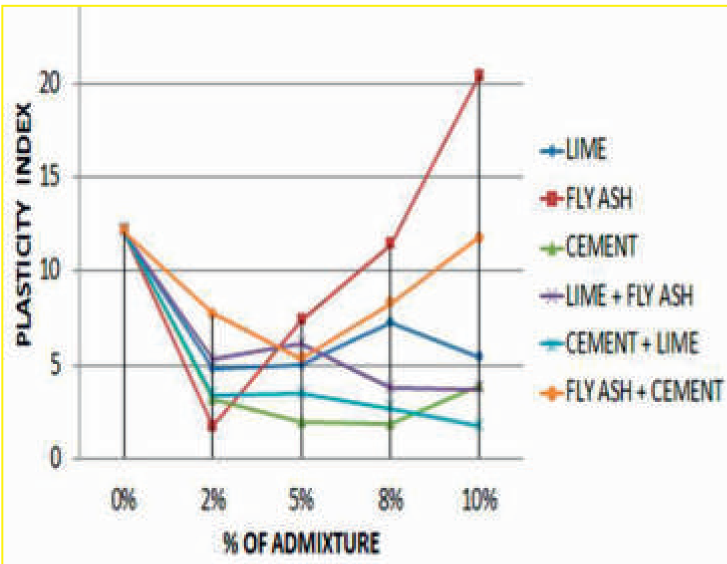

Fig. 4. Effect of Admixture on Plasticity Index of the Soil

Conclusion

Applications of untreated and treated soils for use as subgrade require determination of plasticity index. This study revealed considerable reduction of plasticity index for treated soils (2-3%). The reduction in the plasticity index values is attributed to adsorption of positive ions onto the clay particle surface which ultimately reduced repulsion between successive diffused double layer and enhanced edge to face contacts between successive clay sheets. Hence, compared to other stabilizers and their admixtures 5 to 8 % of cement content was found to be more effective in stabilizing the Kanawa soils.

Recomendation

It is recommended that a defined pedological map of Nigeria be produced to serve as a guide to Engineers, particularly in road construction.

References

Bassey. B.O; Nwachukwu, N.K and Bala, M.M. (2011) Stabilization of soft soils from Okigwe using granulated blast furnace slag and fly ash. (Unpublished) University of Nigeria Nssuka.

Chairman, J.H. (1998). Laterites in road pavements. Special publication by the construction industry research and information association. Storey Gate, London.

Reyment, R.A (1955). The Cretaceous Ammonoidea of southern Nigeria and the Southeastern Cameroons. Bulletin geological survey, Nigeria, 25: 1-112.

Wudda, E.M. (2014). Sedimentology and paleoenvironment of deposition of the DebaFulani member of the Pindiga formation around Kwodon-Kanawa area Upper Benue Trough.NE Nigeria. (Unpublished) Nasarawa State University, Keffi.

Zaboski. P.M, Ugodulunwa, F. A., Nnabo, P. and Ibe, K. (1998). Stratigrapgy and Structure of the Cretareous Gongola Basin, North Eastern Nigeria. Bulletin de Centres des Recherches Exploration Production elf-aquitaine, 21:153-186.

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Evaluation of Suitability of Rocks Using Volumetric Joint Count for Dimension Stone Quarry in Supare, Ondo State, Southwestern Nigeria

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Abstract

Fracture characterization of rocks in Supare, Ondo State, South western, Nigeria was examined in respect to their suitability for dimension stones. Detailed geological mapping of the area carried out on scale of 1:12,500 indicated that the dominant rocks are granite-gneiss followed by granite and migmatite. The principal joint direction trends NNE-SSW which also corresponds to the regional structural pattern of the area. The volumetric joint count for discontinuities was carried out via Scan Line mapping and values obtained from all examined outcrops ranges from 0.1 to 5.33m^{-3} with average spacing varies from 0.7 to 2.45m. The volumetric joint count revealed that most of outcrops have volumetric joint value less than 3.0 and can be exploited economically for dimension stone production with potential of producing medium block. A few of the granite gneiss recorded volumetric joint count less than 1.0 and have the potential of producing large block while a few of the granite outcrops have higher volumetric joint count greater than 3.0 and thus can be quarried as aggregates for construction use in building and road construction. It is suggested that the geologist and the mining engineers should take into cognizance the geological evaluation (joint density) as fundamental in prospecting and exploration for dimension stone quarry.

Keywords: Supare Southwestern Nigeria, Dimension Stone, Volumetric joint count.

Introduction

The term 'dimension stone' covers a wide variety of naturally occurring stone used for the external and internal decoration of buildings. They include limestone, marble, sandstone, gabbro, granite, serpentine, and gneiss (Smith, 1999). According to Dunda 2003, for a rock body to qualify as a deposit of dimension stone, the following criteria must be considered:

(i) Geological criteria (frequency and location of discontinuities, fracture/ joint density). (ii) Technical criteria (Physical and Mechanical properties of the rock).

(iii) Decorative criteria (colour, texture, mineralogy).

(iv)Technological criteria (workability of the rock mass processing which include cutting, polishing, grinding and carving.

Geological and geotechnical characterization of dimension stone are essential for construction industry and will help in selecting appropriate use of these building stone. The views of mining and civil engineers as well geologists on prospecting for suitable rocks for dimension stones have been studied. Saliu *et al*., 2012 showed the current technology and mechanization employed in blocking, that is exploiting and processing Nigerian granite measured up to the standard of the world most advanced countries. They inferred that granites processing industrially demands large block dimension, and the large block size production is being controlled and regulated by the natural fracture pattern of the outcrops intended to be used. Harrison and Hudson (2000) concluded that the characteristic of individual joints such as trace length, orientation, aperture, planarity, roughness, location are used in classification and grouping of joint and surface morphology. They revealed that, the most significant parameters for evaluating the geo-mechanical properties of rock mass are the joint trace length. Fracture network characterization, persistence of fractures and density are imperative in determining the in-situ block size distribution of granitic outcrops, using either numerical or empirical methods (Sousa, 2007). The volumetric joint density (J_v), joints spacing (S_n) and block volume methods are typical examples of empirical methods. Volumetric joint density is a parameter recommended for evaluating and assessing block sizes (International Society of Rock Mechanics, 1981).It is a measure of joints intersecting a volume of rock mass. It is defined as number of joints per m^3. Loudes *et al.,* 2000 recommended (2.4m x 1.3m x 0.7m) at least as for a block size. It is also observed that the surface area of a block which is formed by interception of the sub-vertical fracture, for commercial block exploitation must be at least $2m^2$. Priest and Hudson (1981) studied the probable means used for fracture measurement which include drill hole method, geophysical acoustic method, and surface exposure method which include both hand mapping and more recent application of remote methods such as photogrammetry.

An integration of both scan line and window mapping are appropriate for dimension stone prospection, evaluation and exploitation where detailed fracture characterization is a requirement for in-situ block size assessment (Palmstrom, 2005). Joint set spacing is the distance between individual joint within a joint set. The joint spacing and average joint spacing are frequently used in the assessments, evaluation and description of rock masses.

The volumetric joint density (J_v) as termed by Palmstrom (1986) and Sen and Eissa (1991) can be analysed from the joint set spacing within a volume of rock mass as given in equation(I):

$$Jv = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + ---- \quad \ldots(1)$$

where S_1, S_2 and S_3 are joint set spacing.

In addition, random joint can be included by assuming a random spacing (Sr) for each of these. According to Palmstrom (1985), experience has indicated that this can be set to Sr = 5m; thus, the volumetric joint count can be expressed generally as

$$Jv = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + ---- + \frac{N_r}{5} \quad \ldots(2)$$

In this case Nr = number of random joints. Mathematically, Jv can be easily measure from common joint observations, since it is a function of measurements of joints set spacing or frequencies. In an event where many irregular or random joint occur, Jv can be calculated by counting all joints observed in an area of known size.

Physiography of the Study Area

The study territory has a low and high relief with elevations ranges between 300m – 500m. In the south western part is a river that is ephemeral as it flows during the raining season and dries up during the dry season. There are two major rivers in this location namely River Omi-oruwe and River Akure, both characterized with different distributaries.

Land Use

The Low-lying terrains of the study area are cultivated for farming yam, corn and cocoa in a very large scale. A mechanized active dimension stone quarry (Sutol Crushed Rock quarry, Supare) is situated to south west central area along Supare- Emure road to the west. Supare covers hectares of land that is divided into different land use categories like government, educational, industrial and institution. Supare central part is densely populated with its inhabitant engaging in subsistence farming and petty trade.

Geology and location of the Study Area

The study area lies between latitude 7°27' – 7°29' N and longitude 5°40' – 5°42' E on Owo sheet 265 NW. The area was mapped on a scale of 1:12500. It covers an estimate of area of about $13.4km^2$. Supare Akoko lies within the undifferentiated migmatite-gneiss complex of Nigeria Basement rock as classified by Rahaman (1973) and these accounts for over 99% of the basement rock in the terrain. The area is accessible through good road network that passes through the area in the east-west direction running from Akungba Akoko (in the east) and Emure (in the west). This area is dominated by three rock type: granite-gneiss, granite and migmatite. The geological map is shown on figure 1.

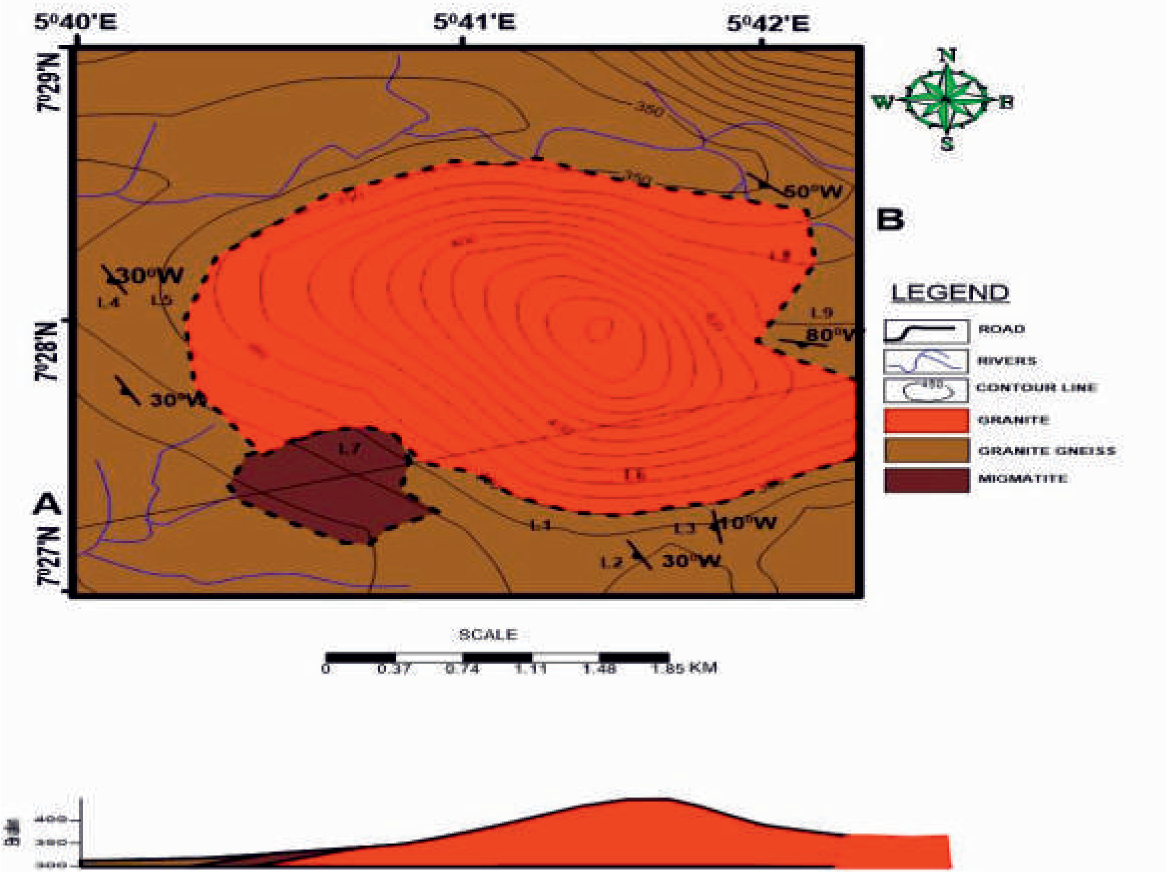

Figure 1: Geological map of the area of study

Materials and Methods

Structural analysis investigation was carried out to select more desirable outcrops for dimension stone quarry development. Orientations of the joint set were determined using compass clinometer. Quantifications of fracture pattern of rocks were examined to describe the block size distribution characteristics. Rock samples were obtained from the field with the use of geological hammer. The coordinate of the sample location was obtained using global positioning system (GPS) and measuring tape. Scan line mapping was carried out by the use of measuring tape between 20-30 metres length, tensioned at two places and laid on the rock face. Among the features for each discontinuity documented are:

(i) The scan line distance to the point at which the fracture intersects the scan line
(ii) Strike and dip direction
(iii) Trace length of the fracture
(iv) Number of the end point of the fracture observed on the face.

Result and Discussion

Field Observation

In Supare persistence joint is dominant and 60% for joint spacing are more than 1.5 meters. This spacing would produce in-situ block size distribution that can yield block commercially (Sousa, 2007). The joints, elevation and GPS readings are presented on table 1while table 2A is a General Discontinuities Properties of the Selected Rocks. Tables 2B and 2C contain the Mean Joint Spacing(S)m of Rocks and Joint Orientation Summary of Rocks $(000/00)^0$ respectively.

Table 1: Summary of Elevation and GPS Reading of Sample Points

S/N0	Location (L)	Rock Type	Longitude (E)	Latitude (N)	Elevation (m)
1.	L1	Granite gneiss	005°41'16.8"	07°27'14.4"	355
2.	L2	Granite gneiss	005°41'34.8"	07°27'03.6"	362
3.	L3	Granite gneiss	005°41'42.0"	07°27'14.4"	388
4.	L4	Granite gneiss	005°40'04.8"	07°28'01.4"	369
5.	L5	Granite	005°40'15.6"	07°28'01.2"	388
6.	L6	Granite gneiss	005°41'45.6"	07°27'25.2"	382
7.	L7	Migmatite	005°40'48.0"	07°27'32.4"	348
8.	L8	Granite	005°42'03.6"	07°28'15.4"	348
9.	L9	Granite gneiss	005°42'10.8"	07°28'04.8"	349

Table 2A: General Discontinuities Properties of the Selected Rocks

S/No	Sample Location	Scan Line Length (m)	Volumetric Joint count (joint/m3)
1	L1	21	1.85
2	L2	20	1.3
3	L3	20	3.92
4	L4	25	0.1
5	L5	20	2.39
6	L6	20	5.33
7	L7	20	2.45
8	L8	20	4.3
9	L9	21	2.45

Table 2B: Mean Joint Spacing(S)m of Rocks Under Study

Location	L1	L2	L3	L4	L5	L6	L7	L8	L9
	2.7	1.97	1.0	11.0	0.97	1.2	1.7	1.15	1.80
	1.60	3.70	1.24	-	2.10	0.73	1.64	1.23	1.34
	2.83	1.57	0.83	-	2.15	0.75	1.84	1.04	1.57
	2.0	-	1.10	-	2.45	0.84	1.67	1.67	2.0

Table 2C: Joint Orientation Summary of Rocks Under study $(000/00)^0$

Location	L1	L2	L3	L4	L5	L6	L7	L8	L9
Strike	010	172	185	290	050	190	058	081	010
Dip	40	60	18	36	44	10	47	40	80
Strike	070	170	188	-	058	030	240	010	070
Dip	40	76	38	-	40	50	10	18	70
Strike	050	268	190	-	250	350	030	062	080
Dip	30	80	70	-	53	28	10	65	36

Structural geology

The observed structural features such as joints, faults and foliation were measured using compass clinometer and the data obtained were used to plot a rosette diagram for the area using rock-works software (2006 version) as shown in figure 2. The rossette diagram revealed the structural configuration of the study area which is useful in mineral prospection, exploration and exploitation. It also indicates the zone of weakness for the rocks intended for use as dimension stones. The principal joint direction in the area is NNE-SSW (Fig. 2), which conforms to the dominant structural deformation of the outcrops in the study area due to tectonic movement. From the rosette diagram (Fig 2), the highest fracturing was along NNE-SSW which also corresponds to the regional structural pattern of the area. It implies that the orogenic and epirogenic forces acted on the rock in the area along NNE-SSW axis.

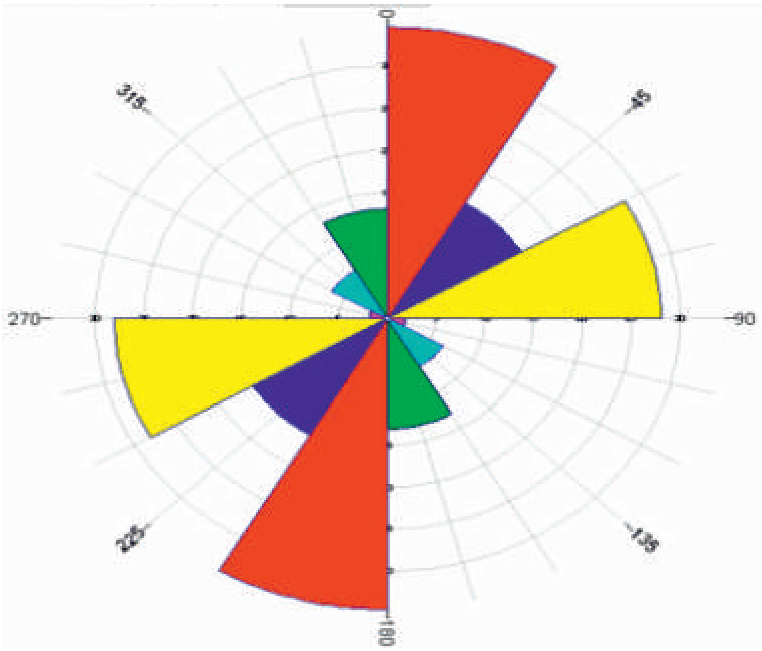

Figure 2: Rosette diagram of the Study Area

Volumetric Joint Density/ Count

The Volumetric joint counts were acquired via fracture network characterization for the nine outcrops under consideration to identify suitable outcrops for dimension stone production. The results as shown in Table 2 show that locations L1, L2, L4, L7 and L9 have a Jv, value less than 3.0. This agree with earlier works of Elci and Turk (2014) that any outcrop that would be economically exploited for dimension stone production must have a Jv, value less than 3.0. Location L3 falls in the boundary zone, which implies that caution should be taken in exploring this granite gneiss for commercial blocks as it could render the outcrop uneconomical for commercial block production. The values of Location 6 and 8 exceeded the recommended limit of 3.0 therefore cannot be considered for dimension stone production. The volumetric joint count (Jv), of L4 is less than 1.0, implying it has the potential of producing large block while other outcrops fall within the third category of description of blocks, which indicated that they have the potential of producing medium blocks as proposed by ISRM in (Sousa, 2010). The relationship between calculated volumetric joint counts and their respective outcrops are represented in Figure 3.

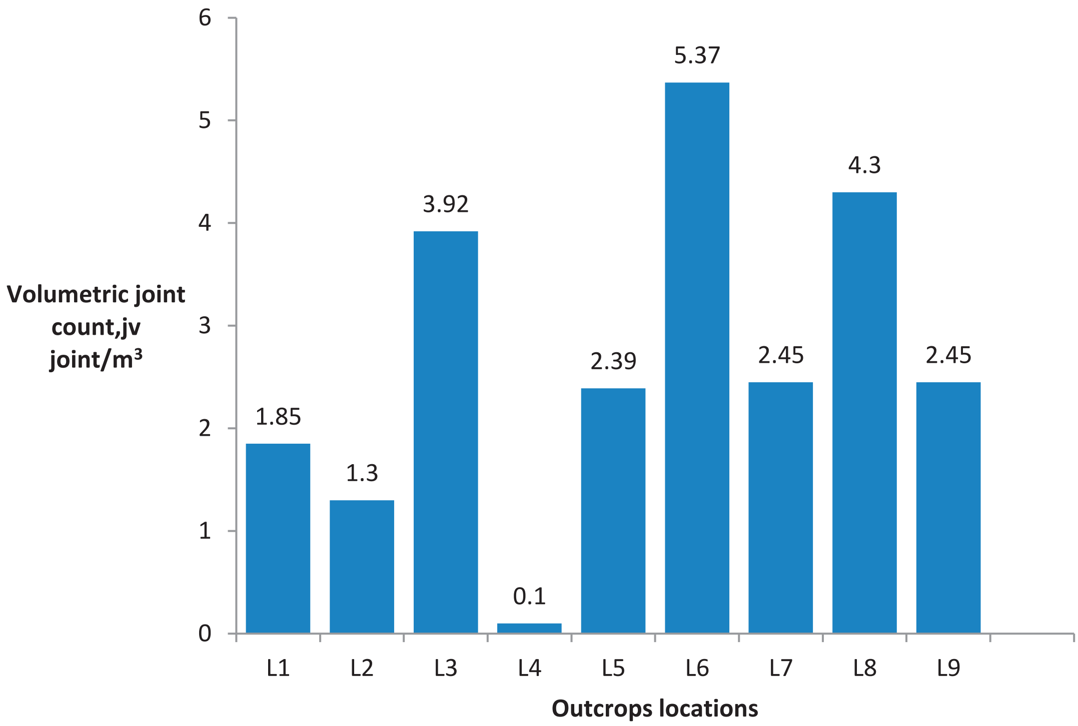

Figure 3: volumetric joint counts of selected outcrops

Conclusion and Recommendations

Conclusion

Geological parameters, mechanical and physical properties are the controlling factors in the classification of dimension stone. Geological mapping as well as various outcrops assessed indicates that the area explored is underlain by medium to coarse grained granite, granite-gneiss and migmatite with granite-gneiss dominating the study area. The results revealed that outcrops with higher volumetric joint count greater than 3.0 have low recovery potential. Location L1, L2, L4, L5 L7 as well as L9 have volumetric joint count values ranging from 0.1-2.45 m^{-3} which is closer to maximum recovery value of 3.0, thereby indicating that they can be economically exploited for dimension stone production and with the potential of producing medium blocks except for L4 outcrop with less than 1.0 Jv that has the potential of producing very large block. However, Location L3, L6 and L8 could be regarded as aggregates stone deposit and thus be quarried for constructional work and common use.

Recommendation

Mining, Building, Structural and Civil Engineers should not only dwell with geotechnical assessment of rocks as the only determinant in the selection and production of dimension stones but should take into cognizance the geological evaluation (joint density) as fundamental in prospecting for suitable outcrops for dimension stone quarry.

This is imperative because the economic feasibility of a quarry depends on the block size production of the quarry. However, it is needful that all stakeholders and stone merchant should know the importance and the unique properties of natural stone when selecting dimension stones as a component in a building system, hence involvement of professionals from prospecting stage to completion should be given priority so as to obliterate completely the shortcomings quacks.

References

Daunda, S., Kujundzic, T. (2003). Digital Textbook; *The Exploitation of Dimension Stone,* Faculty of Mining, Geology and Petroleum Engineering, Zagreb.

Elci, H, and Turk N. (2014). Rock mass block quality designation for marble production International *Journal of Rock Mechanics and Mining Sciences* 69, (2014), pp 26-30.

Harisson, J. P., & Hudson,J.A.(2000). Engineering Rock Mechanics. *An Introduction to the Pprinciple*.Elsevier.

ISRM "Suggested Methods. Commissioning on Testing Methods International Society for Rock Mechanics (ISRM), pp. 75-105, 1981, Pergamon Press, Oxford, UK.

Loudes, H. S, Selonen, O., & Ehlers. C. (2000). Evaluation of Dimension Stone in Gneissic Rock-a Case History from Southern Finland. *Engineering Geology* 58(2), 209-223.

Palmstrom, A (1985). Rmi-A Rock Mass Characterization System for Rock Engineering Purposes. Phd Thesis University of Oslo, Norway. pp 409.

Palmstrom, A. (1982). The Volumetric Joint Count. A Useful and Simple Measure of the Degree of Jointing. *Proc.Int.Congr.IAEG*. New Delhi. Pp.221-228.

Palmstrom, A. (2005). Measurement of and Correlation between block size and rock quality designation (RQD). Tunneling and Underground Space Technology, 20, 362-377.

Priest, S. D., & Hudson, J. A. (1981). Estimation of Discontinuity Spacing and Trace Length using Scan line Survey. *International Journal of Rock Mechanics and Mining Science & Geomechanics Abstracts.* 18(3), 183-197.

Rahaman, M. A. (1973). The Geology of the District around Iseyin Western State of Nigeria, *Phd. Thesis*, University of Ibadan (unpublished), pp 268.

Saliu, M. A., Olaleye, B. M., Hallem, J. O. (2012). Modified Volumetric Joint Count to check for Suitability of Granite Outcrops for Dimension Stone Production. *Journal of Engineering Science and Technology*, 7(5), 646-660.

Sen Z., and Eissa E .A. (1992). *Volumetric rock quality designation*. J Geotecch. Engn., Vol 117, No 9, 1991, pp 1331-1346.

Smth, M.R., Stone: Building stone rock fill and armour stone in construction. *Geological Society Engineering*, Geology special publication No .16.1999.

Sousa, L. M. O. (2007). Granite Fracture Index to check Suitability of Granite Outcrops for Quarrying. Engineering Geology, 92(3-4), 146-159.

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Strategic Equipment Maintenance Management in A Medium Scale Quarry, Ogun State, Nigeria.

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Abstract
Poor performance of granite aggregate quarries is a big challenge to the mineral industry in Nigeria. It threatens the future prosperity of the industry and granite aggregate supply to meet the ever increasing demand for infrastructural development projects. One major factor impacting on the reliability of quarries is the maintenance management system of the quarry equipment. This paper presents the present situation on equipment maintenance management system of Geoworld quarry in Ogun State, Nigeria. Maintenance management audit of the quarry was carried out through questionnaires with respect to five basic elements of maintenance management system (resource management, information management, preventive maintenance and equipment technology, planning and scheduling and maintenance support). 'SWOT Clock' Strategic Behaviour Model was adapted to suggest a rationalistic typology for the quarry management in considering the quarry's strategic direction on equipment maintenance based on the interaction between the quarry's capabilities and resources from the view point of strengths and weaknesses (SW) and between the opportunities and threats (OT) identified in the quarry's environment. Findings show that improvement strategies adopted will impart positively on the areas of deficiencies of the quarry by moving it from state of survival to growth.

Key words: strategic behavior, SWOT clock, maintenance management.

1.0 Introduction

Easy money is gone and quarry managers now worry about how to stay competitive in the new global economy that has emerged. It is time for quarries to concentrate on their core business, squeeze out the waste and differentiate themselves from their competitors in meaningful ways. It is becoming clear that there is no one best way of doing anything, whether it's selection of equipment or their maintenance management. The best way to operate depends critically on the characteristics and capabilities of the quarry and the competitive context in which it finds itself.

In order to benefit from the changing conditions, a quarry has to adopt a strategy for improvement that fits the specific needs of the quarry at that point in time in its life. Slow and steady improvement is appropriate in some situations; attempt at dramatic breakthroughs through process reengineering are appropriate in others. Moreover, different improvements require different resources, management styles, and support structures.

Quarries need to ask and then answer the question “what is our business?'. Addressing this question is the single, most important step in crafting a corporate business strategy. The quarry must clearly understand not only who are its customers and its competitors, but also what it sees as its competitive advantage. It must clearly identify its key business strategies. However, it is not just individual strategies in isolation, but the combination of the individual business strategies that, when combined, produces the quarry's overall competitive strategy.

A Quarry must decide which competencies and organizational context it must develop to help implement its strategy. Even after deciding on the competencies, culture, structure and incentives that are needed, the quarry still needs to harmonize them together in such a way that, on one hand they support and complement each other and on the other hand they collectively support and promote the chosen strategy.

One competency that must be developed by all quarries is the maintenance management function. Khan and Darrab (2010) reported that the purpose of maintenance is not only to upkeep the plant machinery and equipment preventing them from failures and breakdowns, increasing reliability, maintainability, and availability of the operating system for maximizing production, but also to improve quality and boost higher productivity through improving capacity, faster and more dependable throughput, reducing inventory, and lowering operating cost. A research in maintenance in Nigerian industries (Eti et al, 2004) shows that maintenance is not given a high priority, hence plants are often underutilized and run at high costs. Alsyouf (2006) showed in a case study that at least 14% of potential improvement in return on investment are directed to contribution of maintenance functions to lost profit, which is due to unplanned stoppages and bad quality caused by maintenance related problems. Blanchard (2004) demonstrated that a large percentage (e.g. 70% for some systems) of total life cycle cost for a given system is attributed to operating and maintenance activities. Maintenance management have been grouped into five key areas; resource management that deals with how adequate is maintenance staffing, their skill, remuneration and motivation; information management which determines kinds of maintenance records kept in the quarry, their applications for evaluating key performance indicators(KPIs) and their influence on management's decisions; preventive maintenance and equipment technology assess the level of mechanization in the quarry and adoption of appropriate preventive and predictive maintenance effort; planning and scheduling measures adequate planning and scheduling compliance before any major maintenance work is carried out; and maintenance support determine the level of spare parts inventory kept in the quarry and the relationship between the quarry management and the original equipment manufacturers or their agents.

This study involves maintenance management audit of Geoworld quarry, this quarry is located in Obafemi- Owode local government area of Ogun State with GPS coordinates, N07º 07' 25", E003º 37' 46". Over the years, Geoworld quarry have continued to experience operating costs that are far in excess of what was estimated in their feasibility study report. The poor performances have been pinned to equipment maintenance management problems. Deficient maintenance practices have continued to affect productivity and profitability. This paper is therefore aimed at identifying the maintenance management challenges of Geoworld quarry with the view to provide strategic directions on equipment maintenance management for optimal productivity.

2.0 The Theory and Application of SWOT (Strenght, Weakness, Opportunity and Threat) Clock Strategic Behaviour Model

The SWOT Clock model proposes a strategic formula which relates Leading Strategy (LS) as dependent variable with Weighted Power Intensity (WPI) as independent variable. The clock behaviour reflects the effected change of the LS pointer over the time series scale factor. The CLOCK model offers a series of steps and principles in consolidating a strategy:

2.1 Principle no. 1 - The Generic Integrated Behaviour

There is a generic behaviour, reflecting the interaction between 'quarries and their environment,' that depict situation in which more opportunities can be seen than threats; more strength can be seen than weaknesses; and vice versa.

2.2 Principle no. 2 - Defining the Independent Variables to Calculate the Intensity of Power

The power intensity of the four variables (Opportunities, Threats, Strengths and Weaknesses) was evaluated by using a matrix that is based on the following components:

I. **Influencing Factor (IF):** The factor according to which the characteristics of a quarry and/or its environment are analyzed. The list includes factors that in the management and decision makers' view influence the quarry's level of power ('weaknesses', 'strengths') and environmental forces ('opportunities', 'threats'). In general, these factors reflect the perception of the quarry's stakeholders. This is also expressed in the studies by Bernroider (2002); and Lee and On Ko (2000). Establishment of the “IF” was done by the Delphi approach which reflects individual management perception. After establishment, the list of Influencing Factor is kept constant in the CLOCK strategy formula.

ii. **Relative Weight (RW) of the influencing factor:** The importance and influence of any factor that the quarry considers to be important in determining and consolidating its strategy. Deciding on the relative weight of the influencing factor is one of the greatest difficulties in applying the SWOT approach. Wheelen and Hunger (2011), suggest assigning a relative weight to the influencing factor in a subjective and arbitrary manner, on condition that the total sum of the relative weight of all the factors equals to 100%. In this way, it was possible to offset the influence of bias in the final result. The CLOCK model keeps the Relative Weight as a constant value in the strategy formula.

iii. **A quantitative, Objective Measuring Scale index:** A measurable index representing the factor's quantitative value. The index was determined according to the characteristic represented by the factor. For example, the resource management (%) was determined according to the level of maintenance resources i.e. labour, material and cost. Planning and Scheduling (%) reflects the level of efficiency in maintenance job scheduling, and market demand (%) reflects the level of patronage, and so on.

iv. **Relative Intensity (RI) positioning index:** Each IF was positioned according to three levels of an Interval Scale: level 3 reflects High position, level 2, Medium position, and level 1, Low position.

v. **Weighted Intensity (WI):** The weighted intensity represents the contribution of each factor to the total power intensity of each of the SWOT variables, calculated as the multiplication of the Relative Intensity (RI) and its Relative Weight (RW) determined according to the current positioning of the appropriate quantitative measuring index.

vi. **Weighted Power Intensity (WPI):** Reflects the total intensity of all the factors positioned in each of the SWOT variables, and is calculated as the total sum of the Weighted Intensity of those factors.

2.3 Principle no. 3 - Developing a WPI matrix for the environment and the quarries

Two matrixes of identical structure exist, one for the quarry environment (external factor) and the other for the quarry's maintenance management (internal factor). Using these matrices, the power intensity was quantitatively calculated for the four SWOT variables.

2.4 Principle no. 4 - Consolidating the 'Leading Strategy' (LS) direction

Four generic strategic directions exist, resulting from the simultaneous integration of the Weighted Power Intensity of the two external factors ('opportunities,' 'threats') with the two internal factors ('strengths,' 'weaknesses'), which were defined as follows:

i. **Growth (S+O):** a situation in which the WPI of 'opportunities' is larger than the WPI of 'threats' and that of 'strengths' is larger than that of 'weaknesses.' The Growth strategy can inform local production of items/wearable parts; commercialization of workshop i.e. turner shop; contract maintenance services to other quarries and so on.

ii. **Leverage (W+O):** a situation in which the WPI of 'opportunities' is larger than the WPI of 'threats' and that of 'weaknesses' is larger than that of 'strengths.' This situation calls for the Leverage strategy. This strategy could be applied in the directions of developing human resources (i.e. maintenance crew skill upgrade through training); investments in infrastructure and equipment (investment in maintenance facilities such as crane, hyab, mobile service vehicle, turning machine, etc.); developing business units; developing and encouraging innovativeness and creativity; and so on.

iii. **Response (S+T):** a situation in which the WPI of 'threats' is larger than the power intensity of 'opportunities' and that of 'strengths' is larger than that of 'weaknesses.' Therefore, the Response strategy employs 'strengths' to push away the 'threats'. This strategy could be applied and used by cooperation with another similar quarry for maintenance assistance; focusing and differentiating (plan production base on maintenance requirement, for example, a quarry can work five days per week and spend one and half days for maintenance of equipment depending on the criticality of maintenance problems); performance improvement; enhanced human resources motivation (adequate payment of overtime allowance to maintenance crew); and so on.

iv. **Survival (W+T):** a situation in which the WPI of 'threats' is larger than the power intensity of 'opportunities' and that of 'weaknesses' is larger than that of 'strengths'. The Survival strategy reflects the quarry's struggle to maintain its continued existence as a 'living body.' In this kind of strategy, action and application modes could include Design out i.e. Re-engineering the facility by disposing off the problematic equipment and acquiring a better facility that the quarry can afford at that time; vertical integration by the buyer (trade- off facilities by giving out weak equipment) to acquire better equipment from the manufacturer/ vendor; stood offs; and so on.

Thus, the CLOCK strategy formula can be defined as:

$$LS = f(WPI) = f(IF, RW, WI) \quad \ldots(1)$$

The positioning of the Weighted Power Intensity of each SWOT variable in the SWOT CLOCK Diamond Behaviour Model reflects the quarry's Leading Strategy (LS). Placing the values of the Weighted Power Intensity of each variable creates four triangles. Each triangle represents a combination of an external (environmental) variable with an internal variable of the quarry on the corresponding quadrate. Four possible strategies simultaneously at a certain moment in time are created, Growth, Response, Survival and Leverage. Intuitively, the Leading Strategy is determined by the largest triangle in size, out of all the possible strategy triangles.

2.5 Principle No. 5- 'The Strategic pointer'

The strategic pointer (henceforth, 'POINTER') points to the strategic direction that was determined by an analysis of the current position. The 'POINTER' is the weighted vector of the four SWOT forces, each having a direction and intensity. Vector diagram was drawn by using the WPI of 'strengths' drawn vertically allocated upwards. Then, the allocation of the WPI of 'opportunity' continued horizontally to the left. From this point, the WPI of 'weaknesses' continued to be allocated downwards, and finally, the WPI of 'threats' was allocated to the right. The 'POINTER' vector position was indicated accordingly (in red color) in any of the strategy quadrate (depending on the vector diagram). It is important to note here that, the pointer's positioning is momentary.

3.0 Methodology

This study involves maintenance management audit of Geoworld quarry using questionnaires and interviews. The questionnaire survey was administered to quarry staff including operation and maintenance (O&M) managers, and maintenance technicians. Out of the 30 questionnaires administered in the studied quarry, approximately 80% were returned. This questionnaire addresses questions in five key maintenance areas; resource management, information management, preventive maintenance and equipment technology, planning and scheduling, and maintenance support. Furthermore, the current maintenance practices were explored through interview and their responses / submissions were rated subjectively as: below average; average; and above average with credit points 1, 2, and 3 respectively. The data collected were presented using MS Excel software. 'SWOT Clock' Strategic Behavior Model was adapted to suggest a rationalistic typology for managers and decision makers in considering the quarry's strategic direction on equipment maintenance. The model examined the interaction between the quarry's capabilities and resources from the view point of strengths and weaknesses (SW) and between the opportunities and threats (OT) identified in the quarry environment. The external analysis of the environmental forces focused on identifying opportunities and threats created by the business environment; and internal analysis that is analyzing the quarry's internal forces focused on positioning resources (tangible) and capacities (intangible) from the view point of its strengths and weaknesses, in an effort to adopt appropriate maintenance strategy.

4.0 RESULTS

This section presents the SWOT analysis and SWOT clock behavior model of present and future situations for the studied quarry.

4.1 SWOT Analysis of Present Situation in Geoworld Quarry

The SWOT analysis of the present situation in the studied quarry explains the effects of internal and external factors on the successful maintenance management of the quarry's equipment as shown in Tables 1 and 2. From the Tables, vector diagram and SWOT Clock were drawn as represented in Figures 1 and 2.

Table 1: Matrix for the Intensity of Geoworld Quarry's Strengths and Weaknesses

Matrix of Geoworld Quarry's Power Intensity							
Internal Influencing Factor (Maintenance Management)	**Relative Weight (100%)**	**Power Intensity of 'Strengths'**			**Power Intensity of 'Weaknesses'**		
		1	2	3	1	2	3
Resource Management	15				1		
Information Management	10					2	
Preventive Maintenance	20					2	
Planning and Scheduling	15					2	
Maintenance Support	15	1					
Plant and Equipment Technology	25		2				
TOTAL	100	15	50	0	15	90	0
	Weighted Power Intensity	65			105		

Table 2: Matrix for the Intensity of Geoworld Quarry's Opportunities and Threats

Matrix of the Quarry Environment Power Intensity							
External Influencing factor(Environment)	**Relative Weight (100%)**	**Power Intensity of 'Opportunities'**			**Power Intensity of 'Threats'**		
		1	2	3	1	2	3
Market Demand	25					2	
Government Agency Regulatory Compliance	15					2	
Effect of weather	25					2	
External Maintenance Relationship	35		2				
TOTAL	100	0	70	0	0	130	0
	Weighted Power Intensity	70			130		

Table 3: Summary of the Weighted Power Intensity of the variables in the CLOCK model for Geoworld Quarry

Strength Intensity	Opportunity Intensity	Weakness Intensity	Threat Intensity
S	O	W	T
65	70	105	130

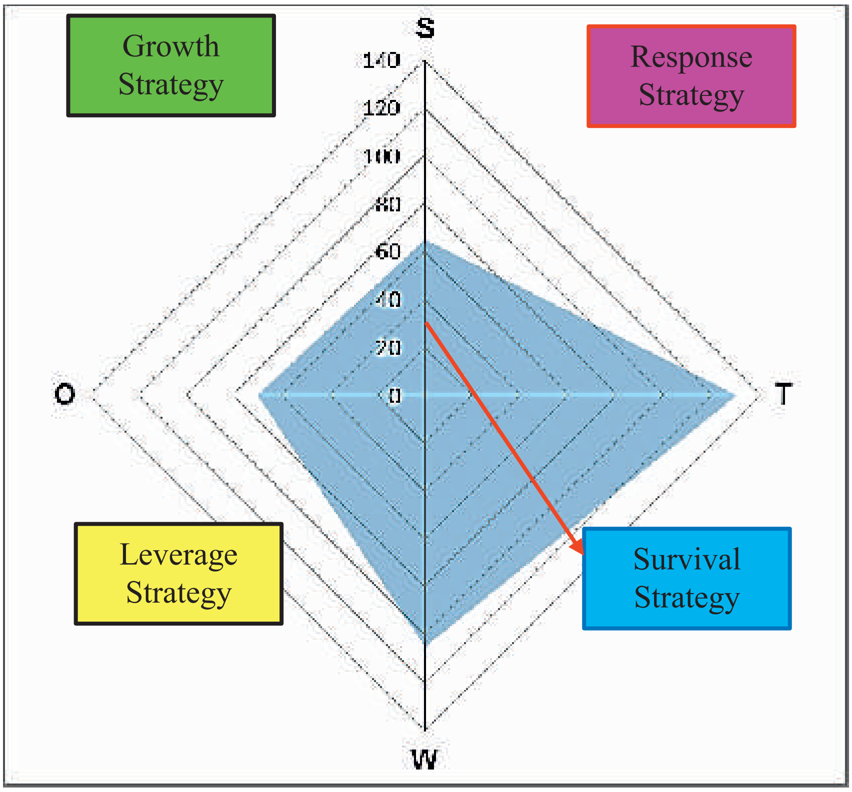

Figure 1: SWOT Clock Diamond Behaviour model for Geoworld Quarry

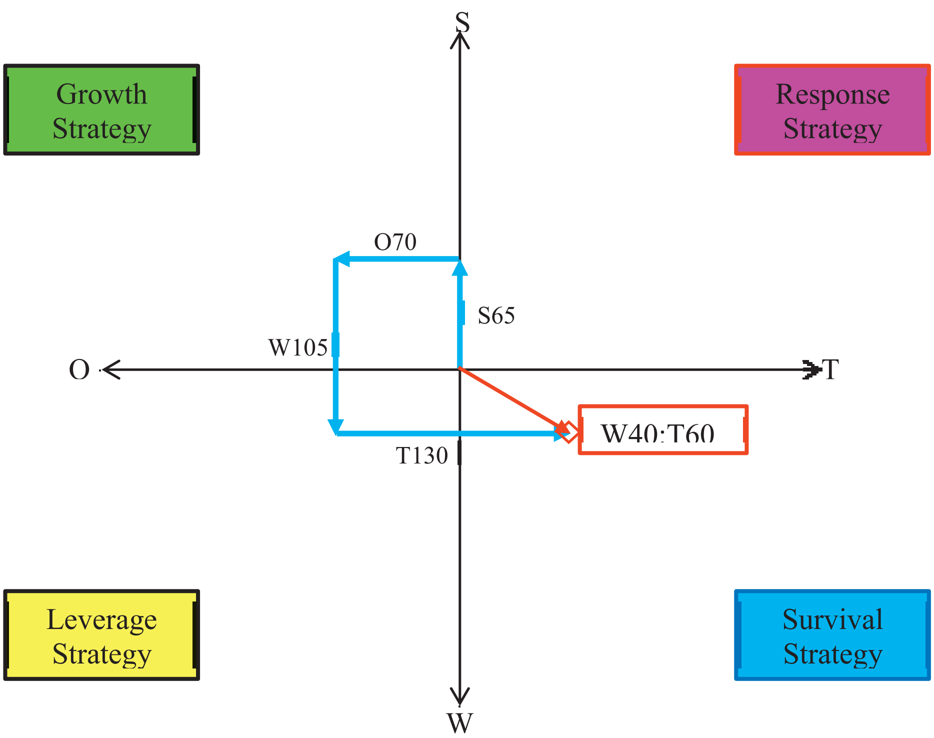

Figure 2: POINTER Strategic Position for Geoworld Quarry

4.2 SWOT Analysis of Future Situation in Geoworld Quarry

The SWOT analysis of the future situation in the quarry shows an improvement design strategies for future operations in the quarry. This improvement design explains the effects of internal and external factors on the successful maintenance management of the quarry's equipment.

In future, it is expected that the management of Geoworld quarry would increase their understandings of the nature of failures associated with their equipment. As such there will be no variations in the relative weight (RW) of the internal influencing factors (IF), rather we envisage their power intensities (PI) to respond to management strategic improvements due to years of practice/ operations. However, changes in Government policies regarding mineral industry and economic situation of the country will certainly cause variations in the external influencing factors (IF) and their relative weight (RW). For the purpose of this evaluation, we assume drop in market demand for quarry products and a strict enforcement of environmental regulation. These changes will affect the relative weight of market demand from 25 to 15 and relative weight of regulatory compliance from 15 to 25, as shown in Tables 4 and 5.

The corresponding strategic decision directions are represented by the SWOT clock and vector diagram shown in Figures 3 and 4.

Table 4: Matrix for calculating the Intensity of Geoworld Quarry's Future Strengths and Weaknesses

Matrix of Geoworld Quarry's Power Intensity							
Internal Influencing Factor (Maintenance Management)	**Relative Weight (100%)**	**Power Intensity of 'Strengths'**			**Power Intensity of 'Weaknesses'**		
		1	2	3	1	2	3
Resource Management	15	1					
Information Management	10	1					
Preventive Maintenance	20	1					
Planning and Scheduling	15	1					
Maintenance Support	15		2				
Plant and Equipment Technology	25				1		
TOTAL	100	60	30	-	25	-	-
	Weighted Power Intensity	90			25		

Table 5: Matrix for the Intensity of Geoworld Quarry's Future Opportunities and Threats

Matrix Of The Quarry Environment Power Intensity							
External Influencing factor(Environment)	**Relative Weight (100%)**	**Power Intensity of 'Opportunities'**			**Power Intensity of 'Threats'**		
		1	2	3	1	2	3
Market Demand	15	1					
Government Agency Regulatory Compliance	25	1					
Effect of weather	25					2	
External Maintenance Relationship	35		2				
TOTAL	100	40	70	-	-	50	-
	Weighted Power Intensity	110			50		

Table 6: Summary of the Future Weighted Power Intensity of the variables in the CLOCK model for Geoworld Quarry

Strength Intensity	Opportunity Intensity	Weakness Intensity	Threat Intensity
S	O	W	T
90	110	25	50

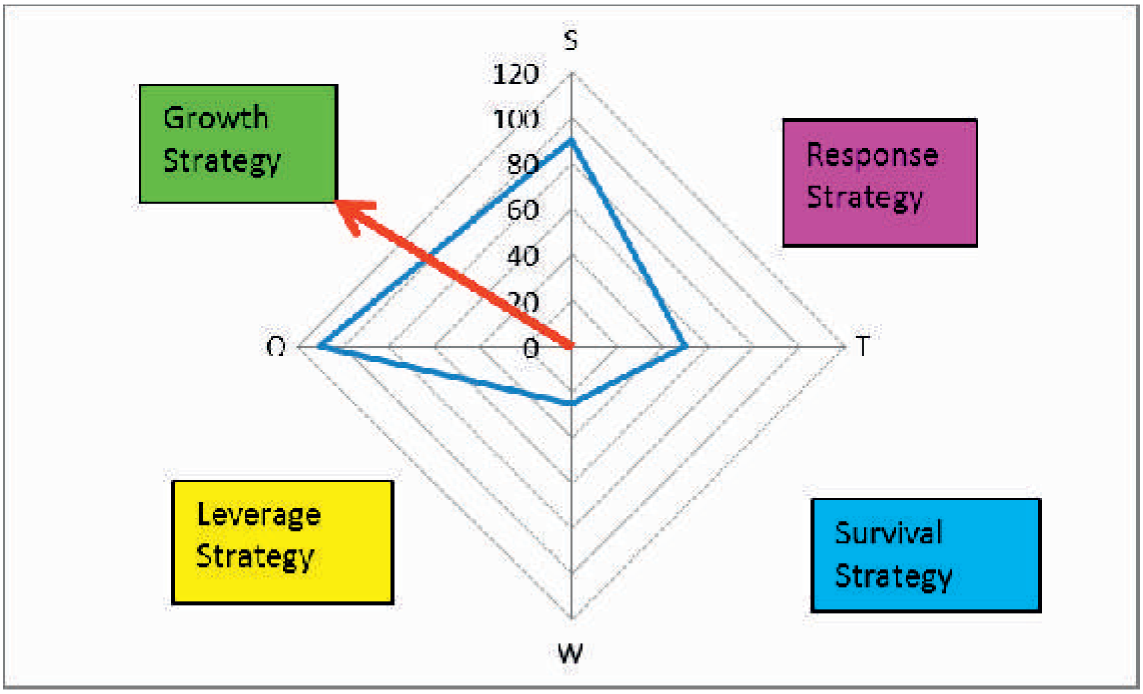

Figure 3: SWOT Clock Diamond Behaviour model for Geoworld Quarry

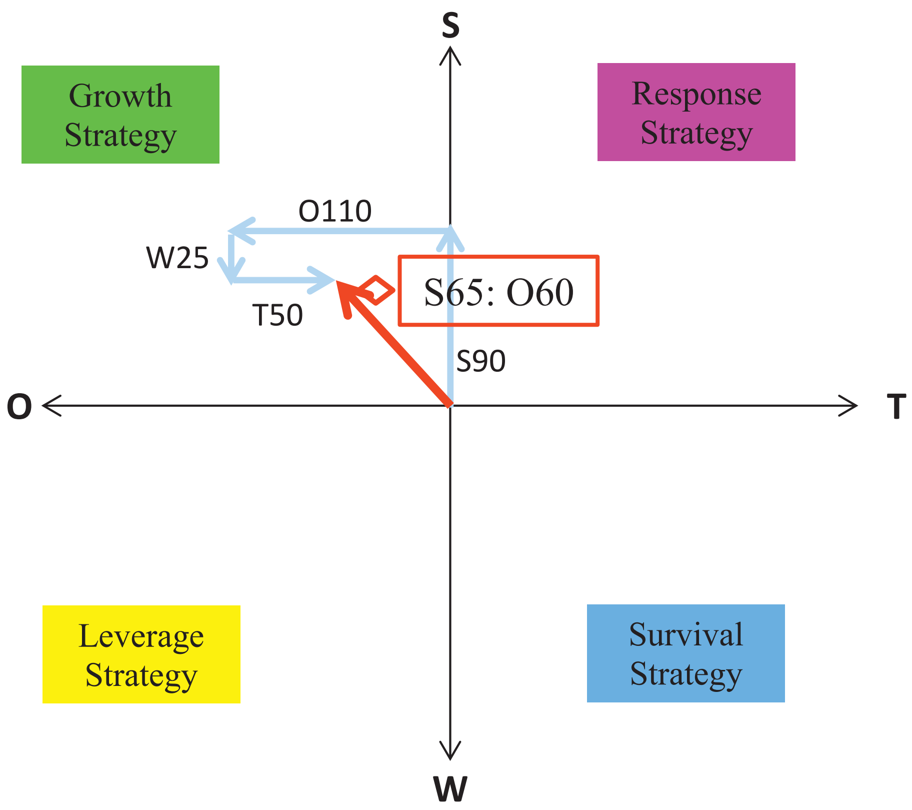

Figure 4: POINTER Strategic Position for Geoworld Quarry

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5.0 DISCUSSION OF RESULTS

The SWOT analysis of the present situation in Geoworld quarry was carried out to evaluate the effects of internal and external factors on the successful running of the quarry as shown in Tables 1 – 3. Five maintenance management factors that will enhance the availability and utilization of equipment in the quarry have been evaluated based on presumed weighted factors of criticality. External factors that provide opportunities or threaten the operation of the quarry have equally been rated accordingly.

The positioning of the Weighted Power Intensity of each SWOT variable in the 'SWOT CLOCK Diamond Behavior Model reflect the quarry's Leading Strategy (LS). Placing the values of the Weighted Power Intensity of each variable creates four triangles. Each triangle represents a combination of an external (environmental) variable with an internal variable of the quarry on the corresponding quadrate. Four possible strategies simultaneously at a certain moment in time are created, Growth, Response, Survival and Leverage. Intuitively, the Leading Strategy is determined by the largest triangle in size, out of all the possible strategy triangles (Nathan, 2012).

In the quarry, the overall maintenance management weakness is greater than the strength; threats from external factors outweigh the opportunities (Table 3) and the vector diagram of the situation (Figure 2) swings 236.3 and the SWOT clock stands within the survival sector (Figure 1).

It is important to note here that; the pointer's positioning is momentary. It turns according to the corresponding strategic positioning on the time series axis. The pointer position is a temporary one. It could remain in the same strategic quadrate for quite a long time, and change its direction position later on. This movement is similar to the pointer's move in an analogical clock; hence the name “The SWOT CLOCK”.

The strategic direction highlights the strategic question of How? That is, How to grow? How to respond? How to lever? and How to survive?. In the quarry, the pointer point in the SURVIVAL quadrate leaving the quarry's management with the strategic question of How to Survive:

It becomes pertinent that the managers of Geoworld quarry management will have to focus more of their effort on improving their strengths to push away their threats, most importantly in the area of preventive maintenance, maintenance planning and scheduling and information management. Though, consequently the strengths would become weaker but more opportunities will evolve than the threats and the pointer will move to LEVERAGE. At the leverage status, the management will have to apply opportunities to strengthen weaknesses. The quarry will combine opportunities and stretch new strengths affecting the pointer to move to Growth Leading Strategy quadrate.

5.1 SWOT Analysis of Future Situation in Geoworld Quarry (Improvement Design for Survival Strategies for Future Operations)

In designing an improvement for the survival strategies occasioned by internal capabilities and environmental factors affecting the equipment maintenance management systems of Geoworld quarry, we considered and assumed the possibility of variations in the nation's economy and Government policy as they affect the nation's mineral industry. Change in nation's economy like it is happening now as a result of dwindling global oil price, which has limited the available resources for Nigerian government to fund engineering construction projects. Furthermore, strict environmental regulatory enforcement will mandate the quarries to comply with Government agency's laid down standard on environmental issues. As such, there will be low patronage of quarry products with less pressure on production; and operations will be carried out in clean environment. Tables 4 – 6 and Figures 3 and 4 present the possible outcomes from the scenarios. Geoworld quarry's situation will consequently change to GROWTH.

6.0 Conclusion and Recommendations

This paper has adapted 'SWOT CLOCK Diamond Behavior Model to identify the strategic direction of the studied quarry on equipment maintenance management system and from the investigation carried out, the following conclusions were drawn:

i. equipment maintenance is not given utmost attention and this informed the inappropriate and/ or lack of maintenance management system in the studied quarry as depicted by the result of maintenance management audit;
ii. maintenance department is not adequately staffed; and
iii. change in nation's economy and strict compliance with environmental standards can affect the strategic behavior of quarries' decision makers regarding equipment maintenance management.

It is therefore recommended that, management's view about equipment maintenance as a 'cost centre' should change. Management should establish appropriate maintenance management system coupled with competent maintenance technician to guarantee high availability of equipment.

References

Alsyouf, I. (2006), Measuring Maintenance Performance using a Balanced Score Card Approach, Journal of Quality in Maintenance Engineering, Vol. 12, pp. 133-149.

Bernroider, E., (2002), “Factors in SWOT Analysis Applied to Micro, Small- to-Medium and large Soft Enterprise: An Austrian Study”, European Management Journal Elsevier, Vol. 20, No. 5, pp. 562- 573.

Blanchard, B.S. (2004): Logistics Engineering and Management, 6th ed., Prentice Hall Pearson, p. 546.

Eti, M. C., Ogaji, S. O. T. and Probert, S. D. (2004): “Implementing total productive maintenance in Nigerian manufacturing industries”, Applied Energy, Vol. 79, pp. 385- 401.

Khan, M.R.R. and Darrab, I.A. (2010): Development of Analytical Relation Between Maintenance, Quality and Productivity, Journal of Quality in Maintenance Engineering, pp. 341-353.

Lee, S.F. and On Ko, A. S., (2000), Building Balanced Scorecard with SWOT Analysis, and Implementing Sun Tzu's 'The Art of Business Management Strategies' on QFD Methodology”, Managerial Auditing Journal 15/ 1/ 2, MCB University Press, pp. 68- 76.

Nathan, T. (2012), The “SWOT CLOCK” Strategic Behaviour, (www.swotclock.com), p15.

Wheelen, T.L. and Hunger J.D. (2011), Strategic Management & Business Policy (7th Ed.) Prentice Hall.

Ige et al (2017) Nigerian Mining Journal, (15) 58 - 69

Evaluation of Engineering and Geochemical Properties of Crushed Aggregates for Road Construction in Ilorin, Kwara State

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Abstract

This work presents the results of geo-engineering and geochemical studies of selected crushed aggregates with a view to determine their suitability for road constructions. Samples were collected from individual rocks for various laboratory analysis which include; petrographic examination, geochemical composition, mechanical and physical properties. The results revealed that specific gravity ranges from 2.48 to 2.66, the porosity are within 2% which is very good with the exception of porphyritic granite which is slightly higher with 2.22%. The point load index ranges from 5.96 to 12.92 which are represented by porphyritic granite and augen gneiss respectively while the Schmidt rebound number is highest with 49.4 in banded gneiss and least in with 40.4 in augen gneiss. The petrographic analysis reveals the major minerals in the samples to be quartz and plagioclase which are felsic in nature which is also confirmed with geochemistry of the rocks which also indicates that the samples are silicious, co-genetic and originated through the same process. Comparing the Los Angeles abrasion, impact and crushing values obtained from the laboratory destructive test with international standards, most of the rocks have acceptable value and therefore can be used as aggregates for road applications.

Keywords: Aggregates, Engineering properties, Geochemistry, Road Construction,

Introduction

There has been increase in road construction and high demands for crushed rocks as construction materials in Ilorin, Kwara state and elsewhere in Nigeria but durability has always been a big problem which is determined by the quality of geo-material used as an input. In most cases, this is due to inadequate understanding of decisive factors that control the suitability of aggregates and durability of roads. Aggregates are crushed rocks which could be produced from different types of rocks; igneous, metamorphic and even sedimentary rocks, however, to achieve required quality geo-materials as an input in road construction, characteristics such as petrography, geochemistry, mechanical and physical properties of aggregates which have controlling effect on engineering application need to be properly tested and assured before the road is built.

The importance of using the right type and quality of aggregates cannot be overemphasized. For road construction and other engineering purposes, only the rocks with ability to withstand optimum stress with any form of deformation should be used and physical and mechanical properties should be the predominant factor in the selection of aggregates (Neville, 1996). In various ways in which aggregate is used, it is exposed to a variety of stress, and the response of the structure in which is it used will largely depend upon the properties of the aggregate. It needs to resist heavy loads, high impacts and severe abrasion, and it also needs to be durable in the prevailing environmental conditions. Therefore, selecting the right aggregates material with the necessary characteristics is imperative in order to overcome the frequent problem of road failure (Egesi and Tse, 2012).

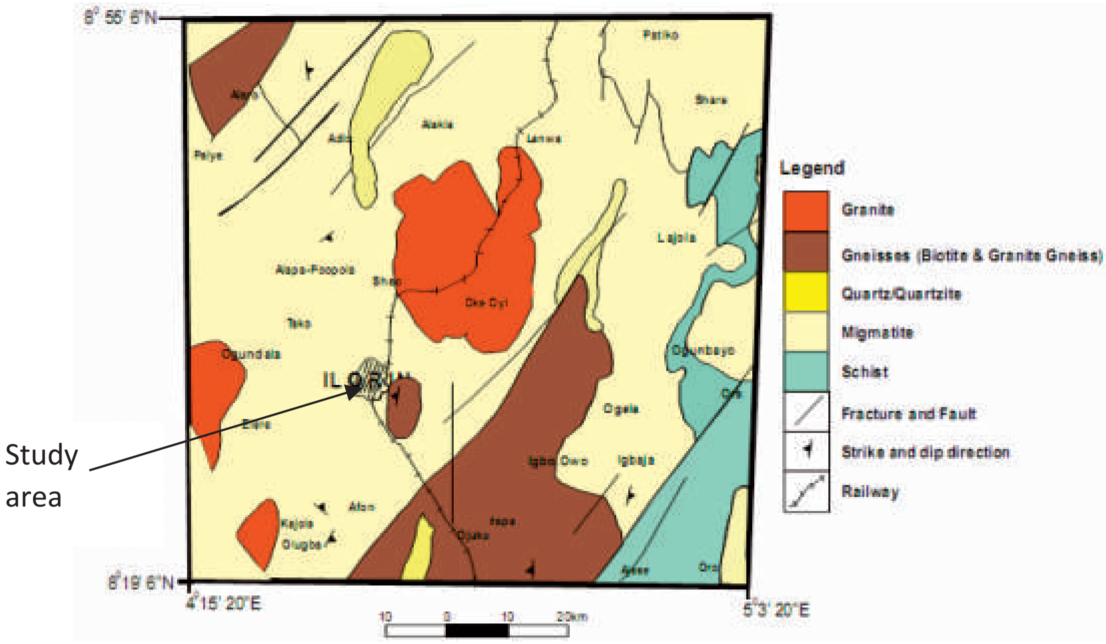

Fig. 1: Geological Map of Study Area and Environ (after Ige, 2010).

The study area is Ilorin metropolis and its environs in the central West Africa region. It lies within the Nigeria basement and situated on an undifferentiated Precambrian basement complex of granitic and metamorphic origin and form part of the regional North-western highlands of Nigeria running North-western – South-eastern parallel to the river Niger (Annor and Freeth, 1985). Some of those rocks include the migmatite, granites and gneisses (Oluyede, 1998).

Materials and Methods

A number of in-situ hard-rock samples were collected from active quarries and outcrops considered to be potential future quarry sites during this field investigation. Rock samples representing Migmatite, Banded-gneiss, Granite-gneiss, Augen-gneiss and Porphyritic granite were used for this research. These samples were used to measure and study geochemistry, density, water absorption, specific gravity, porosity, petrographic examinations, mechanical properties and a number of relevant engineering tests. For the destructive tests, the samples were prepared in such a way that blocks of rocks were collected directly from the individual rock types and reduced manually into smaller pieces and then crushed to the required size with mini laboratory jaw crusher to get the necessary size grading for the various tests. The strength tests were carried out in accordance with BS 1990 and physical properties tests were conformed to guidelines of ISRM, 1985.

The whole rock geochemical analyses were carried out to determine percentages of elements present in the samples as suggested by ASTM, 2003 for major element in percentage trace elements in part per million and converting factors prepared by Randy Korotev was used to convert the elements to major oxide and also Petrographic analysis of the rocks technique was thin section and the slides were observed under petrological microscope and modal analyses were carried out to determine the minerals present in the rock samples and their percentages. Although, identification of the constituents of rocks cannot alone provide a basis for predicting the behaviour of aggregates in service. Service records are important in evaluating suitability of aggregates but in the absence of a performance record, the aggregates should be tested and evaluated before they are used in road application.

Results and Discussion

Petrography and Modal compositions of the rock types

Petrography was used to evaluate the aggregate material and also to examine the Alkali-Aggregate-Reaction (AAR) risk in aggregates which remains to be one of the major causes of damage in concrete as suggested by Lopez-Buendia *et al.,* 2006. Hammersley (1989) also noted that the petrography of a rock, involving field inspection, can be of value in any assessment of its potential suitability for use as aggregate.

Rock features like minerals present and their mode of occurrence, percentage composition of each mineral and texture have been highlighted. Detail petrographic examination of the rocks under a polarizing microscope reveals the presence of quartz, plagioclase, biotite, opaque minerals and hornblende in some of the rocks (Plate 1-5) and modal composition of the rocks is presented in Table 1. Aggregates of any type or combination of types may perform well or poorly in service depending on the exposure to which the concrete is subjected.

Petrography of Migmatite

The thin section shows that the migmatite is composed of quartz that is colourless and interstitial spaces between plagioclase, opaque minerals, hornblende and biotite (Plates 1). Biotite crystals exhibit one directional cleavage and it is dark to light brown in colour in plane and crossed polar.

Petrography of Banded Gneiss

The rock is medium grained in texture and comprises of plagioclase occurring in the interstitial spaces between quartz and biotite (Plate 2). Anhedral crystals of quartz occur within the plagioclase feldspar. Quartz occupies interstitial positions between biotite and plagioclase. Biotite which is brown in colour has been partially replaced by chlorite while crystals of plagioclase exhibit albite twinning and is partially replaced by sericite.

Petrography of Granite Gneiss

The rock is medium to coarse grained in texture and comprises of biotite occurring in the interstitial spaces between quartz and plagioclase (Plate 3). Anhedral crystals of quartz occur within the plagioclase feldspar. Quartz occupies interstitial positions between biotite and plagioclase. Biotite is black in colour and crystals of plagioclase exhibit albite twinning.

Petrography of Augen Gneiss

The rock is coarse grained in texture and comprises of quartz, plagioclase and biotite (plate 4). In the thin section, the modal composition is quartz 43%, plagioclase 41% and biotite 16% (Table 4).

Petrography of Porphyritic Granite

The porphyritic granite consists of quartz, orthoclase, plagioclase, opaque minerals, hornblende and biotite. The feldspars are mainly large euhedral crystals of orthoclase in a finer matrix of quartz, biotite and plagioclase. The quartz appears colourless; biotite is brownish and shows pleichroism. Quartz crystals are angular in shape and are grayish in color when viewed in plane and crossed polar. Biotite crystals exhibit one directional cleavage and are dark to light brown in color in plane and crossed polar. Iron oxide mineral in the thin section is opaque which is dark coloured when observed under plane and crossed polars, while crystals of plagioclase exhibit twinning.

Table 1: Modal Composition of Minerals in Rock Samples

MINERALS	MIGMATITE	BANDED GNEISS	GRANITE GNEISS	AUGEN GNEISS	PORPHYRITIC GRANITE
	COMPOSITION	**COMPOSITION**	**COMPOSITION**	**COMPOSITION**	**COMPOSITION**
QUARTZ	33%	36%	34%	43%	37%
ORTHOCLASE	--	--	--	--	3%
PLAGIOCLASE	26%	32%	30%	41%	25%
OPAQUE MINERALS	7%	4%	6%	--	4%
HORNBLENDE	18%	--	14%	--	16%
BIOTITE	16%	28%	16%	16%	14%
TOTAL	100%	100%	100%	100%	99%

Geochemistry of the Rock Types

It is revealed from the geochemical analysis that rocks have high content of silica and aluminium. The oxide of silicon (SiO_2) content ranges from 58.23 to 72.33. The average silica (SiO_2) content of the rocks is 64.20 which is a little bit lower than the SiO_2 contents are evident from petrographic studies which revealed minerals present to be felsic i.e. quartz and plagioclase.

In the study area, strong negative correlation is noted in plots of variation diagrams of SiO_2 (wt%) against Al_2O_3, K_2O, CaO, MgO, Na_2O and Fe_2O_3 (wt%). It shows each oxide component in the granitic rocks from Ilorin which varies with some other oxide components. The variations in SiO_2% (index of differentiation) with Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O and K_2O (Figs. 2-6) suggest that the porphyritic granite, granite gneiss, migmatite, banded gneiss and augen gneiss formed through the same process of crystallization. According to Harker variation diagram, the plots show data spread and also exhibit significant data scatter without correlation.

The alkali metals (Na and K) are often highly mobile elements during metamorphism and weathering (Pearce *et al.,* 1975) but Na_2O against SiO_2 and K_2O against SiO_2 diagrams show significant data scatter with lack of correlation for K_2O and low positive for Na_2O. This indicates that these major elements undergo varying mobility during metamorphism confirming low to medium grade for the samples (greenschist to lower amphibolites facies). Also, negative correlation between SiO_2 and other major oxides shows they are co-genetic and exhibit almost the same weathering properties according to Amuda, *et al.,* 2014.

Table 2: Result of Chemical Composition of Rock Samples in the Study Areas

Sample Code	MIGMATITE	BANDED GNEISS	GRANITE GNEISS	AUGEN GNEISS	PORPHYRITIC GRANITE
Major Elements in %					
Ti (%)	0.21	0.28	0.32	0.25	0.26
Si (%)	27.22	30.29	29.51	33.81	29.23
Al (%)	8.58	7.14	9.25	6.63	8.56
Mn (%)	0.08	0.06	0.04	0.05	0.04
Fe (%)	6.45	5.34	4.62	1.19	4.49
P (%)	0.14	0.14	0.07	0.07	0.07
Mg (%)	1.87	1.12	0.68	1.27	1.34
Ca (%)	3.47	2.49	2.37	3.09	3.09
Na (%)	2.57	2.70	1.91	2.83	2.64
K (%)	2.22	2.86	1.79	2.04	3.20
Trace Elements in part per million, ppm					
Pb ppm	0.03	0.04	0.03	0.02	0.04
Re ppm	1.22	0.97	1.24	0.51	1.37
Zn ppm	0.03	0.03	0.04	0.04	0.04
Sr ppm	0.15	0.85	0.21	0.01	1.17
Rb ppm	0.04	0.04	0.06	0.06	0.08
Nb ppm	2.12	1.69	1.23	0.24	1.43
Cu ppm	0.01	0.01	0.01	0.02	0.02
Zr ppm	0.06	0.04	0.05	0.03	0.07

of all the samples tested is within the standard limit. Low specific gravity value recorded for Porphyritic Granite was probably as a result of fracture that might contain water and alteration of feldspar (Amuda et. *al.,* 2014). Banded gneiss has high specific gravity of 2.66 due to the fine texture and closely packed minerals. However, most of them still fall within heavy weight aggregate as average specific gravity of rocks vary from 2.6 to 2.8 according to Shetty, 2005.

Porosity of the Rocks Aggregate

The porosity of rocks aggregate ranges from 1.42 to 2.22% which is very low (<2%) with the exception of Porphyritic granite collected from the study area which has 2.22% (Table 4) which might be due to micro cracks . A study conducted in 1995 by Pigeon and Pleau suggested that a limit of 2 percent be placed on the porosity of coarse aggregates to prevent damage from occurring. However, Smith and Collis, 1993 noted that an aggregate may satisfy porosity limit but there is no guarantee that problems with concrete will not occur.

Bulk Density of the Rocks Aggregate

Bulk density is a function of the particle specific gravity and the void ratio. This takes into account the effects of voids present in the aggregate at a given degree of compaction (Waqa, 2004). The average bulk density of the studied rocks ranges from 2.61 g/cm to 2.81 g/cm. These values fall within the acceptable limit of greater than 2.60 g/cm according to Mallo, 2012 cited Akpokodje, 1992.

Aggregate Impact Value (AIV) of Rocks Aggregate

The results of the aggregate impact value test are shown in table 4. Average value of the results ranges from 24.17% to 31.32%. Granite gneiss has the lowest average impact value of 31.32%, followed by 29.89% for augen gneiss and the best AIV is recorded from porphyritic granite with 24.17% followed by migmatite with 27.85%. The IS 283-1970 code specifies that aggregate impact value shall not exceed 45% by weight for aggregate used for concrete other than wearing surface and 30% by weight for concrete used for wearing surfaces, such as runways roads and pavement. Aggregate Impact Value (AIV) below 10% is regarded as strong and AIV above 35% would normally be regarded as too weak for use in road surface (Egesi and Tse, 2012).

Aggregate Crushing Value (ACV) of Rocks Aggregate

Aggregate Crushing Value gives a relative measure of the resistance of aggregate rocks to crushing under gradually applied compressive load (Shetty, 1982). Result of the ACV test conducted on the selected samples is shown in table 4. The average ACV ranges from 29.59% to 32.92%. Migmatite, granite gneiss, augen gneiss and porphyritic granite gave a value that is slightly higher than the 30% which according to Shetty 2005, the crushing value of aggregate is restricted to 30% for concrete used for roads and pavements and 45% may be permitted for other structures. The lower the value, the stronger the aggregate, that is the greater its ability to resist crushing. Therefore, crushing value of 30 percent and above is not good for road construction.

Los Angeles Abrasion Value (LAAV) of Rock Aggregate

The average LAAV ranges from 21.33% to 32.75%. Porphyritic granite has the best LAAV of 21.33% followed by granite gneiss with 25.35% while the lowest LAAV is 32.75% (Migmatite). Generally, these LAAV ranges indicate these aggregate are highly sound with regard to AASHTO T-96 section 904.03 standards which specified the maximum allowed LAAV of aggregates for sub-base to be

TABLE 3: Major Oxides Composition (Wt%) of Rocks in the Study Areas

S/N	ELEMENTS	MIGMATITE	BANDED GNEISS	GRANITE GNEISS	AUGEN GNEISS	PORPHYRITIC GRANITE
1	SiO_2	58.23	64.80	63.13	72.33	62.53
2	Al_2O_3	16.21	13.49	17.48	12.53	16.17
3	Fe_2O_3	9.22	7.63	6.61	1.70	6.42
4	CaO	4.86	3.48	3.32	4.32	4.32
5	MgO	3.10	1.86	1.13	2.11	2.22
6	K_2O	2.67	3.45	2.16	2.46	3.85
7	Na_2O	3.46	3.64	2.57	3.81	3.56
8	P_2O_5	0.32	0.32	0.16	0.16	0.16
9	TiO_2	0.33	0.47	0.53	0.42	0.43
11	Mn_2O_3	0.10	0.08	0.05	0.06	0.05
12	ZrO_2	0.08	0.05	0.07	0.04	0.09
13	LOI	0.6	0.5	0.6	0.4	0.4
TOTAL %		**99.18**	**99.77**	**97.81**	**99.94**	**99.80**

Engineering Properties of the Rocks Aggregate

In an effort to produce the required quality geomaterial, it is essential to understand the engineering properties of aggregate and its modes of production. The engineering properties of crushed rock aggregates and data represented here are related to the samples collected from quarries and natural outcrops from the studied area. The lists of selected tests for the current study are: Specific Gravity; Point Load Index; Los Angeles Abrasion Value (LAAV); Porosity; Bulk density; Aggregate Crushing Value (ACV); Aggregate Impact Value (AIV), and Schmidt Rebound Hardness. The samples utilized for conducting these tests, however, remained confined to crushed rocks obtained from existing quarries and outcrops.

Specific Gravity of the Aggregates

Generally, there is a direct positive relationship between high specific gravity and high strength of aggregates (Kandhal and Lee, 1970; Neville, 1973, 2000). Rock of this high quality often possesses good specific gravity properties. The specific gravity of the samples was determined using AASHTO: T-85 standards and the value ranges from 2.61 (Augen Gneiss) to 2.66 (Migmatite and Banded Gneiss) as shown in Table 4. The specific gravity (SG)

50%, base course 40%, and asphalt concrete to be 35% and 16% for concrete aggregate. All the values are within the safe limits for most construction work and also indicate that these rocks are not only strong but also possess superior resistance to abrasive action.

Schmidt Rebound Hardness of the Rocks

Hardness is one of the most investigated properties of rocks, and yet it is also one of the most complexes to understand. The average Schmidt hammers rebound number for the samples ranges from 40.4 - 49.4. Generally, the Schmidt hammer rebound number is influenced by the hardness of the constituent minerals of a rock, and the rebound number is corresponding with UCS value.

Point Load Index of the Rocks

The Point load index value (Is_{50}) of the study samples ranges from 5.96MPa to 12.92MPa represented by samples (Porphyritic granite) and (Augen gneiss) respectively. According to the classification by Franklin and Broch, 1972, 40% of the tested samples are very high strength and 60% are extremely high strength. The Point Load index is a crude strength characteristic measured in the absence of uniaxial compressive strength as there is always a good relation between the Uniaxial Compressive Strength and the Point Load index value. According to Dearman (1991), the Uniaxial Compressive Strength should be higher than 35MPa for concrete aggregate production and so, in this regard all the studied samples are quite suitable for concrete aggregate production.

Table 4: Summary of Engineering Properties

S/N	DESCRIPTION	ENGINEERING PROPERTIES OF AGGREGATES							
		SG	PLI	POR	B. D	SRH	AIV %	ACV %	LAAV %
1	**MIGMATITE**	2.66	9.90	1.73	2.61	43.2	27.85	32.21	32.75
2	**BANDED GN.**	2.66	12.73	1.42	2.68	49.4	28.8	29.59	26.01
3	**GRANITE GN.**	2.58	11.26	1.49	2.81	41.6	31.32	31.10	25.35
4	**AUGEN GN.**	2.61	12.92	1.87	2.65	40.4	29.89	31.90	27.10
5	**PORPHYRITIC GR.**	2.48	5.96	2.22	2.67	42.4	24.17	30.30	21.33

The rocks show a variety of textural and mineralogical characteristics which might have influence on their physical and mechanical properties as well as their use as construction materials. The rock material and aggregate properties of the rocks were compared with the various standards and evaluated for their suitability for different end uses. The engineering property are found to be a very useful property in assessing durability and suitability of the various rocks used as building stone and concrete aggregates, however, this is not a big problem in the study area since all the values fall within the acceptable range, which imply these rocks could be used as aggregate for various applications.

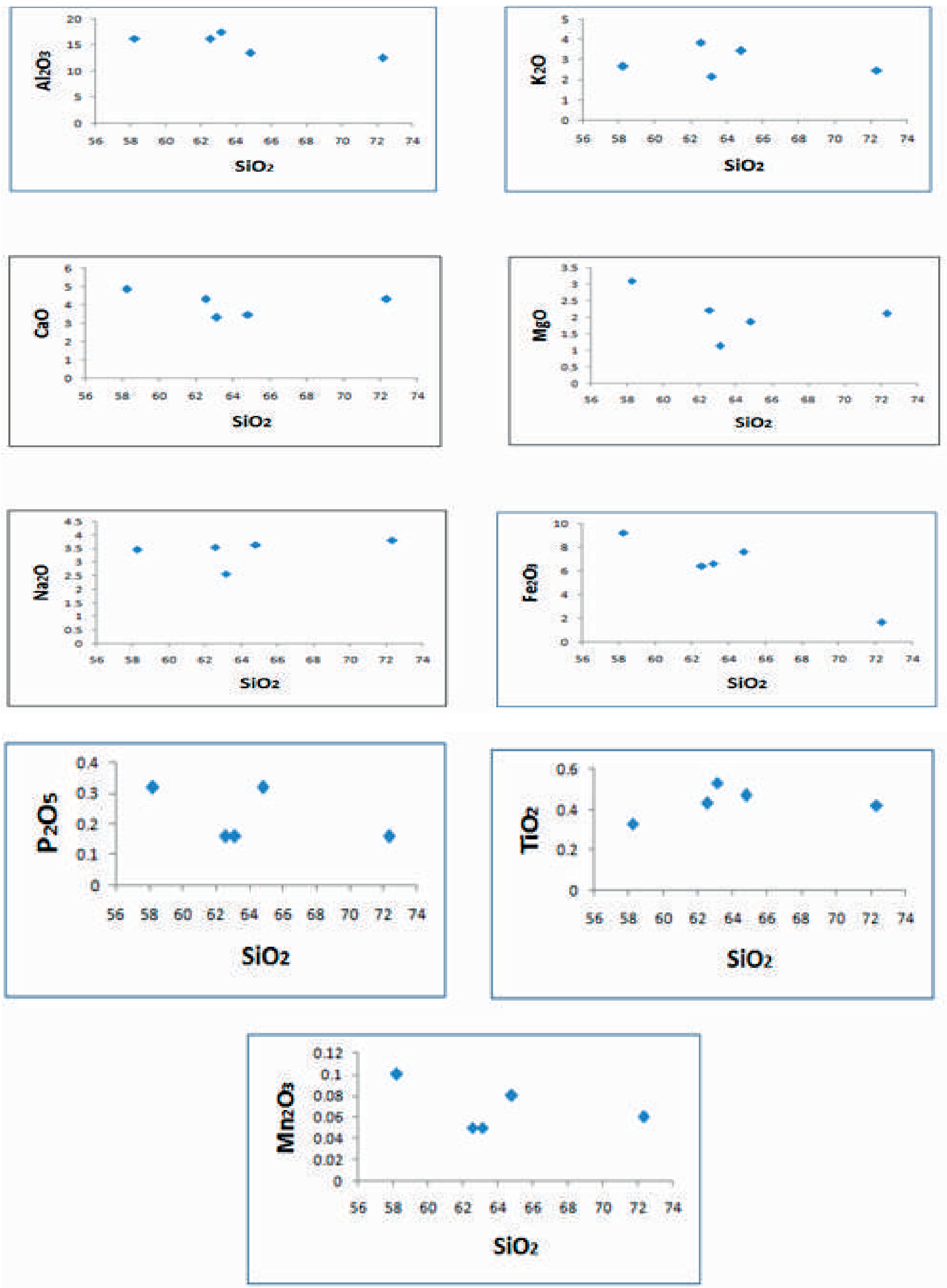

Figure 2: Harker Variation Plots of SiO_2 against other Major Oxide

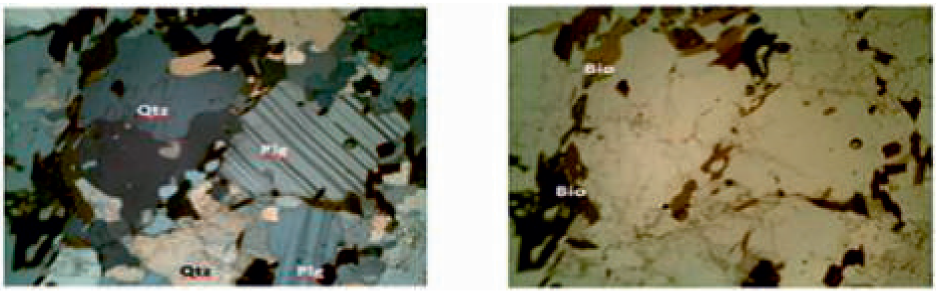

Plate 1: Petrography of Migmatite in Plane and Cross Polar

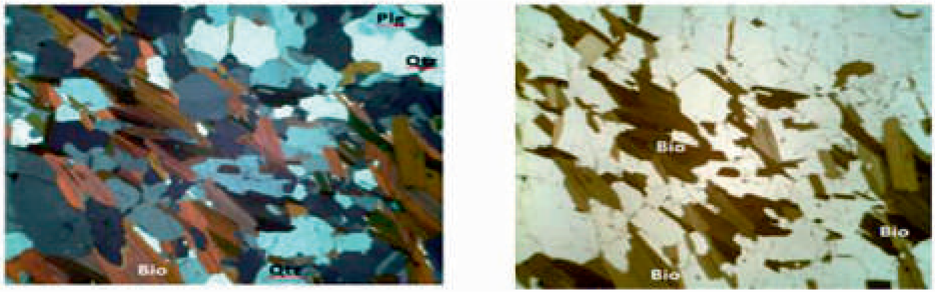

Plate 2: Petrography of Banded Gneiss in Plane and Cross Polar

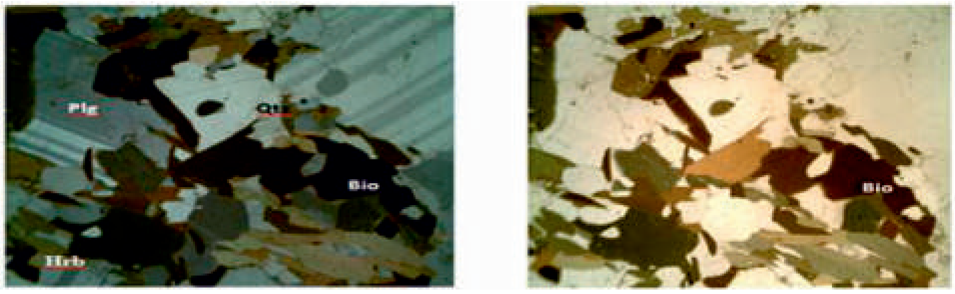

Plate 3: Petrography of Granite Gneiss under Plane and Cross Polar

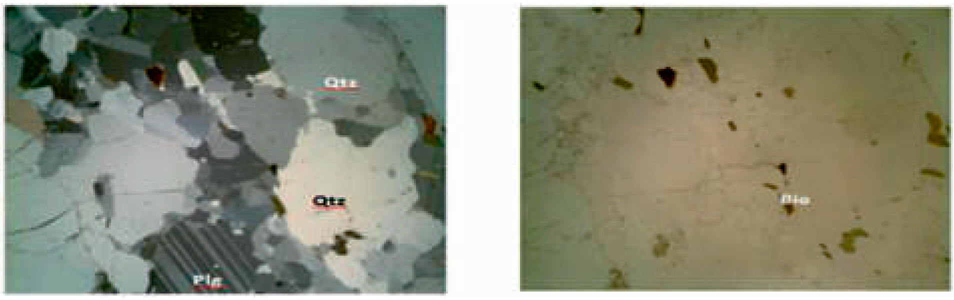

Plate 4: Petrography of Augen Gneiss under Plane and Cross Polar

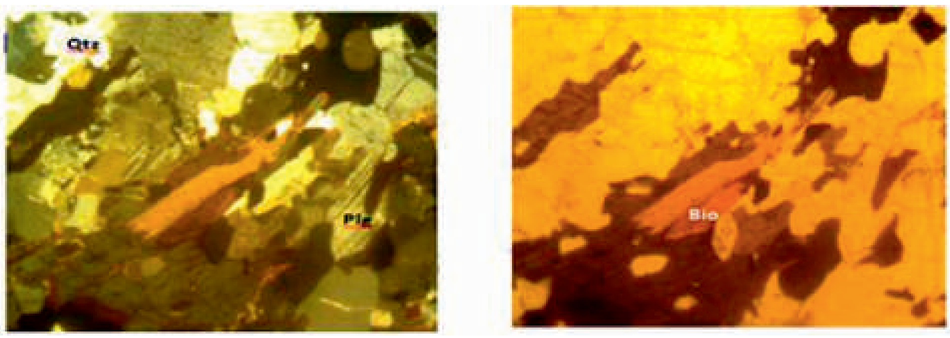

Plate 5: Petrography of Porphyritic Granite under Plane and Cross Polar

Conclusion

The petrographic analysis reveals the major minerals in the rocks to be quartz and plagioclase which are felsic in nature. The microcrack and fracture present in some of the rock type is a deformation that results from the effect of overburden pressure on the plutonic rocks. Also, it is confirmed from geochemistry analysis that the analysed rocks are siliceous. From the Harker variation plots, the negative correlation between SiO_2 and other major oxides shows that the rocks they are co-genetic and exhibit almost the same weathering properties.

Generally, the evaluated rocks are geotechnically stable. The specific gravity for most of the rocks are up to 2.6 except for one (porphyritic granite) which make them heavy weight rock. Comparing the impact, abrasion and crushing value obtained from laboratory destructive test with standards, most of the rock can be used for most construction works like concrete embankments, foundations, and asphalt for highway and pavement. However, Porphyritic granite because of its low specific gravity and high porosity should be restricted for use in road construction.

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References

Akpokodje, (1992): "Macroeconomic Policies and Private Investment in Nigeria, In:B.E.Aigbokan (ed), Rekindling Investment for Economic Development in Nigeria, Ibadan. The Nigerian Economic Society, 21-24.

Annor A.E., Freeth S.J., (1985): Thermotechnic Evolution of the Basement Complex around Okene, Nigeria with Special Reference to Deformation Mechanism, Precamb Res. 28: 269-281.

American Association of State Highway and Transportation Official, AASHTO, (2001): Specific Gravity and Absorption of Coarse Aggregate. Washington DC. Technical specification. No. T85.

Amuda, A. G., Uche, O. A. U and Amuda, A. K. (2014): Physic-Mechanical Characterization of Basement Rocks for Construction Aggregate: A Case Study of Kajuru Area, Kaduna, Nigeria. Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 11, pp. 46-51.www.iosrjournals.org

ASTM (2003): Standard Test Method for Determination of Point Load Strength Index of Rock, Annual Book of ASTM Standards, Vol.04.08, D 5731, pp. 3

British Standard Institute BS 812-110 (1990): Methods for Determination of Aggregate Crushing Value (ACV), Publication of BSI (London).

British Standard Institute BS 812-112 (1990): Methods for the Determination of Aggregate Impact Value (AIV), Publication of BSI (London).

Dearman, W.R. (1981): Engineering Properties of Carbonate Rock, General Report. Bulletin of the International Association of Engineering Geology 24, 3-17

Egesi, N. and Tse, A. C. (2012): Engineering-Geological Evaluation of Rock Materials from Bansara, Bamenda Massif Southeastern Nigeria, as Aggregates for Pavement Construction. Geosciences 2012, 2(5) Pp. 107-111. Found online at http://journal.sapub.org/geo.

Franklin, J. and Broch, E. (1972): J. Rock Mech. Min. Sci. 9(6)(1972) 669-697.

Hamersley, G.P. (1989): The Use of Petrography in the Evaluation of Aggregates, Concrete, Vol.23, Pp.23-37

Ige, O. O. (2010): Landfill Site Selection for Municipal Solid Waste Assessment of Soils as Mineral Seals around Ilorin, South-western Nigeria. Unpublished Ph.D Dissertation, Department of Geology and Mineral Sciences, University of Ilorin, Nigeria. 231p.

ISRM (1985): Rock Characterization

Testing and Monitoring: International Society of Rock Mechanics Commission (ISRM) Standard, Ed. E. T. Brown, Pergamon press. pp. 75 – 105.

Kandhal, P.S and Lee, D.Y. (1970): An Evaluation of the Bulk Specific Gravity for Granular Materials, Highway Research Board, Highway Research Record No.307

Lopez Buendia, A.M., Climent, V., Verdu, P., (2006): Lithological Influence of Aggregate in the Alkali-Carbonate Reaction Cement and Concrete Research, Elsevier Ltd. Valencia, Spain, Vol. 36.

Mallo Stephen J., (2012): The Re-Emerging Mining Industry in Nigeria: Issues for Appropriate Manpower Training Continental Journal of Sustainable Development 3(2): 15-25. ISSN:2251-0486

Neville, A.M. (2000): Properties of Concrete 4th ed. Pearson Education Asia Pte, Ltd. Edinburgh, U.K. 844p.

Neville, A.M. (1999): Concrete Technology Longman Group U.K., First ISE Reprint 1999.

Edinburgh. U.K.

Oluyede, P. O., (1998): Structural Trends in the Nigerian Basement Complex. In: P.O. Oluyede (Co-coordinator) Precambrian Geology of Nigeria, Geol. Surv., Nigeria Publ., Pp. 93-98.

Pearce, M., Gorman, B. E. and Birkett, T. C. (1975): The Relationship between Major Element Chemistry and Tectonic Environment of Basic and Intermediate Volcanic Rocks, Earth science Letter, Vol. 36. Pp. 121-132.

Pigeon, M., and Pleau, R. (1995): Durability of Concrete in Cold Climates. London, U.K; Chapman and Hill, 244p.

Shetty, M. S. (2005): Concrete Technology Theory and Practice (6th Edition). Chand and Company Limited, New Delhi.

Smith, M. R. and Collis, L. (2001): Aggregates-Sand, Gravel and Crushed Rock Aggregates for Construction Purposes (3rd Edition), the Geological Society London, p. 339.

Smith, M.R. and Collis, L., (1993): Aggregates, Sand, Gravel and Crushed Rock Aggregates for Construction Purpose (2nd Edition), Geological Society Engineering Geology Special Publication No. 9, Imperial College of Science, Technology and Medicine, London.

Waqa, I.R., (2004): Geological and Geo-Technical Characteristics of Aggregate Source Rocks