GEOMECHANICAL PROPERTIES AND ECONOMIC POTENTIALS OF DOLERITE ROCKS FROM S.E. NIGERIA

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ABSTRACT
As developing nations strive to catch up with the rest of the world, good quality construction stones, if found locally and harnessed would help save cost and also ensure the development of local industries. The study area, Cross River State (SE Nigeria), which is within longitudes 8^0 00' E to 9^0 12' E and the parallels 5^0 35' N to 6^0 40' N, is rich in diverse kinds of igneous and metamorphic rocks, of which some are already being quarried for commercial purposes. A total of thirty (30) dolerite samples were collected from fourteen (14) different localities within the three major geological terrains in Cross River State (Oban Massif, Ikom-Mamfe embayment and Obudu Plateau) and analyzed for their geomechanical properties. Results of sample analysis from these study areas show that density ranges between 2.73 g/cm^3 and 2.89g/cm^3; Porosity ranges between 1.09% and 1.29%; water absorption capacity is between 0.29% and 0.76%; average specific gravity ranges from 2.79 to 2.93; durability index range from 97.66% - 98.31%; Schmidt Hammer strength ranges from 42.88 N/mm^2 to 48.93 N/mm^2;and uniaxial compressive strength varies from 47.55N/mm^2 to 51N/mm^2. Even though the geochemistry of dolerites in general maybe a major setback for their use, all the dolerite samples from the study area, show acceptable physical and mechanical properties, which make them very suitable for the construction/dimension stone industry.

INTRODUCTION
Mankind's progress maybe measured in mineral usage. With the evolution of human civilization and the quest to develop modern roads, buildings and general structures, the place of construction stones (an industrial mineral) continues to gain prominence. Evidence abounds from all visible industrialization trends that there is and will always be an increasing dependence of man on industrial minerals. As developing nations seek to catch up with the rest of the developed world, it is pertinent to look inwards and harness locally available industrial minerals, which would help to save cost and also ensure the development of local industries. Good quality construction stones, if found locally, can be harnessed to build lasting bridges, school buildings, low cost estates, and other desired structures. Cross River State (SE Nigeria) is rich in diverse kinds of igneous, metamorphic and sedimentary rocks, some of which are already being quarried for commercial purposes. This paper looks at a particular rock type: dolerite, which is found in appreciable quantity in all the geological terrains of Cross River State and can serve as good construction/dimension stone due to its black brilliance when polished, but has been neglected by commercial quarries for a long time, except for local and very small scale miners (Fig. 1b). The geomechanical (physical and mechanical) properties of these rocks (dolerites) from the three major geological terrains within the state are analyzed and their suitability in the construction/dimension stone industry will be evaluated. The study areas are within longitudes 8^0 00' E to 9^0 12' E and

latitudes 5^0 35' N to 6^0 40' N and covers the three major geological terrains in Cross River State (Oban Massif, Ikom-Mamfe embayment and Obudu Plateau (Fig. 2).

GENERAL GEOLOGY

The study area is naturally subdivided into the Oban massif, Ikom-Mamfe embayment and Obudu Plateau.(Fig 2). The Oban massif is composed of Precambrian basement, which is overlain in the south by Cretaceous-Tertiary sediments of the Calabar Flank. The geology includes metamorphic rocks such as phyllites, schist, gneisses, amphibolites and charnockites with igneous intrusions such as dolerites, granites, granodiorite, diorite, tonalite and monzonite. The most prominent fracture set in Oban Massif is the NNW-SSE, with a trend of 150^0-160^0 from the north. Others are NNE-SSW, E-W and NW-SE sets (Oden et al., 2012). The Ikom-Mamfe embayment, which probably resulted from the block rotation of the Obudu basement with respect to the Oban massif (Oden et al., 2012), is predominantly a sedimentary environment in which Albian sandstones and limestone are overlain by a sequence of Lower Turonian sandstones, shales and limestones, all o which are intruded by series of post- Turonian minor basic to intermediate intrusives, (Hossain 1981). The Obudu Plateau consists dominantly of migmatitic gneisses, schists and a few amphibolites, all of which have been intruded by acidic, basic and ultra basic igneous rocks (Ekwueme, 1994; Ephraim, 2012). This area has a rugged topography with hilly ridges separated by lowlands. Structural data (Oden et al., 2012) shows that the most prominent fracture set in Obudu is the NW-SE which trends 140^0-150^0 from north. Minor sets occur in the NNE-SSW, E-W and ESE-WNW directions.

The dolerites in the Oban massif and Ikom-Mamfe Embayment occur as minor intrusives in association with schists, granodiorite and sometimes gneisses, but are mostly emplaced in the sandstones, shales and limestones of the Eze-Aku Formation. Generally they exhibit sharp contact relationship with their host rocks. In the Obudu massif, they occur in a NE-SW and N-S trend in association with amphibolites, gneisses and schists. They seem to be emplaced in pre-existing fractures or as sills, concordantly in the sedimentary rocks.

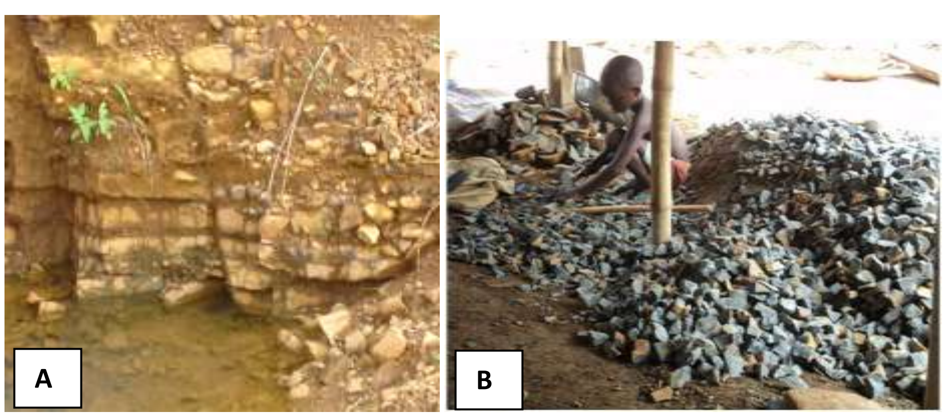

Fig. 1. (A) Dolerite occurring as sills with shale in between the layers in the study area(B) Dolerite being crushed to smaller fragments for construction works.

Fig. 2. The geologic map of Cross River state showing the basement areas (Oban and Obudu massif) and the sedimentary area (Ikom-Mamfe Embayment). Insert is the map of Nigeria.

Materials and methods

A total of thirty (30) dolerite samples were collected from fourteen (14) different localities within the three major geological environments in Cross River State. For convenience of expression the following acronym will be used: DOM for Oban Massif, DIME for Ikom-Mamfe embayment and DOMA for the Obudu Plateau. Samples from the Oban Massif (DOM) were collected at Agoi-Ibami, while the Ikom-Mamfe embayment samples (DIME) were collected from Usumutong, Ugep, Ekori, Adim, Agwagune, Ohana, MkpaniandObubra.The samples from the Obudu Plateau (DOMA) were collected at Okorotong, Otugwang, Bedia, Okorshie and Amunga. These samples were subjected to various physical and mechanical tests (density, specific gravity, porosity, durability index, water absorption, Schmidt hammer strength, and uniaxial compression)in accordance with recommended standard procedures.

Table2: Result of mechanical and physical properties of dolerite samples

Sample No	Density (G/CM^3)	Specific Gravity	Porosity (%)	Durability Index (%)	Water Absorption (%)	Schmidt Hammer Strength (N/MM^2)	uniaxial compression (n/mm^2)
Oban Massif (DOM)							
1	3.07	3.00	0.34	99.21	0.26	40.88	ND
2	2.71	2.89	1.33	97.92	0.67	48.33	50.80
3	2.70	2.89	1.35	97.81	0.68	48.23	51.20
Average	2.83	2.93	1.01	98.31	0.54	45.81	51.00
Ikom – Mamfe Embayment (Dime)							
4	2.73	2.89	0.55	97.83	0.65	45.33	ND
5	2.73	2.75	0.61	97.56	0.76	31.17	ND
6	2.43	2.75	4.55	97.30	1.59	33.67	36.80
7	2.47	2.70	4.35	97.71	1.20	35.67	35.20
8	2.74	2.75	0.57	97.17	0.78	43.63	ND
9	2.76	2.75	0.58	98.04	0.78	40.52	ND
10	2.83	2.89	0.54	98.42	0.75	34.57	ND
11	2.99	2.89	0.44	97.72	0.47	43.24	ND
12	2.89	2.89	0.43	97.82	0.37	39.38	ND
13	2.69	2.75	1.10	97.05	0.90	45.90	ND
14	2.67	2.75	1.19	96.68	0.99	43.35	ND
15	2.72	2.88	1.30	98.36	0.58	48.30	50.80
16	2.80	2.80	1.11	98.48	0.55	48.50	51.20
17	2.65	2.80	1.40	97.78	0.71	48.00	51.60
18	2.69	2.88	1.43	97.83	0.74	48.17	51.80
19	2.79	2.89	0.95	98.37	0.54	49.83	51.40
20	2.81	2.89	0.90	98.81	0.53	49.67	51.60
Average	2.73	2.82	1.29	97.82	0.76	42.88	47.55
Obudu massif (doma)							
21	2.88	2.88	1.11	98.07	0.28	49.50	46.00
22	2.85	2.72	1.33	97.28	0.31	48.25	46.80
23	2.87	2.52	1.14	97.58	0.34	49.00	55.20
24	2.99	2.95	0.50	98.54	0.14	45.50	54.00
25	2.96	2.88	0.73	98.23	0.20	51.00	56.00
26	2.93	2.94	0.71	97.63	0.23	45.25	52.30
27	2.79	2.82	1.48	97.08	0.42	48.50	44.80
28	2.73	2.46	1.88	96.90	0.50	52.00	42.00
29	2.88	2.77	1.29	97.03	0.27	50.75	44.00
30	2.97	2.98	0.70	98.23	0.17	49.50	52.00
Average	2.89	2.79	1.09	97.66	0.29	48.93	49.31

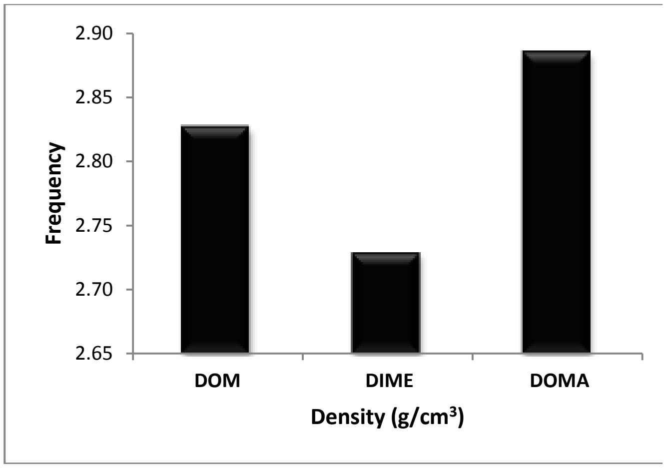

Fig. 3: Histogram of average density values; the DOMA have the highest average.

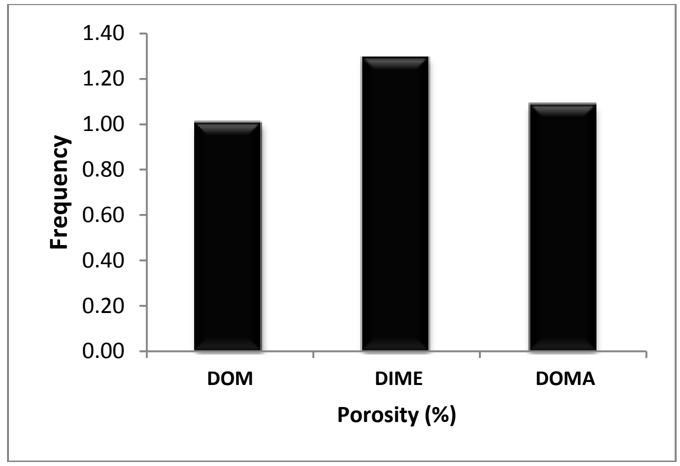

Fig. 5: Histogram of average porosity values; the DIME have the highest average.

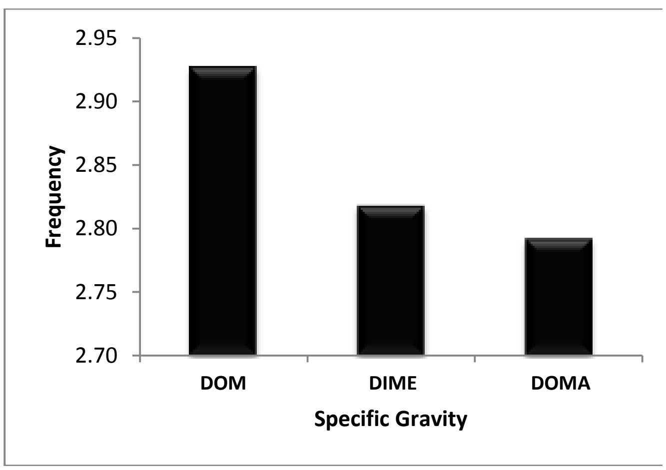

Fig. 4: Histogram of average specific gravity; the DOM have the highest average.

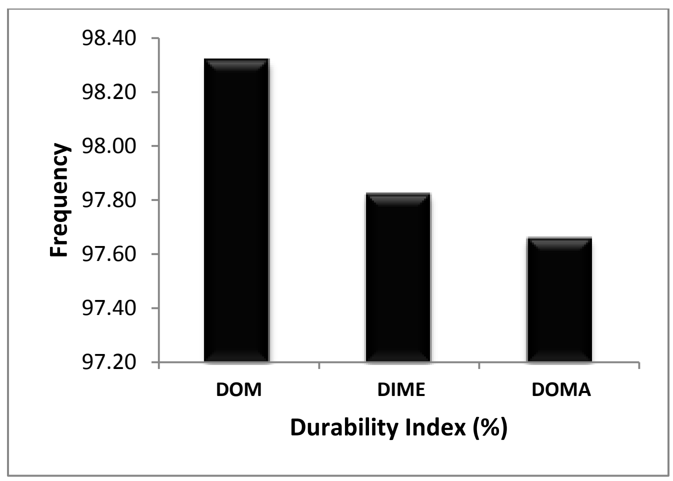

Fig. 6: Histogram of average Durability Index values; the DOM have the highest average.

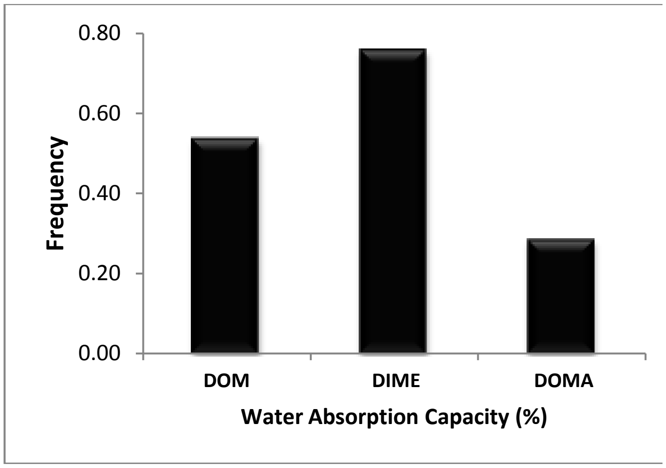

Fig. 7: Histogram of average water absorption values; the DIME have the highest average.

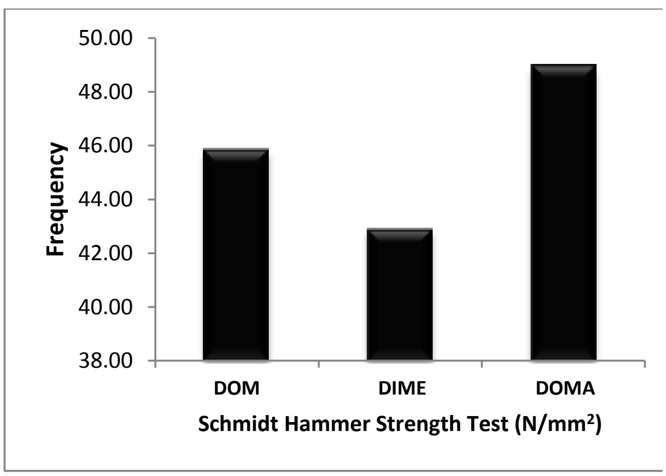

Fig. 8: Histogram of average Schmidt Hammer strength values; the DOMA have the highest average.

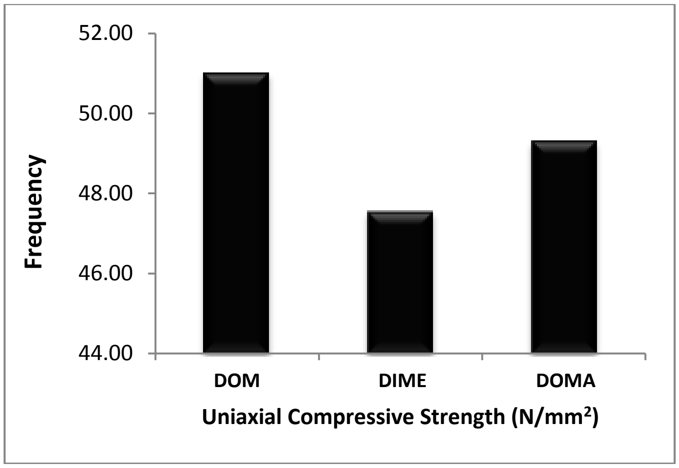

Fig. 9: Histogram of average uniaxial compressive strength; the DOM have the highest average.

RESULTS

Table 1 details the results of various physical and mechanical test conducted in all the dolerite samples obtained from the study areas. From the results obtained, density values in DOM range from 2.7-3.07g/cm^3 with an average value of 2.83g/cm^3; the DIME samples have density values ranging from 2.43-2.99 g/cm^3 and an average value of 2.73 g/cm^3; while DOMA have value ranging from 2.73-2.99 g/cm^3 with an average value of 2.89 g/cm^3.The DOMA have the highest density average (Fig. 3). Specific gravity values range from: 2.89-3.0 and an average of 2.93 in the DOM; 2.7-2.89 and an average of 2.82 in DIME; and 2.46-2.98 with an average of 2.79 in DOMA. The DOM has the highest average specific gravity value (Fig. 4). Porosity values vary widely from 0.34-1.35% with an average of 1.01% and from 0.43-4.55% with an average of 1.29 in DOM and DIME respectively. In DOMA, the porosity values are not as widely varied as it ranged from 0.5-1.88% with an average of 1.09%. Though average porosity values from the three major locations are similar, DIME has the highest value (Fig. 5).The average Durability Index (DI) values vary narrowly in all the samples from the geologic areas (DOM, DIME, and DOMA). It ranges from 97.81%-99.21% with an average of 98.31% in the DOM samples; 96.68-98.81% with an average of 97.82% in DIME; and 96.9-98.54% with an average of 97.66% in DOMA. The DOM has the highest DI among all the samples studied (Fig. 6). The water absorption capacity varies narrowly in DOM (0.26-0.68%, with an average of 0.54%) and the DOMA samples (0.14-0.5%, with an average of 0.29%). But in DIME, the water absorption capacity varies widely from 0.37-1.59% and an average of 0.76%. The DIME samples has the highest water absorption capacity (Fig. 7).The Schmidt Hammer strength result vary narrowly in the DOM (40.88-48.33N/mm^2, with an average of 45.81N/mm^2) and DOMA samples (45.25-52.00 N/mm^2, with an average of 48.93 N/mm^2). But in DIME, the Schmidt Hammer strength varies widely from 31.17-49.83 N/mm^2 and an average of 42.88 N/mm^2. The DOMA has the highest average Schmidt Hammer strength value (Fig. 8).Similarly, the uniaxial compressive strength(UCS)values vary narrowly in the DOM (50.8-51.2N/mm^2, with an average of

51N/mm^2) and DOMA samples(42.0-55.2 N/mm^2, with an average of 49.31N/mm^2). But in DIME, the UCS varies widely from 35.2-51.8 N/mm^2 and an average of 47.55N/mm^2. DOM has the highest average uniaxial compressive strength value (Fig. 9).

DISCUSSION

The Dolerites are generally fine-medium grained, grey to dark ash with some black coloured types. The medium grained variety is more abundant on top of the hills while the fine-grained dolerites occur mostly along fractures and fault zones. They are also free from soft patches and cracks, which is a good criterion for any stone to be used as dimension stone. Average density values of the dolerites the from study area range between 2.73 and 2.89g/cm^3 (Fig. 3). According to Leaman, (1973), these rocks have good densities and are suitable for use in the construction industry as construction stones are expected to have density values between 2.7 g/cm^3 and 3.2 g/cm^3. In terms of rock porosity, which is the ratio of the space taken up by the pores in a rock to its total volume, the dolerites from this study area have average values slightly higher (1.09-1.29%(Fig. 5)) than the expected average (1.0%) for materials to be used as construction stones (Leaman, 1973). Nevertheless, the above average porosity values does not seem to have significant effect on the general water absorption capacity of the studied rocks, as they all have average water absorption values (0.29% - 0.76% (Fig. 7)) far below the maximum limit (5%) for any construction stone. It may be that even though the rocks have pore spaces, they are not inter-connected thereby making the water absorption level very low. Good construction stones are expected to have average specific gravity values not less than 2.5 (Leaman, 1973). From the results obtained, it is evident that the rocks from study area are good and well suited for the construction stones industry as they have average specific gravity values between 2.79 and 2.93 (Fig. 4).
The durability index (DI) of rocks is an indication of how much "wear and tear" a rock can withstand and this index is related to almost all the other geomechanical properties of the rock. Based on the average durability index of the rocks from the study area, (DOM = 98.31, DIME = 97.82, DOMA = 97.66 (Fig. 6)) and according to Gamble's Slake Drum durability classification (Johnson and Degraff, 1988), the dolerites from the study area fall into 'class B' – high durability for the DOM and 'class C' – medium-high durability for the DIME and DOMA. Also based on the Deere and Miller (1966) classification of intact rocks on the basis of strength, majority of the dolerite from the study area are categorized as 'medium strength' or 'strong'. These indicate that the dolerites from this study area can be used with confidence as construction stones.

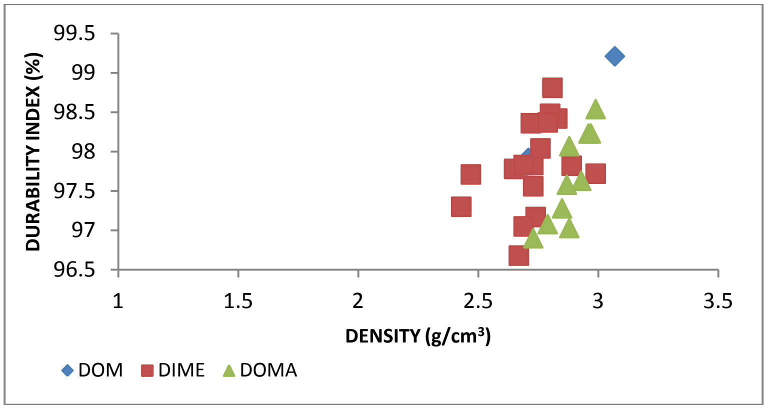

Fig. 10: Durability index against density of dolerite from study area.
As density increases, the durability also increases.

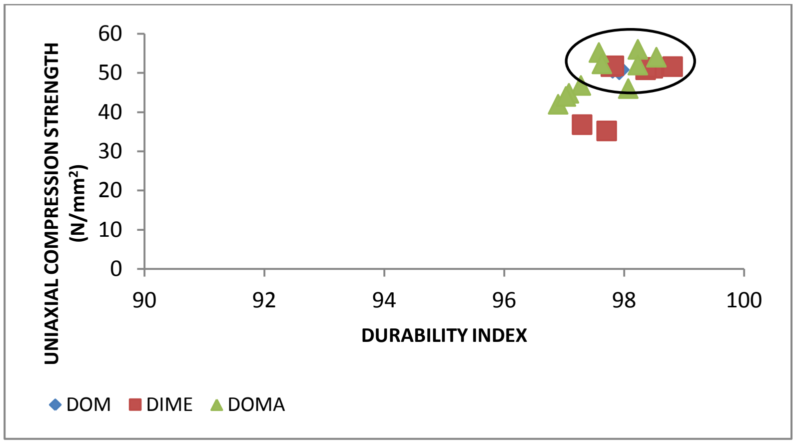

Fig. 11: Uniaxial compressive strength against the durability index of dolerites from study area.
Majority of the rocks cluster in the 50-60 N/mm^3 /97-99% area, which is good as construction materials

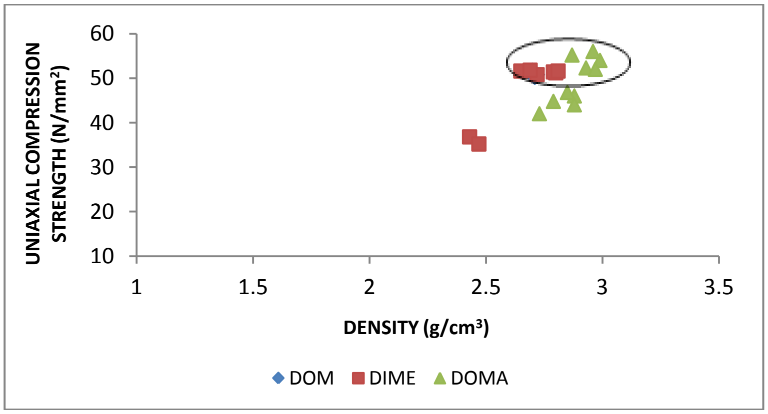

Fig. 12: Uniaxial compressive strength against density of dolerites from study area.
Majority of the rocks cluster in the 50-60 N/mm^3 /2.7-3.0g/cm^3 area.

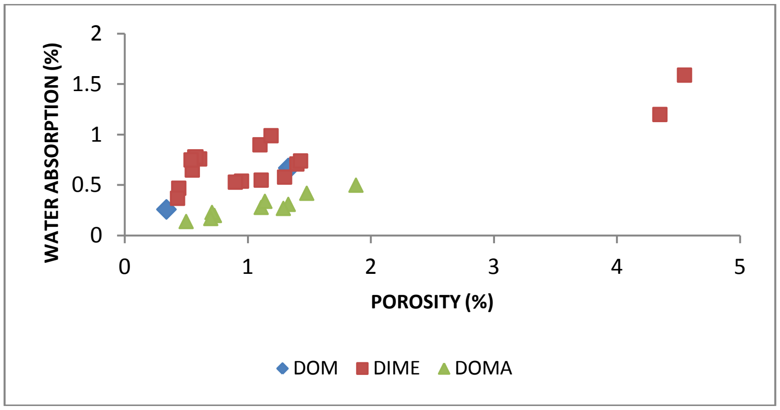

Fig.13: Water absorption capacity against porosity of dolerites from study area. As the porosity increases, the water absorption capacity also increases. The two samples with >4% porosity are actually weathered and altered.

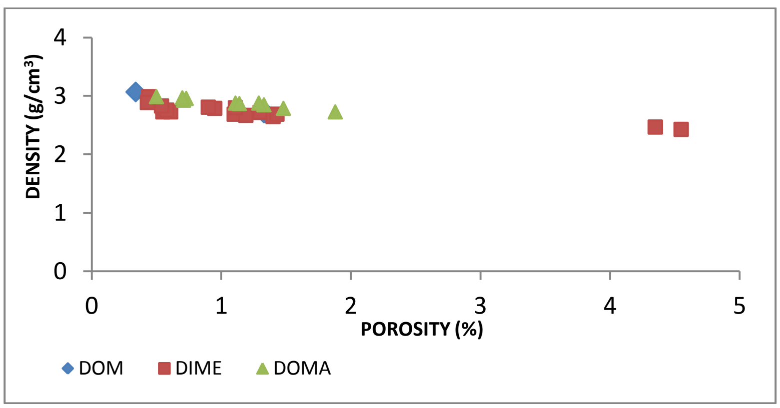

Fig. 14: The density against porosity plot show that increase in porosity leads to decrease in density values.

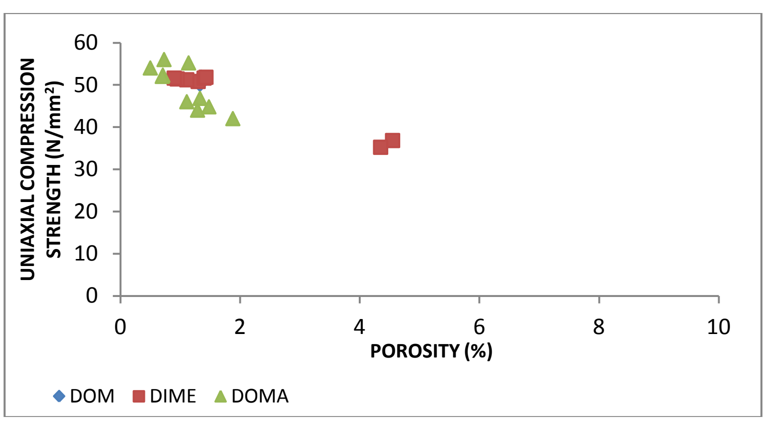

Fig. 15: The uniaxial compressive strength against porosity plot also shows the effect of porosity on the eventual strength of the rock. The more porous samples are actually weaker.

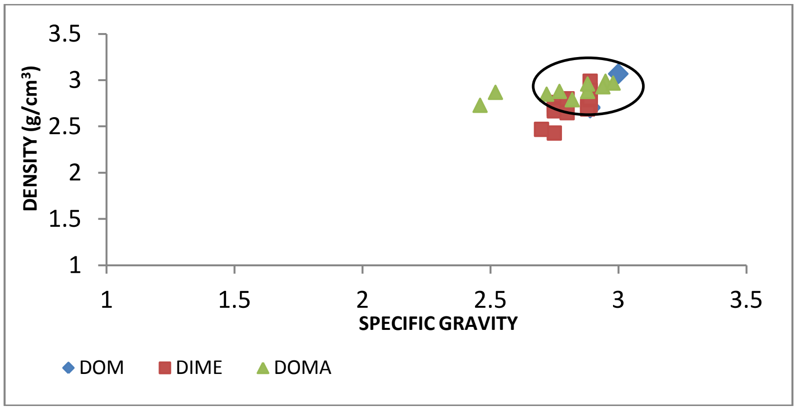

Fig. 16:The rocks from this study area have high density and specific gravity as they fall into the 2.7-3.0g^{-cm3}/2.7-3.0 range.

Relationships between index properties

In Figs. 10 and 11, the durability index of the rocks was plotted against the density and uniaxial compressive strength (UCS), while in Fig. 12, uniaxial compressive strength was plotted against density and a positive correlation was obtained. Hence as the density of the rock increases, both the durability index and uniaxial compressive strength also increase. Thus the rocks falls within the DI/Density ratio of 97.0-99.5% /2.70-3.0g/cm^{3}and UC/DI ratio of 50-60 N/mm^3 /97-99%, which is a good indication of dense and durable rocks suitable for construction works especially in residential/office buildings which would have high human traffic and activities, and to withstand high load impact for a reasonably long period of time (Esu et al., 1994, Leaman, 1973).

Figs.13, 14 and 15 show a directly proportional relationship existing in the dolerites from study area between porosity and water absorption, density and uniaxial compressive strength. It is observed that an increase in porosity leads to increase in water absorption capacity, decrease in density and also decrease in the uniaxial compressive strength of the rocks. Generally, the rocks have low porosity values, hence low water absorption capacity which otherwise, would have resulted in swelling and weakening of the rocks. This attribute makes the rocks under investigation good for tiling, flooring, and other 'water-tight' construction purposes.

A majority of the dolerites from the study area show high density/specific gravity values and they cluster within the 2.7-3.0g$^-$cm^3 and 2.7-3.0 range (Fig. 16). This value range according to Leaman, (1973), is good for rocks that are suitable for use as construction stones. It is believed that high compaction of the mineral crystals in the rocks is responsible for this high density/specific gravity ratio and also the low porosity, low water absorption and high density characteristics. A close inspection of the parameters indicates that porosity is the most fundamental of them all, for it tends to influence most of the other properties.

CONCLUSIONS

On a general note, all the dolerites (DOM, DIME, and DOMA) from the study area, show acceptable physical and mechanical properties, which make them very suitable for the construction/dimension stone industry. But the DOM is considered the most suitable when compared to all other samples (DIME and DOMA) because it has the highest average value of specific gravity, durability index, and uniaxial compressive strength, the lowest porosity and moderate density, water absorption and Schmidt Hammer strength values (Table 2). These are good qualities that make the DOM suitable and highly recommended for construction works especially for swimming pools, dams and bridges. The DIME, even though has characteristics better or comparable to world average dolerites, is considered the least preferred among those of the study area, because it has the lowest uniaxial compressive strength, Schmidt Hammer strength, and density along with the highest water absorption capacity and porosity values. Since the sedimentary overburden on the outcrops is thin, usually <2meters (Fig. 17), quarrying these rocks for commercial purposes would be economic and a viable business. But it is advisable that the environmental conditions within which it would be used should be properly evaluated before its application and due to the weathering pattern of dolerites (i.e. from top to bottom or from sides inwards), the first few meters around a dolerite sill or dyke should be avoided when quarrying for construction stones. A note of caution must be sounded here in the usage of dolerite as a construction stone. The geochemistry of dolerites in general does not make them very desirable to be used especially for outdoor road construction or beautification projects, since they are very rich in ferro-magnesian minerals which can weather and change the colour of the structure, even as the strength and durability of the rock are being significantly affected. But in indoor flooring and tiling and for use in concrete making, these rocks should be considered an alternative to the popular gneisses and granites as they all have similar geomechanical properties.

Geomechanical properties	Density	Specific gravity	Porosity	Durability index	Water absorption	Schmidt hammer strength	Uniaxial compressive strength
Highest value *Values of parameters decreases downwards* ↓	**DOM**	**DOM**	**DIME**	**DOM**	**DIME**	**DOMA**	**DOMA**
	DIME	**DIME**	**DOMA**	**DIME**	**DOM**	**DOM**	**DOM**
Lowest value	**DIME**	**DOMA**	**DOM**	**DOMA**	**DOMA**	**DIME**	**DIME**

Table 2:Geomechanical parameters variation in the geological terrains (Oban and Obudu massifs and Ikom-Mamfe embayment)

*** DOM-Oban massif; DOMA-Obudu massif; DIME-Ikom-Mamfe embayment**

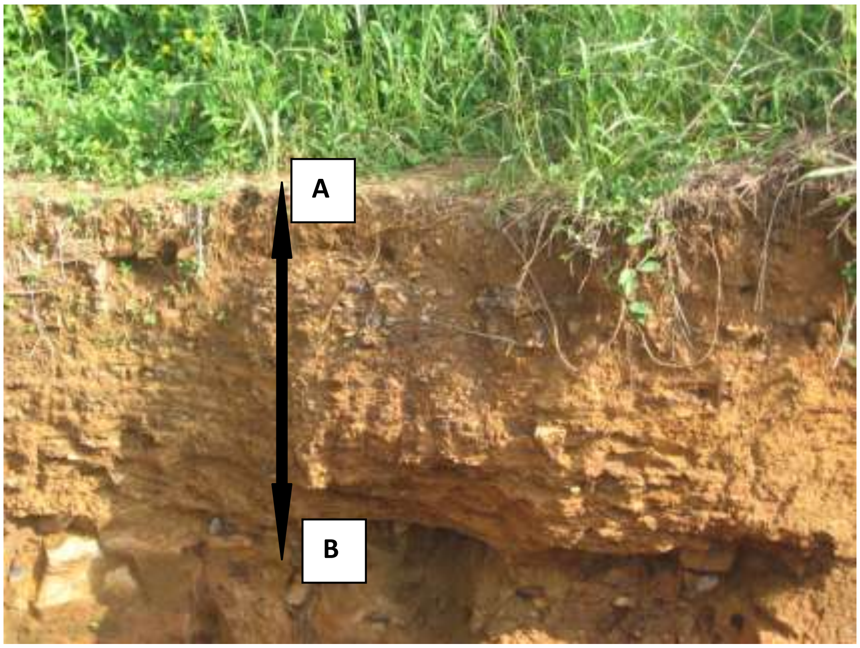

Fig.17. Sedimentary overburden on dolerite sill

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