COMPOSITIONAL CHARACTERISTICS AND FUNCTIONAL APPLICATIONS OF OBAJANA MARBLE DEPOSIT IN THE PRECAMBRIAN BASEMENT COMPLEX OF CENTRAL NIGERIA

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ABSTRACT

The determination of mineralogical and geochemical characteristics and physical parameters of Obajana marble deposit was carried-out with a view to establishing its compositional features and appraising its functional applications in various industrial products and processes. Obajana marble is closely associated with metasedimentary, ultramafic and granitoid assemblages of the Precambrian Lokoja-Jakura Schist Belt of central Nigeria. Mineralogical data from petrographic and and x-ray diffraction studies reveal the marble to be mainly calcitic, with minor amounts of dolomite, quartz, phlogopite and graphite. Geochemical analyses of the marble using inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS) reflect the calcitic (CaO 53.39 wt. %; MgO 1.098 wt. %) nature of the marble bodies. SiO_2 concentrations range between 0.58 and 4.12 wt. %, with the average concentration of 1.90 wt. %. Al_2O_3 (0.243 wt. %), Fe_2O_3 (0.114 wt. %) and TiO_2 (0.029 wt. %) contents are generally low; while Na_2O, K_2O and P_2O_5 concentrations are less than 0.12 wt. %. These chemical data portray the very high purity level of the Obajana marble deposit. Similarly, the results of physical parameters for the marble indicate that bulk density (2.55g/cm³), compressive strength (13.84 Mpa), hardness (3.0), specific gravity (2.71), water absorption capacity (0.49%), apparent porosity (0.64%), colour brightness (83) and pH (8.3) are within the range for calcitic marble. Appraisal of the functional potential of the marble based on mineralogical, chemical, physical and mechanical characteristics indicate that Obajana marble is suitable for cement feedstock, iron and steel fluxes, fillers in paints and paper making and as extenders in the manufacture of glass and carbonate based chemicals. The marble also finds suitable environmental applications in water treatment (water acidity reversal), owing to its high pH (8.3) value and very low cobalt contents (0.35ppm); while in sewage management, it can be utilized in silica and phosphate removal from sewage effluents; as well as its application in agricultural soil conditioning.

Keywords: Obajana Marble, Compositional Characteristics, Functional Applications, Central Nigeria

INTRODUCTION

Marble bodies are widely distributed within the Precambrian Basement Complex of Nigeria. These bodies are commonly associated with the Schist Belts (Fig.1), which may be regarded as infolded belts (perhaps initially protobasins) into the multiply deformed and variably metamorphosed migmatite-gneiss-quartzite complex (McCurry, 1976; Grant, 1978; Rahaman, 1988). The Schist Belts generally show distinctive petrological, structural and metallogenic features (Elueze, 2002; Elueze and Okunlola, 2003); occupying an essentially N-S trending troughs, and are more prominent in the western half of the country (Oyawoye, 1972; McCurry, 1976; Turner, 1983). However, other belts have been highlighted in central Nigeria (Emeronye, 1988; Oluyide and Okunlola, 1995) and further to the southeastern part of the country (Ekwueme and Onyeagocha, 1986; Muotoh *et al.,* 1988; Nwabufo-Ene and

Mbonu, 1989).

In various districts in Nigeria, marble bodies are being mined and applied as ingredients for various industrial products and processes. While the distribution, applications and industrial potentials of some deposits have been investigated (Ofulume, 1991; 1993; Elueze, 1993; Emofurieta and Ekuajeni, 1995; Odeyemi *et al.*, 1997; Okunlola, 2001; RMRDC, 2010a; RMRDC, 2010b; Obasi, 2012), others are largely still in varying stages of geological, engineering and economic appraisals. It is noteworthy and rather surprising to observe that some of these marbles are indiscriminately applied without much regards to their compositional attributes and physical characteristics. For instance, recently collapsed urban buildings and other civil structures in city centres in Nigeria have been linked to poor quality of cements. These have, in part, been traced by some mineralogists and

industrial experts to high calc-silicate gneiss contents in some marble deposits utilized for feedstocks in cement production.

Obajana area lies within the Lokoja-Jakura Schist Belt and it is characterized by low-lying marble bodies, disseminated as lenses within quartz-mica schist at about 4 kilometre to Obajana township. Although, the marble is currently being exploited for cement production, there are however inadequate compositional and geotechnical data on the marble for other functional utilizations. Therefore, there is the need to determine the mineralogical, geochemical and physical characteristics of the marble deposits, in order to lucidly elucidate its functional applications. This is anticipated to complement other efforts towards sustainable development of industrial mineral sector of the country.

GEOLOGICAL SETTING
Geology of Lokoja-Jakura Schist Belt
Rocks of Obajana area lie within the Lokoja-Jakura Schist Belt of the Nigerian Basement Complex. The Nigerian Basement Complex forms part of the Neo-Proterozoic to Early Palaeozoic Pan–African mobile belt that lies between the Archaean to Lower Proterozoic West African and Congo-Garbon cratons (Clifford, 1970; Black et al., 1979) (Fig. 1). The Precambrian Basement Complex rocks have been loosely categorized into three broad tectono-stratigraphic units: the reworked and multiply metamorphosed ancient migmatite-gneiss-quartzite complex, metasediments (Schist Belts); and the Pan-African intrusive series (Van Breemen, 1977; Elueze, 1988; Rahaman, 1988; Elueze, 2000; Ajibade et al., 1989; Dada et al., 1998). Intruding these units are post-tectonic undeformed minor felsic and mafic intrusives (Adekoya et al., 2003; Dada, 2006). The Precambian Basement Complex is polycyclic in nature, having witnessed at least three thermotectonic events, the latest being the Pan-African Orogeny, which is largely responsible for widespread igneous activities and the dominant N-S structural trends of the basement rocks (Grants, et al.,1972; Turner, 1983).

The Schist Belts essentially comprise metamorphosed pelitic to semipelitic and quartzitic assemblages (Elueze, 1980; 1981;

Annor, 1983; Fitches et al., 1985; Ige and Asubiojo, 1991; Adekoya, 1996). Associated with these major petrological units are other minor rock units, which are variably distributed and frequently applied in discriminating the belts (Elueze, 2002). They comprise ferruginous and carbonate rocks, which are commonly banded iron-formations (BIFs), marbles (calcitic/dolomitic) as well as calc-silicate rocks; while mafic (metaigneous) and ultramafic (talc schists) rocks with associated gold mineralizations have been documented in some of the belts (Olade and Elueze, 1979; Elueze, 1981; Adekoya, 1995; Olobaniyi and Annor, 2003).

Basement rock exposures in the Lokoja-Jakura Schist Belt are dominated by gneissic and metasedimentry rocks (Hockey, et al, 1986; Okunlola, 2001). The metasediments comprise the quartz-mica schists, phyllites, with minor occurrences of quartzite, graphite schist, silicate facies iron-formations and marble. Marble commonly occurs as elongated lensoidal bodies within the metasedimentary rocks. Intruding these rock units are syntectonic to late tectonic granitoids.

Field Occurrence and Petrography
Obajana district is underlain by granite gneiss, quartzite, quartz-mica schist, phyllites, silicate facies iron formation, marble and biotite granites (Fig. 2). The biotite granite gneiss constitutes the largest portion of the crystalline rocks of the area, displaying fairly hilly topographic features. It is generally dark grey in colour and medium to coarse-grained, showing weak gneissose foliation, but the lineation is commonly well defined by the alignment of biotite and microcline porphyroblasts. Petrographic examination reveals microcline, oligoclase (An_{25-30}), quartz, biotite, hornblende with sphene and other opaques as accessory minerals.

Quartz mica schists are well exposed, invariably forming rounded hills and also discontinuous ridges in the area. Intensive weathering in some localities also shows them as low-lying outcrops, and often appears white to light grey. Thin section studies indicate the dominance of quartz with granoblastic texture and the characteristic wavy

extinction on a complete rotation of the microscope stage under crossed polars. Muscovite laths with the distinctive platy cleavage are observed to occupy the intergranular spaces between the interlocking quartz grains. Phyllite outcrops as low-lying ridges, showing the

concordant NNE-SSW foliation trends with other metasediments of the area. It is fine grained, bluish grey in colour and shows silky white lustre. Optical studies show muscovite, chlorite, quartz and sericite as the dominant minerals, with epidote, zircon and opaques as the
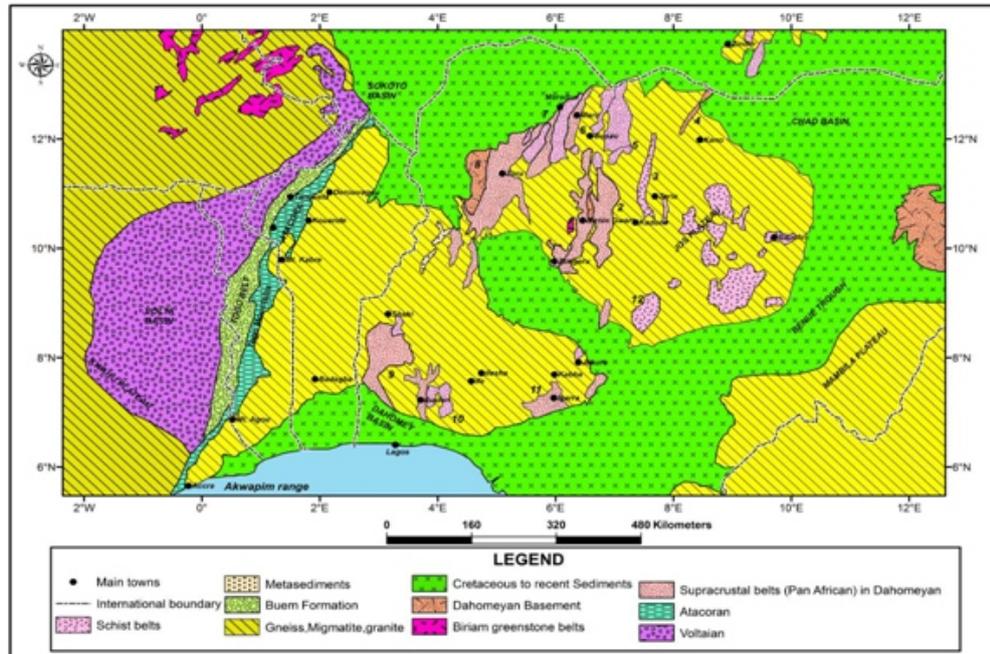

Fig.1: Schist Belt Localities in Nigeria within the Context of the Regional Geology of Parts of West Africa (Modified after Wright *et al.,* 1985). 1. Zungeru-Birnin Gwari, 2. Kusheriki-Kushaka, 3. Karaukarau, 4. Kazaure, 5. Wonaka, 6. Maru, 7. Anka, 8. Zuru, 9. Iseyin-Oyan River, 10. Ilesha, 11. Igara, and 12. Muro Hills.
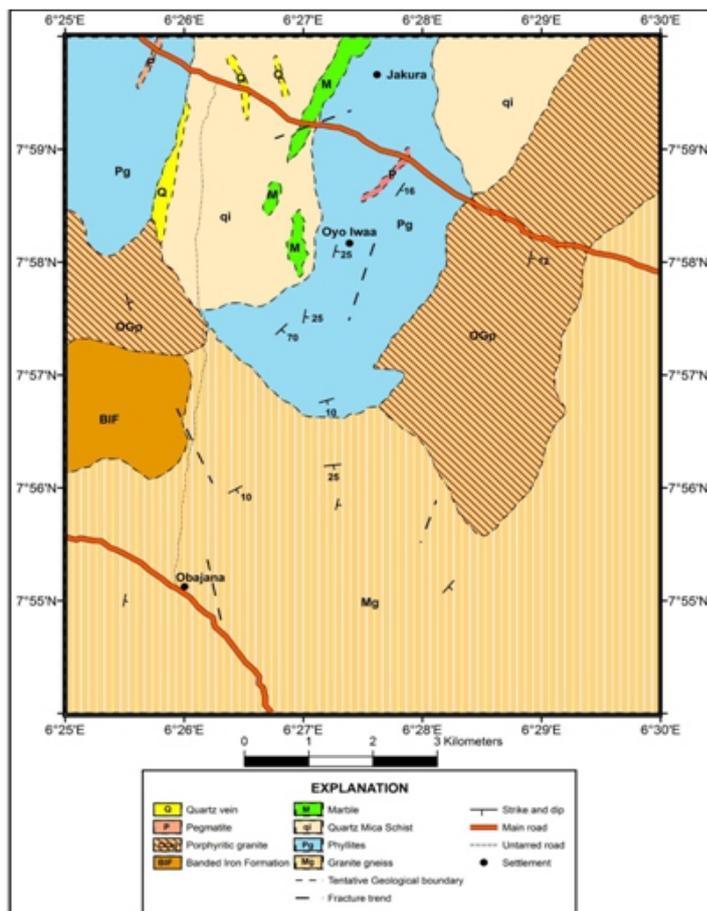

Fig. 2: Geological Map of Obajana Area (Modified after Okunlola, 2001)

Quartzite essentially occurs as intercalations with quartz muscovite schist and phyllite. It is medium to coarse-grained and massive. Petrographic studies indicate subequant to equant mosaic granoblastic texture of quartz grains. Silicate facies iron formation of the area is dark grey to brown in colour and fine to medium-grained. It displays thin light quartz-rich bands, alternating with magnetite-bearing dark bands. Thin section examination indicates the banded iron formation to be composed of subhedral magnetite, sphene plus other opaque ores as accessory minerals interbanding, with the fine to medium granoblastic quartz grains.

Marble bodies of Obajana are exposed along River Mimi channels as low-lying N-S trending lensoid bodies. Outcrops at the quarry sites are equally low-lying, and where they are masked by soils, they are usually marked by sparse vegetation of short grasses. Under the microscope, the marble is observed to consist of mainly calcite, with minor amounts of quartz, graphite and phlogopite. The calcite appears greyish white to colourless, hypidioblastic in shape, exhibiting rhombohedral cleavage and showing prominent polysynthetic twinning. Phlogopite shows subhedral to euhedral hexagonal crystals and often pale brown in colour. Graphite largely appears as small black patches in thin section.

The biotite granite of the area shows porphyritic texture of microcline phenocrysts, set in groundmass of quartz, microcline, plagioclase, biotite, hornblende and opaque ores. In thin section, alkali feldspar phenocrysts with the characteristic cross-hatched twinning are surrounded by smaller grains of other minerals. Myrmekitic intergrowths between plagioclase and quartz are present. Plagioclase shows well developed Carlsbard twinning, but often with some grains displaying alteration to sericite that partially obliterates the twinning.

MATERIALS AND METHODS
Marble samples were collected as rock chips from mine pits and fresh exposures of the marble bodies. Care was taken to ensure that samples collected were representative of the two prominent colour variations, the grey and white varieties. Thirty-eight representative samples (each weighing about 2.5-3.0 kg) were collected from different parts of the marble deposit, out of which twenty-nine samples were selected for thin sectioning, X-ray diffraction studies, geochemical analyses and physical and mechanical properties determinations.

Samples of both marble varieties were thin sectioned for petrographic examination, using plane and cross polarized light. Marble samples for X-ray diffraction studies were crushed, pulverized and sieved to appropriate size fractions (2 μm). The pulverized portions were subjected to X-ray diffractometry at ACME Laboratories, Vancouver, Canada, using a PaNalytical X' Pert Pro Diffractometer, equipped with a Cu X-ray tube and Ni monochromator and operated at 40 KV and 30 mA. Diffraction charts were provided at a scan rate of $1°/2\theta/min.cm$. The obtained diffraction patterns were compared with well-established standards and interpreted with reference to the Joint Committee on Powder Diffraction Standards (JCPDS, 1974) Tables of X-ray powder diffraction patterns.

Major and trace element abundances of the pulverized representative samples were determined, using inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS) at the ACME Laboratories, Vancouver, Canada. The applicable fusion and decomposition procedures are specified in the 4A and 4B (ICP-AES and ICP-MS) analytical package of the Laboratory (www.acmelabs.com, accessed September 2012). This involves the use of lithium metaborate/tetraborate (as fusion reagent) to decompose 0.2 g portion of the pulverised samples and the subsequent digestion of the fused aliquots in nitric acid for the eventual ICP-AES and ICP-MS analyses. Loss on ignition was determined by weight difference after ignition at $1000°C$. Detection limits for major elements is 0.01%, while the one for trace elements range between 0.1 ppm to 5 ppm.

Physical and mechanical characteristics of the marble samples were determined, using procedures and specifications of the American Society for Testing and Materials (ASTM, 1976), which are applicable in Nigerian geotechnical

tests. The physical tests carried out include the pH, porosity, bulk density, specific gravity, loss on ignition, shear strength, compressive strength, hardness, water absorption, aggregate impact value and colour brightness (Jimoh, 2012).

RESULTS AND DISCUSSION
Mineralogical Characteristics of the Marble
The minerals identified under plane and crossed polarized light include calcite, quartz, graphite and phlogopite. Calcite is the dominant mineral, while other minerals occur in minor amounts. The distinction between calcite and dolomite was not easily resolved using petrographic microscope but greater details were derived from X-ray diffractograms.

X-ray diffractograms reveal that Obajana marble bodies are composed dominantly of calcite with minor amounts of quartz and dolomite. The mineralogical data of the white coarse-grained marble variety based on calculated peak height ratio show that the sample is composed of 95% calcite and 5% quartz (Fig. 3a); while the white fine grained Obajana marble sample indicate 98% calcite and 2% quartz (Fig. 3b). The grey coarsed grained marble type, however, shows 97% calcite and 3% dolomite (Fig. 3c). The phlogopite and graphite peaks are, however, not reflected in the diffractogram. This may be ascribed to the poor absorption of X-ray by these minerals.

The mineralogical composition of Obajana marble indicates its high calcitic and low silica nature when compared with other marble bodies in Nigeria (Igbeti, Emofurieta and Ekuajemi, 1995; Elebu, Zojak, 1981, Kwakuh, McCurry, 1976; Burum; Okunlola, 2001). The calcitic nature of Obajana marble makes it suitable as cement raw materials, ingredient for iron and steel fluxes, fillers in paper and paints manufacturing and as extenders in glass making and carbonate based chemicals, as well as water and soil acidity treatment purposes

Chemical Characteristics of the Marble
Chemical data presented in Table1 show the major and some selected trace elements composition of the marble. The SiO_2 concentrations of the marble are generally low, indicating a range of 0.58 to 4.912 wt. % and average concentration of 1.90 wt. %. The CaO contents of the marble range between 49.9 and 55.25 wt. %, showing 53.31 wt. % as the average value. The high CaO (53.31 wt. %) concentrations of the marble reflect its calcitic nature while the average MgO (1.098 wt. %) contents of the marble portray its non-dolomitic nature and the absence of calc-silicate rocks in the marble bodies. TiO_2 (0.029 wt. %), MnO (0.015 wt. %), Fe_2O_3 (0.114 wt. %) and Al_2O_3 (0.243 wt. %) values are all at low levels. Similarly, average P_2O_5 (0.058 wt. %) Na_2O (0.12 wt. %) and K_2O (0.073 wt. %) equally show low concentrations.

The trace element contents of the marble generally show low levels and restricted variation among samples (Table1). Average Co (<1 ppm), Cu (<3 ppm), Pb (<2 ppm) and Zn (<3 ppm) are generally low and indicate the high degree of purity of the marble. However, the high Sr (2740 ppm) and Ba (67 ppm) contents are probably indicative of the geochemical association of calcium with these elements. Compared with average and range of chemical data of marble bodies elsewhere (Table 2), the marble is observed to be highly calcitic and show high level of purity. These compositional attributes are consistent with specification for use as raw material for cement production, iron and steel fluxes, fillers in paper and paint production, as extenders in glass making, and ingredient in carbonate based chemical product as well as its applications in soil and water acidity reversal.

Physical Characteristics of the Marble
Physical tests of Obajana raw marble samples were performed to ascertain its functional roles in some industrial products and processes. Summary of the physical characteristics of the marble as compared to other marble samples elsewhere are presented in Table 3.

Results of the pH determinations (Table 3) of the powdered samples which range between 8.2 and 8.3 show that there are no marked differences in the pH values of the marble samples, and these values are comparable with Shapfell Marble (Dowrie et al.,, 1982), Cheetor Marble (Scott and Durham, 1984) and Indiana marble (Boynton, 1980). These pH values of the marbles make them suitable for ameliorating acid soils and in optimising maximum growth in crops. Most

tropical soils are acidic due to high precipitation, acid rains and depletion of basic nutrients by plants and the application of nitrogen fertilizers. The range of apparent porosity of between 0.61% and 0.66% for the marble are of no remarkable difference. These low porosity values make Obajana marble suitable for various construction purposes.
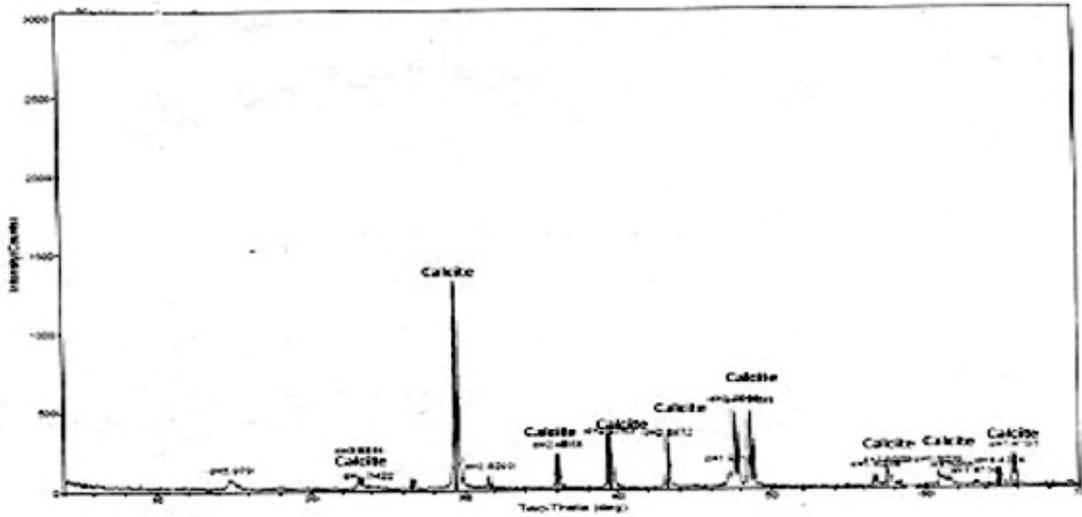

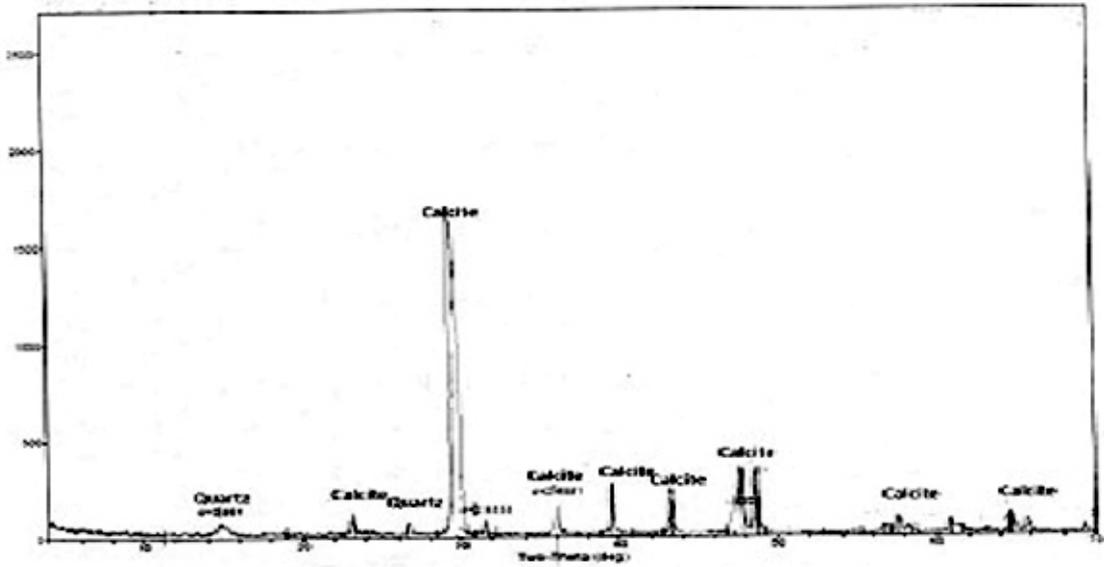Fig. 3a: X-ray diffraction results of Obajana marble samples

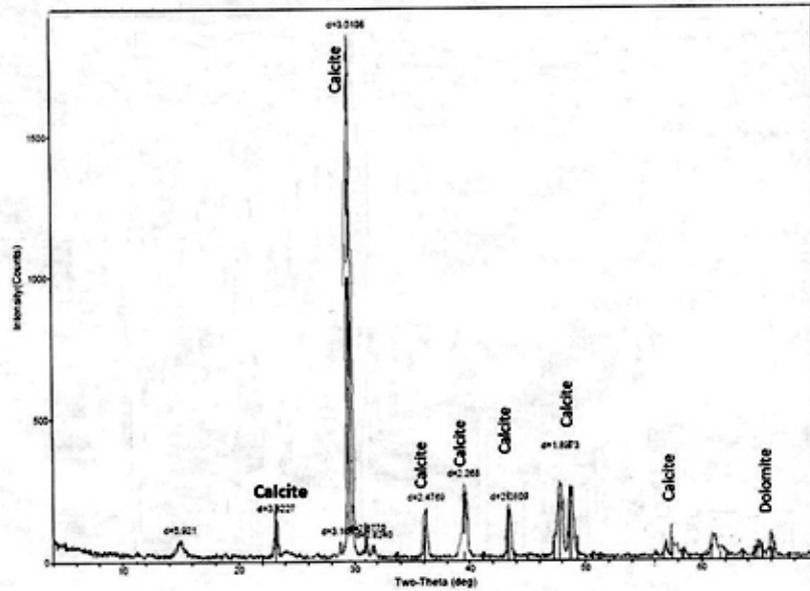Fig. 3b: X-ray diffraction results of Obajana marble samples

Fig. 3c: X-ray diffraction results of Obajana marble samples

Table 1: Chemical Composition of Obajana Marble.

wt. %	OBM1	OBM2	OBM3	OBM4	OBM5	OBM6	OBM7	OBM8	OBM9	OBM10	Mean	Range
SiO_2	4.12	2.12	0.58	1.36	1.12	0.67	2.54	0.67	3.12	2.72	1.902	0.58-4.12
Al_2O_3	0.13	0.62	0.08	0.43	0.34	0.10	0.52	0.11	0.16	0.21	0.243	0.08-0.52
Fe_2O_3	0.08	0.22	0.06	0.24	0.19	0.09	0.25	0.08	0.07	0.04	0.114	0.04-0.25
TiO_2	0.08	0.04	0.01	0.03	0.02	0.01	0.03	0.01	0.02	0.04	0.029	0.01-0.0.08
MnO	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.03	0.015	0.01-0.03
MgO	2.11	0.85	0.18	2.89	0.73	0.31	1.06	0.41	1.46	0.98	1.098	0.18-2.89
CaO	49.90	53.02	55.25	51.66	54.28	55.18	52.29	55.24	53.98	53.32	53.31	49.9-55.25
Na_2O	0.31	0.15	0.07	0.12	0.01	0.07	0.11	0.07	0.21	0.08	0.12	0.01-0.31
K_2O	0.21	0.14	0.02	0.04	0.06	0.01	0.09	0.02	0.08	0.06	0.073	0.01-0.21
P_2O_5	0.09	0.06	0.03	0.05	0.05	0.08	0.05	0.12	0.03	0.02	0.058	0.02-0.12
LOI	42.62	42.71	43.05	42.96	42.40	43.08	42.88	43.18	42.18	41.12	42.18	41.12-43.18
Total	99.67	99.49	99.34	99.76	99.65	99.69	99.59	99.63	99.64	99.76	99.63	99.40-99.76
$\%CaCO_3$	96.86	97.07	97.84	97.64	96.36	97.91	97.45	98.14	95.86	93.45	97.16	95.86-99.86
Ppm												
Co	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.1	1-2
Ce	13	4	1	3	2	1	3	4	8	2	4.1	1-13
Cu	6	1	2	3	2	2	3	1	3	2	2.5	1-6
Pb	4	2	<1	1	<1	<1	2	<1	1	1	1.5	1-4
Zn	10	3	1	1	2	1	2	1	2	2	2.5	1-10
Ba	157	100	57	24	64	36	83	50	68	32	67	24-157
Sr	3186	3058	3678	1577	2318	2586	3156	3269	1860	2710	2740	1577-3678
Rb	22	8	1	2	3	<1	4	1	3	5	5.44	1-22

Table 2: Chemical Composition of Obajana Marble Compared with other Marble Bodies in Nigeria

	Obajana (n=10)		Jakura (n=33)		Ososo (n=21)		Igbeti (n=7)		Burum (n=29)	
Oxide	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	1.90	0.58-4.12	0.44	1.47-9.10	1.18	0.03-3.90	0.49	0.10-1.40	3.81	3.52-3.86
Al_2O_3	0.243	0.08-0.52	0.07	0.02-0.15	0.10	0.01-0.17	0.03	0.01-0.05	0.16	0.1-0.75
Fe_2O_3	0.114	0.04-0.25	0.04	0.02-0.07	0.07	0.02-0.22	0.07	0.01-0.23	0.16	0.14-0.28
TiO_2	0.029	0.01-0.08							0.17	
MnO	0.015	0.01-0.03	0.002	0.001-0.005	0.003	0.001-0.005	0.002	0.001-0.005	0.01	0.008-0.01
MgO	1.098	0.18-2.89	0.32	0.26-0.40	1.75	0.48-3.39	20.70	18.01-22.87	20.75	20.58-21.52
CaO	53.31	49.9-55.25	55.33	55.00-55.80	53.64	52.20-55.50	28.94	24.78-32.06	31.0	30.35-32.01
Na_2O	0.12	0.01-0.31	0.03	0.01-0.05	0.02	0.01-0.03	0.01	0.01-0.02	0.05	0.115-0.31
K_2O	0.073	0.01-0.21	0.001	0.01-0.04	0.01	0.00-0.02	0.002	0.001-0.004	0.12	
P_2O_5	0.058	0.02-0.12	-						0.03	
LOI	42.18	41.12-43.18	43.50	43.00-43.80	43.26	41.50-44.04	40.00	32.88-44.40	43.56	42.45-44.17
Total	99.63	99.40-99.76	98.76							
%$CaCO_3$	97.16	95.86-99.86								
Ppm										
Co	1.1	1-2	17	10-20	15	10-20	14	10-20	14	
Ce	4.1	1-13	3	3-6	4	3-6	3	3-6		
Cu	2.5	1-6	5	2-9	6	5-7	9	7-11	4	
Pb	1.5	1-4								
Zn	2.5	1-10	13	13-19	12	10-15	23	15-29	38	
Ba	67	24-157								
Sr	2740	1577-3678								
Rb	5.44	1-22								

I.   Obajana marble (this study)
II. Jakura marble (Emofurieta and Ekuajeni, 1995)
III. Ososo marble (Emofurieta and Ekuajeni, 1995)
IV. Igbeti marble (Emofurieta and Ekuajeni, 1995)
V. Burum marble (Okunlola, 2001).

Table 3: Comparison of the Physical Properties of Obajana Marble Samples with other Marbles

Properties	Range (Obajana)	Mean (Obajana)	Mean (Shapfell)	Mean (Cheetor)	Mean (Indiana)
pH	8.2 - 8.3	8.25	8.1	8.35	8.11
Apparent porosity (%)	0.61 - 0.66	0.64	0.62		0.65
Bulk density (g/cm³)	2.54 - 2.55	2.545		2.56g	2.65
Specific gravity	2.715-2.719	2.717	2.71	2.73	2.71
Loss on Ignition (%)	43.32-44.91	44.12			
Shear Strength (Mpa)	13.81-13.84	13.83		13.92	14.81
Compressive strength (Mpa)	93.46 - 93.77	93.62		90.81	90.5
Hardness	3.00 - 3.10	3.05	3.0	3.0	3.0
Water absorption (%)	0.30 - 0.69	0.5			
Aggregate impact value	18.4 - 20.5	19.5			
Colour brightness	81-84	83	90		

I.   Obajana marble (this study)
II. Shapfell marble (Dowrie, *et al.*, 1982)
III. Cheetor marble (Scott and Durham, 1984)
IV. Indiana marble (Boynton, 1980; Power, 1985)

The bulk density values (2.55 g/cm³, 2.54 g/cm³) and specific gravity values (2.715, 2.719) for the two marble varieties indicate no marked differences. These specific gravity values are within the range for Precambrian marbles (Boynton, 1980; O' Driscoll, 1988) and comparable to Indiana marble (Boynton, 1980) and Cheetor marble (Scott and Durham, 1984). The values are however slightly higher when compared with those of Sharpfell marble (Dowrie *et al.*, 1982). Compressive strength (93.46, 93.77 Mpa) and shear strength (13.84, 13.81 Mpa) are within the range of values for marbles (Boynton, 1980) and meet the specification for use as road bases, construction stone and ornamental stone.

The loss on ignition (LOI) determinations of the marble are intended for extenders and paint end users. The LOI values, which range between 43.32 and 44.91 (Table 3) are consistent for its use for these purposes. Theoretically, the LOI of pure calcium carbonate is equal to 44% weight of carbon dioxide (Evans, 1993). The closeness of the LOI (42.18) values of Obajana marble to this value confirms the high purity level of the marble.

Industrial Properties

The industrial uses of the marbles are invariably dependent on their chemical and physical attributes, which are, in turn, influenced by their mineralogy. Obajana marble is highly calcitic (> 97% $CaCO_3$) and indicates a very low level of impurities, as reflected in its mineralogical and geochemical data. Various physical tests also

show its suitability for some industrial applications. In this investigation, the compositional and industrial studies carried out were on the raw marble. Its high level of purity and its high calcitic nature is hoped to positively impact on its calcined (lime) form for the suggested utilizations.

In the production of Portland cement, the principal requirements include MgO less than 3%, total alkalis (sodium oxide, Na_2O and potassium oxide, K_2O) less than 0.6% and calcium carbonate contents greater than 82% (BGS industrial Minerals Laboratory Manual, 1993: BGS Cement Raw Materials, 2005). Other chemical specifications limit sulphur trioxide (SO_3) and phosphorous pentoxide (P_2O_5) to less than 1%, as well as very low levels of fluorine, lead and zinc (BGS industrial Minerals Laboratory Manual, 1993). Obajana marble is non-dolomitic (showing extremely low MgO), highly calcitic, and show low levels of impurity. The marble will therefore produce a high quality cement clinker, as it meets these specified requirements. It is worthy to note that the marble deposit currently supports a large scale cement production in Obajana township in central Nigeria.

Obajana marble also meets specifications for some other construction purposes, such as soil stabilisation, aggregate materials, building and dimension stones, considering its calcitic nature ($CaCO_3$> 97%). Its use as aggregate materials demands that its specific gravity be generally greater than 2.65 and of low water absorption (invariably indicating low porosity), beside its calcite content. Other than the charming aesthetic appeal, the main requirements of marble as dimension stone include its recrystallized fabric and its potential durability, which are dependent on its pore size (BGS industrial Minerals Laboratory Manual, 1993). Other considerations of marble as aggregate materials include compressive, tensile and shear strength of 20Mpa, 5Mpa and 7Mpa, respectively (ASTM, 1976).

As steel flux ingredient, the calcined form could be employed in the removal of phosphorous, silica and sulphur as slags in the form of calcium phosphate, silicates and sulphides, respectively. The industrial specifications of silica less than 5% (preferably 2%), alumina less than 2%, and magnesia less than 4% with trace amounts of phosphorous pentoxide and sulphur are invariably demanded (BGS industrial Minerals Laboratory Manual, 1993). The chemical composition of the Obajana marble, which largely reflects its high calcitic nature and very high purity level makes it acceptable feedstock for producing high quality lime that can be applied in iron and steel production.

In the manufacture of carbonate based chemical products, such as calcium carbide (CaC) and calcium cyanimide, sodium carbonate, bicarbonate and hydroxide, Obajana marble meets requisite demands of calcium carbonate ($CaCO_3$) contents (exceeding 95%), combined alumina and ferric oxides less than 0.5%, phosphorus in trace amount (0.01%) but shows a slightly higher values above the limits for MgO and silica, which are generally expected to be less than 0.5% and 1.2%, respectively. Marble primarily functions as chemically reactive raw material to generate other relevant chemicals for important industrial processes (BGS industrial Minerals Laboratory Manual, 1993).

Marble, as raw materials for fillers in paints, papers and plastic manufacturing, principally requires appropriate particle fineness, high brightness values and chemical inertness. Specific chemical requirements include high $CaCO_3$ (> 96%) and low MgO (1.1%) contents; other maxima include low Fe_2O_3 (0.25%), SiO_2 (2.0%) and SO_2 (0.1%). Excellent brightness (81-84), low levels of impurity and high calcitic nature present the Obajana marble as acceptable raw material for fillers in paper and paint making. In the paper industry, high calcium marble is required for making soda pulp and sulphate pulp. The marble can be reacted with SO_2 to produce cooking liquor. This acidic liquor is then used to digest constituent of the wood chips except cellulose.

In glass making, marble mainly functions as a flux to facilitate the melting of glass raw materials (mainly silica sand, soda ash, limestone and dolomite) at a relatively low temperature. Chemical limits of carbonate material with ferric oxide (Fe_2O_3) not more than 0.05% and preferably not more than 0.02% for colourless glass are

generally demanded; while marble having up to 0.1% Fe_2O_3 is sometimes accepted for coloured container glass (BGS industrial Minerals Laboratory Manual, 1993). Calcium carbonate in marble for glass making should exceed 96% with silica, alumina and magnesia contents expected to be very low. Obajana marble meets these specifications and thus can be applied in glass manufacturing.

The application of the Obajana marble for water softening and profound reduction of bacteria load in municipal waters can be achieved if the marble is well calcined. A pH of 8.3 is obtained from the powdered samples of the raw marble, but higher pH values could be derived from the calcined form. The absence of Co, Hg and Pb (being deleterious chemical substances) are the major requirements for water treatment and Obajana marble has none of these in either trace or minor amounts. The lime product will be useful in sewage treatment, water acidity reversal and silica and phosphate removal from sewage effluents. These specifications are quite similar to that for water softening and purification.

The agronomic application of Obajana marble for soil acidity reversal and plant nutrient enhancer is revealed from its pH value of 8.3 and its low grittiness. The raw marble and lime product can be utilized as soil ameliorants and nutrient status enhancer.

CONCLUSIONS

The field relationships, mineralogical, chemical, physical and mechanical characteristics of the Obajana marble have been investigated to highlight its potential uses in various processes and products. The Obajana marble bodies are essentially low-lying and occur as disseminated lenses within quartz-mica schist and gneisses of the area.

Mineralogical studies show that the marble bodies comprise dominantly calcite (>96%), with minor amounts of quartz, dolomite, phlogopite and graphite. The chemical data of the marble also confirm its highly calcitic nature and its low level of impurities. The determination of the physical characteristics of the marble, using well established standards and specifications,

combined with the mineralogical and chemical data aptly support the utilization of the marble as feedstock in Portland cement production, iron and steel fluxes ingredient, fillers in paints and paper making, as extenders and chemical additives in glass making and carbonate based chemicals.

The marble is also suitable for water softening, acid water neutralization and reduction of bacterial load in municipal water treatment, plus water acidity reversal and silica and phosphate removal from sewage effluents.

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