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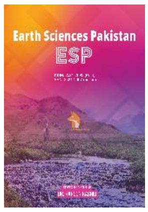

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RESEARCH ARTICLE

GEOCHEMICAL AND MINERALOGICAL CHARACTERIZATION OF MARBLE AND ITS ECONOMIC IMPORTANCE FROM IGUE AREA SOUTHERN NIGERIA

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ABSTRACT

The study area is located at Owan East Local Government of Edo state (Figure 1.1). Igue is located in the South Western part of Igarra (it runs between latitudes 7 12′ 40″N to 7 13′ 22″N and longitudes 6 5′ 21″E to 6 5′ 38.5″ on Auchi Sheet 266. A total of five (5) marble samples from Igue and environs in Southern Nigeria were obtained with the aim of qualifying the marble using XRF as well as XRD techniques and determining its economic importance. The major element composition of the marble deposit shows it has a mean chemical composition of CaO (91.14 wt. %), MgO (0.64 wt. %), SiO_2 (4.17 wt. %), K_2O (0.16 wt. %), Al_2O_3 (2.57 wt. %) and Fe_2O_3 (0.40 wt. %), respectively. The modal composition of the marble is, Calcite (65.1 %), Quartz (14.74 %), Orthoclase (7.66 %), Lime (6.5 %) and Illite (5.96 %). The results of the analysis revealed that the Igue marble is highly calcitic in composition. The ternary plot tends towards CaO and $CaCO_3$ which confirms the former. Subject to beneficiation, Igue marble can be used for cement production. The marble can also be used for sculpture, tiles, chips and decorative purposes.

KEYWORDS

Marble, Limestone, Geochemical, Mineralogical, Calcite.

1. Introduction

Marble is a metamorphic rock that is formed when carbonate rocks are recrystallized during metamorphism. Marble is a rock composed primarily of calcite ($CaCO_3$) and usually contains other impurities such as muscovite, biotite, pyrite, graphite and chlorite etc. (Odokuma-Alonge, 2020). Carbonate rocks can either be sedimentary (limestone) or igneous (carbonatites). It is composed mainly of recrystallized carbonates like calcite ($CaCO_3$) and dolomite (Ca,Mg $(CaCO_3)_2$. When carbonates (mostly sedimentary carbonates) such as limestone or dolomite are subjected to increase in temperature, it causes variable recrystallization of the original mineral grains. As this occurs, the size of the crystals in the rock increases, and the rock develops a distinct crystalline appearance (Tanko and Omosebi, 2021). Generally, marbles are the metamorphic derivatives of sedimentary carbonates.

The formation of marble usually occurs at convergent plate boundaries and begins with the deposition of calcium carbonate rich minerals in a sedimentary basin. After a long period of time, these sediments are subjected to intense heat and pressure at great depths over an extensive area which conforms to regional metamorphism. Marbles are also formed by contact metamorphism when a hot magma intrudes and heats up an adjacent limestone or dolostone.

Marbles may have colours ranging from pure white, grey, green, blue; it could be foliated when its formation is accompanied by various stresss regimes. (Oluwatoyin et al., 2021). Swirls and veins of coloured marble varieties are as a result of different mineral varieties such as iron oxides, clays, sands or silts which were present as layers or grains in limestone hence pure white marble is as a result of metamorphism of very pure limestone or dolostone. The chemical composition of any marble deposit will depend on the original limestone from which it was formed and the physiochemical conditions during such transformations. (Oluwatoyin et al., 2021). The aim of this study is to characterize the marble in Igue area using geochemical and mineralogical analysis.

2. Review Of Study Area

The study area is located at Owan East Local Government of Edo state (Figure 1.1). Igue is located in the South Western part of Igarra (it runs between latitudes 7 12′ 40″N to 7 13′ 22″N and longitudes 6 5′ 21″E to 6 5′ 38.5″ on Auchi Sheet 266. The study area is accessible via major and minor roads, but primarily via minor and pathways. At the time the samples were collected from the field, it was during dry season, the rocks were exposed as the bushes had dried out either by burning or by clearing, thus making the exposure easily accessible. Geomorphology is the study of landforms on the earth's surface, their classification, origin, development and history. The physical characteristics of the earth are studied in geography. Igue terrain comprises of the Igarra schist belt which forms a part of the Precambrian Basement complex.

The study area is made up of metamorphic and igneous rocks. The terrain is uneven and gently undulating in this location, rugged with dendritic drainage pattern. The granites are of higher elevations (highlands) than the metasediments (valleys). The study area falls under the tropical region. The vegetation of the study area is tropical rain forest. The area is made up of rainy season and dry season. The rainy season runs from March-October while the dry season runs from November - February. Due to the fact the terrain is a basement environment; the soil is highly enriched in elements that aid plant growth. The natives of this area are known for agricultural practices like farming, fishing, and hunting. Town's people are known for trading activities.

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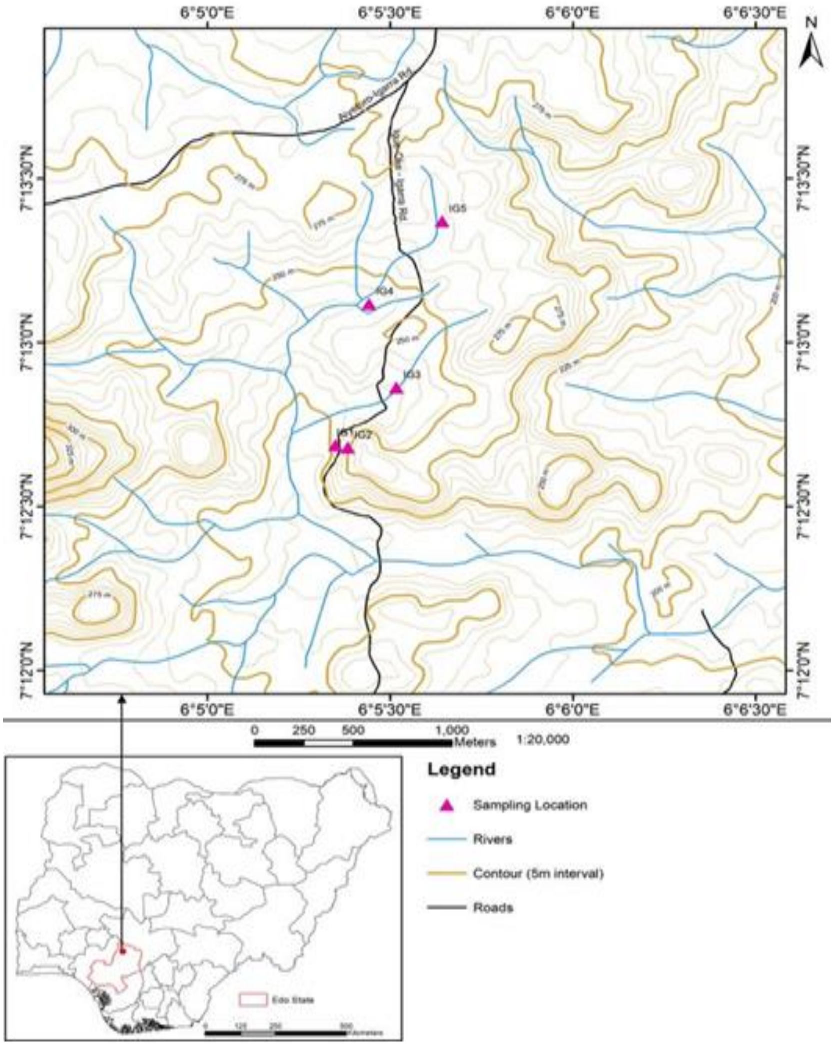

Figure 1: Location Map of Igue and Environs (Owan-East Local Government Area)

3. Geologic Setting

The study area is situated within the Pan African Mobile Belt, northwest of the Congo Craton, East of West African Craton and south of the Tuareg Shield. The presence of basic to ultrabasic rocks which are characteristcs of the Ophiolite Complexes, is evidence that the Pan African belt developed by tectonic processes which involved the collision of passive continental margin of the West African Craton and the active margin of the Tuareg Shield about 600 mya (Black et al., 1979).

The suture is marked by a string of positive gravity anomalies corresponding to the emplacement of ultrabasic and basic rocks including perhaps Ophiolites. The collision of this plate margins is believed to have led the reactivation of the internal region of the Pan African belt. The Nigerian Basement Complex lies within the reactivated part of the internal region of the Pan-African Belt.

The Nigerian Basement Complex is polycyclic and is believed to of at least four major cycles of deformation, metamorphism and based on radiometric age dating it comprises rocks of Liberian (2700+/-200Ma), Eburnean (2000+/-200Ma), Kibaran (1100+/-150Ma) and Pan African (600+/-Ma) (Rahaman, 1976).

The first three cycles featured severe deformation and isoclinal folding, as well as regional metamorphism which was followed by extensive migmatization. The Pan African deformation was accompanied by migmatization and extensive granitization and extensive granitization which produced granites and homogeneous gneiss (Abaa, 1983).The end of the orogeny was marked by faulting and fracturing (Gandu et al.,1986). Based on geochronology, stratigraphy and composition, the rocks of the Nigerian Basement Complex fall into two broad groups: the Pre Pan-African crystalline rocks comprising the migmatite gneisses and ancient granites ;and the Pan African crystalline rocks consisting of the Older Granites and metasedimentary series (Ominigbo, 2022). Typically, the Pan African rocks lie unconformably on the pre Pan-African basement (Ekueme, 1990).

Rahaman (1976) subdivide the basement complex into six major petrological group as follows:

a) Migmatite-Gneiss Quartzite complex

b) Schist belt

c) Charnokitic, gabbroic and dioritic rocks

d) Rocks of the Older Granite suite

e) Metamorphosed and unmetamorphosed calc-alkaline volcanics and hyperbassal rocks

f) Unmetamorphosed dolerite dykes, syenite dykes.

The Migmatite gneiss-quartzite complex accounts for over 60% of the basement complex (Rahaman and Ocan, 1978). These rocks are considered as Basement (*sensu stricto*) and they represent the oldest rocks in the Nigerian Basement Complex. These rocks exhibit variations in composition because of the difference in protolith and the metamorphic (P-T) conditions under which they were formed. Petrographic evidence has shown that the Pan –African reworking has led to the recrystallization of many constituent minerals of the MGC by partial melting. Most of the rocks display medium to upper amphibolite facies metamorphism (Obaje, 2009).

The Schist Belts comprises low grade metasediments with narrow N-S trending belts which are best developed in the western Province of the Nigerian Basement Complex (Figure 3). These belts are considered to be Upper Proterozoic supracrustal rocks which have been infolded into the Migmatite-gneiss Complex. Coarse to fine-grained clastics, pelitic schists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles), and mafic metavolcanics (amphibolites) are among the lithological variants of the schist belts. In the southwestern Basement Complex, the belt is associated with marbles, dolomites and calc-silicate rocks (Obiora, 2005). In the northwest, there is a dominance of schists of greywacke origin comprising meta-pelites, quartzites, phylittes, mica-schists, quartzo-feldspathic schists, paragneiss, Fe-Mn rich quartzites and garnet amphibolites (Dada, 2006).

The Pan African Granites are also known as the Older Granites. The term Older Granite was introduced by Falconer (1911) to distinguish the Older Granites from the discordant tin bearing younger granites of Nigeria. They range in size from plutons to batholiths. The Older Granites are syn and post tectonic intrusions which cut the Migmatite-gneiss complex and the Schist belt. The Older Granites includes rocks of a wide range of composition: granites, granodiorites, adamellites, quartz monzonite, syenites, pegmatites. Granitic to granodioritic compositions are most common (Rahaman, 1976).

3.1 Local Geology of Igue And Environs

Igue area lies within the Precambrian Basement Complex of southwest, Nigeria. According to (Odeyemi, 1981) the basement complex of Igue area comprises

1) Polycyclic crystalline complex of migmatite and gneisses
2) Younger metasedimentary succession
3) Suite of syn to late tectonic intrusive granitoids

The schist occurs as a supracrustal cover on the basement and consists of mica schist, metaconglomerate, calc-gneiss and marble and quartz biotite schist (Odeyemi, 1988). Igue marble is associated with calc-silicate gneiss and occurs as lenses above migmatised schist and below polymictic metaconglomerate. It occurs as low lying herogeneneous bodies intersected at relatively shallow depths (Oluwatoyin et al., 2021). Mineralogical composition shows that rocks in this area consist dominantly of calcite, quartz, k-feldspar, illite. Igue marbles are white to off white in colour exhibiting bandings which range from grey to brown (Plate 1). The area is very rugged due to its undulating topography. The marbles occurs as low lying bodies. Figure 2 shows the geological map of Igue and environs and Figure 3 show Complex (mgn), the Schist Belt (sb) and the Figure 3: Basement Geology of Nigeria: The Migmatite Gneiss Older Granites (og) (Obaje, 2009).

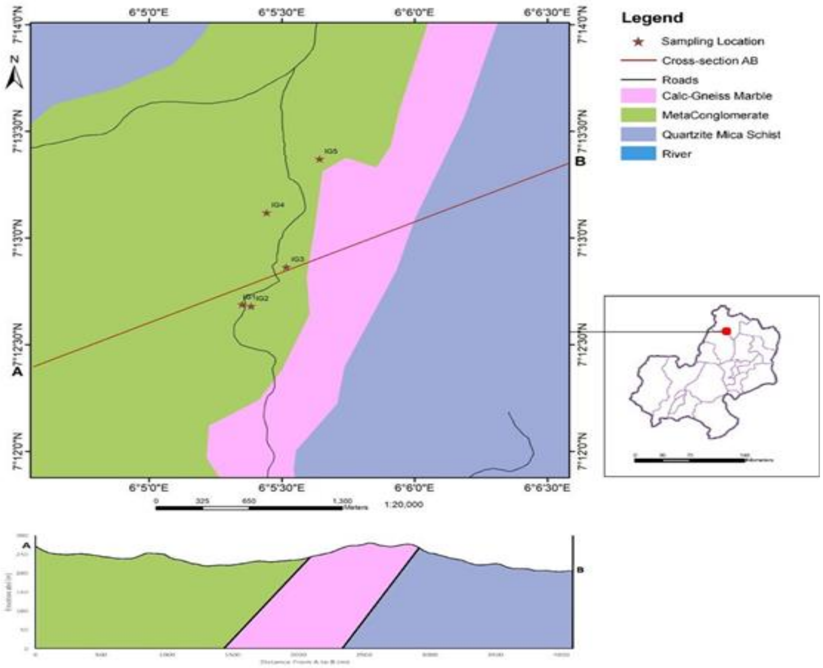

Figure 2: Geologic Map of Igue and Environs

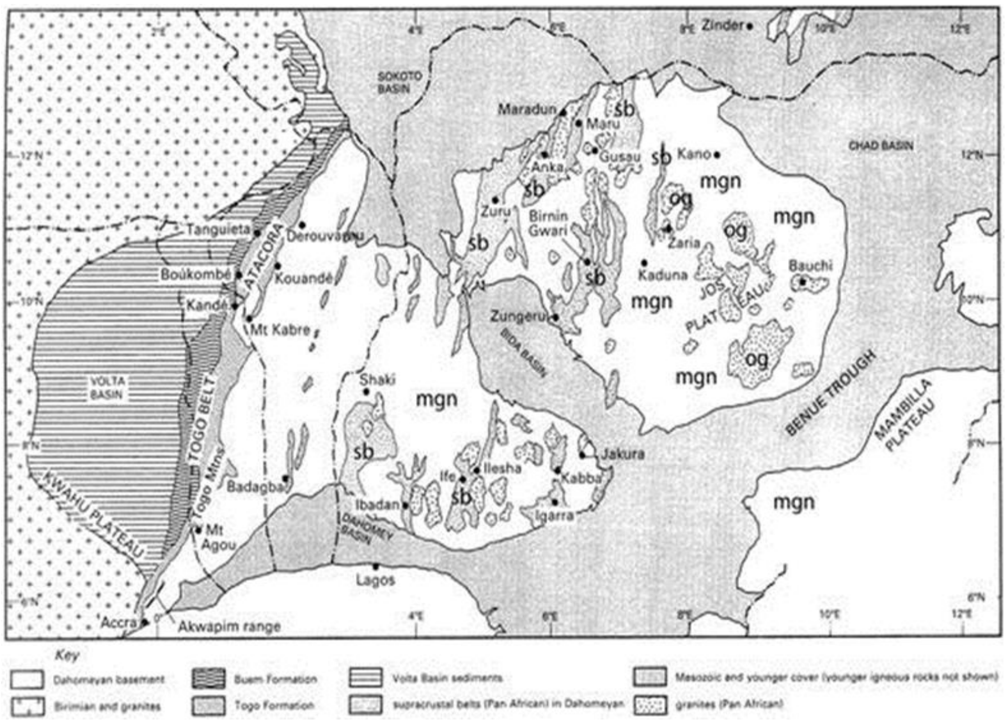

Figure 3: Complex (mgn), the Schist Belt (sb) and the Figure 3: Basement Geology of Nigeria: The Migmatite Gneiss Older Granites (og) (Obaje, 2009)

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Plate 1: An Exposed Marble Deposit in Igue and Environs.

4. Materials And Sampling Method

Five (05) marble samples were taken from the field and taken to the laboratory; Chemical and Mineralogical analysis was carried out in National Steel Raw Materials Exploration Agency (NSRMEA) Kaduna, Nigeria. The Chemical analysis was carried out using X-Ray Fluorescence (XRF) technique while mineralogical analysis was carried out using X-Ray Diffraction (XRD) technique. The XRF model used for analysis was Xenemetrix benchtop EDXRF Spectrometer, Genius IF. The XRD analysis was carried out using Rigaku Miniflex XRD instrument.

Table 1: Location of Sampling Points and their Co-ordinates

Sampling Points	Coordinate	
IG 1 (24) Sample 1	07 12′ 41.2″N	06 5′ 21.0″E
IG 2 (26) Sample 2	07 12′ 40.8″N	06 5′ 23.0″E
IG 3 (19) Sample 3	07 12′ 15.8″N	06 5′ 31.1″E
IG 4 (17) Sample 4	07 13′ 07.1″N	06 5′ 26.5″E
IG 5 (21) Sample 5	07 13′ 22.2″N	06 5′ 38.5″E

5. Presentation Of Results And Discussion

The results of the geochemical composition in the marble samples are shown in Table 1. Based on the analytical results from the XRF analysis of Igue marble in Table 1, the results reveal the presence of the following major oxides and their volume in weight percentages: SiO_2 ranges from 1.59 – 10.36wt. %, MnO from 0.01- 0.33wt. %, K_2O ranges from 0.02- 0.32wt. %, CaO ranges from 84.65 – 94.65wt. %, Al_2O_3 ranges from 2.25 - 2.95wt. %, the average values for the oxides ranges from 0.10 -91.14wt. % as shown in Table 2.

5.1 CaO/MgO Content

CaO content from the analysis has an average value of 91.14%. This can be attributed to the high amounts of CaO from all the respective samples. The high content of the samples is as a result of large amount of Ca-rich minerals deposited in the environment. In calcitic marble, CaO is usually in the order 50 – 54% while MgO is < 15%. Dolomitic marble on the other hand, have CaO values generally in the range of 28 – 31% and MgO values in the range of 15 – 21% (Goldschmidt *et al.*, 1955). Hence, Igue marble is a highly calcitic marble because its CaO content is 91.14%. MgO content has an average value of 0.64%. Low MgO content in marble is indicative of low dolomite content.

5.2 SiO_2 Content

SiO_2 in carbonate rocks comes from both silicate minerals and chert nodules resulting from the influx of near shore silici-clastic materials into the basin of the original limestone deposit which was metamorphosed into marble (Brownflow, 1996). SiO_2 content has an average composition of 4.17% which is indicative that the basin of deposition of the protolith was probably near to the shore (Onimisi, 2017).

5.3 Fe_2O_3 AND Al_2O_3 Content

The Fe_2O_3 content is very low, having a mean value of 0.40% which is an indication that the basin of deposition was probably a reducing environment. The Al_2O_3 content is low and low concentration of alumina indicates low energy environment (Odokuma-Alonge, 2019).

5.4 Alkali Content

Alkali content refers to the amount of Na_2O and K_2O in the marble. The average alkali content is 0.16%. According to a study, alkali content decreases in marble with increase in salinity (Clarke, 1924). The very low alkali content is indicative of shallow, saline environment of deposition of the limestone protolith. Table 3 compares the samples from this study with calcitic and dolomitic marble from previous works.

Table 2: Concentration of major oxides from XRF analysis of the rock samples (Igue Marbles) (wt. %)

Major Oxides	IG1	IG2	IG3	IG4	IG5	Mean Conc.	Min	Max	Std Dev.
SiO2	10.36	1.59	2.65	2.96	3.28	4.17	1.59	10.36	3.519
Al2O3	2.95	2.28	2.75	2.61	2.25	2.57	2.25	2.95	0.302
Fe2O3	0.52	0.11	0.63	0.2	0.51	0.4	0.11	0.63	0.225
CaO	84.65	94.64	92.58	92.18	91.67	91.14	84.65	94.64	3.801
K2O	0.16	0.02	0.17	0.08	0.32	0.16	0.02	0.32	0.113
MnO	0.06	0.01	0.06	0.03	0.33	0.1	0.01	0.33	0.131
MgO	0.001	0.001	0.001	0.71	0.56	0.64	0.001	0.71	0.351
TiO2	0.12	0.04	0.17	0.05	0.21	0.19	0.04	0.21	0.074

Table 3: Comparison of Mean Concentration of Igue marble with Ekirin –aade marble; Ikpeshi marble; Igue-oke marble; Zambezi belt marble Abuja marble (Onimisi, 2017; Odokuma-Alonge et al., 2021; Oluwatoyin et al., 2021; Munyanyiwa and Hanson, 1988; Davou and Ashano, 2009).

Major Oxides	Mean Conc. Marble	Ekirin-Aade Marble (Onimisi , 2017) **(1)**	Ikpeshi Marble (Odokuma-Alonge et al., 2021) **(2)**	Igue-oke Marble (Oluwatoyin et al., 2021) **(3)**	Zambezi belt Marble (Munyanyiwa and Hanson, 1988) **(4)**	Abuja Marble (Davou and Ashano, 2009). **(5)**
SiO_2	4.17	3.6	2.92	3.49	1.98	2.4
Al_2O_3	2.57	1.02	0.5	1.76	0.13	0.92
Fe_2O_3	0.4	0.57	0.19	3.72	0.36	0.04
CaO	91.17	51.08	60.76	71.99	31.04	31.82
MgO	0.64	1.56	1.62	7.11	20.84	19.6
Na_2O	-	0.19	0.11	0.48	-	0.05
K_2O	0.4	0.15	0.27	0.43	0.07	-
P_2O_5	-	0.06	0.4	-	0.045	-

When compared with typical calcitic and dolomitic types, Table 2 shows that Igue marble possesses very high amount of CaO of about 91.1wt. % which is an indication that Igue marble is highly calcitic in composition. The MgO content is high in (4) and (5) which may be as a result of introduction of Mg^{2+} in water leading to the conversion of calcite into dolomite and also from magnesium rich organic matter (Pettjohn,1975). This also implies that marbles (4) and (5) are dolomitic marbles. The presence of aluminosilicates or the high energy environment of the area at the time of deposition could explain the high percentage of Al_2O_3 in this study, which was 2.57% compared to other calcitic and dolomitic marble types in Table 3. The SiO_2 content is also high when compared to other marble types in Table 3 this indicates the contribution of siliciclastic materials into the basin of deposition (Brownflow, 1996).

5.5 Igue Marble for Construction Purposes (Cement Production)

For limestone and marble to be useful in manufacture of cement, the CaO range of 46.65%-52.46% and $CaCO_3$ range of 83.50%-93.90% is needed. A higher MgO value results in the formation of periclase as an intermediate product in the manufacture of Portland cement causing sintering of limestone by alumino-silicate materials such as clay changing into nodules in the cement kiln (Talbot, 1982). Table 3 shows the mean chemical composition of Igue marble and some reference samples of some limestone and marble used for cement production.

Table 4: Comparison of Igue Marble for Construction Purposes (Cement Production) and Reference samples.

Major Oxides	Igue Marble	Reference samples (Blue Circle Industries, 1987)			Ranges
		Lst 1	Lst 2	Mar	
SiO_2	4.17	3.76	4.91	6.75	3.76 – 8.53
TiO_2	0.12	-	-	-	-
Fe_2O_3	0.4	0.66	0.66	1.47	0.66 – 2.07
Al_2O_3	2.57	1.1	1.28	0.71	0.71 – 2.74
MgO	0.64	1.23	0.63	1.48	0.30 – 1.48
CaO	91.17	52.46	51.55	49.8	46.65 – 52.46
Na_2O	-	0.22	TR	TR	TR – 0.06
K_2O	0.4	0.18	TR	TR	TR – 0.06
LOI	-	40.38	40.76	39.65	39.65 – 40.86
$CaCO_3$	68	93.9	92.27	89.14	83.50 – 93.90
$MgCO_3$	-	2.57	1.32	3.09	0.63 – 2.57
S/R	1.05	2.14	2.53	3.1	1.77 – 3.10
A/R	1.43	1.67	1.94	0.48	0.48 – 5.66
LSF	610.96	417	320	242	160 – 417

TR – Trace, Lst. – Limestone; Mar- Marble Sample

Reference limestone samples are obtained from Cement Technology Course Volume (Blue Circle Industries, 1987). Cement clinker is made by combining proper ratios of the chemical components: Silica Ratio (SR), Alumina Ratio (AR), and Lime Saturation Factor (LSF) to regulate the clinker's composition as shown in Table 4. The ratios are calculated using the oxide values CaO, SiO_2, Al_2O_3, and Fe_2O_3. The following are the SR, AR, and LSF values for the conventional cement kiln feed for the marble samples:

$$SR = \frac{SiO_2}{Al_2O_3 + Fe_2O_3} \quad (1)$$

$$AR = \frac{Al_2O_3}{Fe_2O_3} \quad (2)$$

$$LSF = \frac{100(CaO)}{2.8(SiO_2) + 1.2(Al_2O_3) + 0.65(Fe_2O_3)} \quad (3)$$

The recommended SR, AR and LSF values for marbles in production of cement are 1.9 – 3.2, 1.5 – 2.5 and 242 – 417 respectively (Onimisi et al., 2017). The calculated SR, AR and LSF values for Igue marble are 1.05, 1.43 and 610.96 respectively. The SR and LSF do not meet the recommended range. The LSF exceeds the permissible limit of 417, but the Igue marble can still be used if the LSF value is modified to fall within the approved range for cement manufacturing. This can be achieved by mixing with appropriate amounts of lateritic clay to improve its silica, alumina and iron respectively (Panda, 2016).

5.6 Ternary Plot of Geochemical Samples

Figure 4 is a ternary plot of CaO-SiO_2-Fe_2O_3 which illustrates that all samples are plotting towards CaO indicating extremely high amounts of CaO. Low percentages of iron oxides indicate lack of iron bearing minerals such as siderite, magnetite, limonite, hematite etc.

From the plot IG1 has higher amount of SiO_2 (10.36 wt. %) which is an indication that SiO_2 in carbonate rocks comes from both silicate minerals and chert nodules resulting from the influx of near shore siliciclastic materials into the basin of the original limestone deposit which was metamorphosed into marble (Brownflow, 1996).

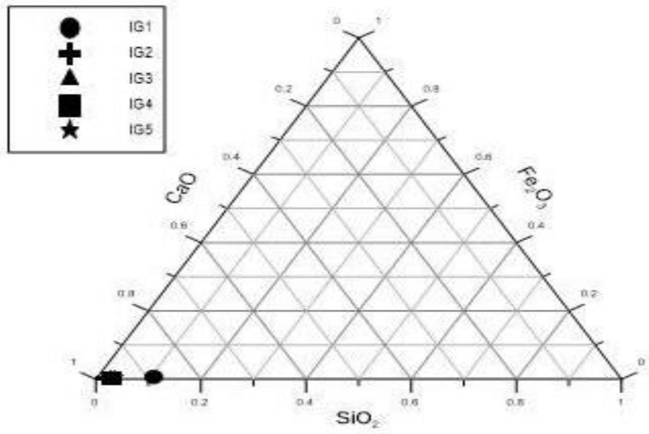


Figure 4: The Ternary Plot of CaO-SiO_2-Fe_2O_3 Showing Positions of the Igue samples.

5.7 Mineralogy

Calcite occurs in the five (05) location ranges (60-68%), quartz ranges from (8.0-20.7%), orthoclase occurrence is from (2.0-14%), lime ranges from (4.5 -8.7%), illite occurrence is from (2.0-11%), according to the analytical results of the XRD analysis on Igue marble in Table 5. Calcite has the highest mineral composition, while lime has the lowest mineral composition. The relationship between calcite and lime is that lime is a product of calcite. Hence, lime probably formed during metamorphism as a result of heat. The main minerals in the samples are calcite, quartz, orthoclase and lime. Illite is formed as a result of weathering of orthoclase. Quartz is the second most abundant mineral which tallies with the geochemical analysis. From the diffractograms, IG2 and IG5 have the highest calcite values with 67 and 68 %, respectively. IG1 has calcite value of 60%. However, Dolomite content is not present in the sample because there is no presence of magnesium minerals. The presence of fine grained clay mineral (illite) in the marble supports the evidence that the original limestone which metamorphosed were probably marine sediments of marls, clay and arkose particles.

The formation and presence of illite is probably from the weathering of feldspars which is in line with the kind of feldspar present (orthoclase). Calcite is an indication of influx of Ca- rich minerals into the basin of deposition before metamorphism occurred. It was discovered that the Igue-Oke marble is used for the production of antacids which cures of stomach ache (Obasi and Isife, 2012). Igue-Oke marble is also used for sculpture, tiles, chips, decorative uses and for construction etc. (Odokuma-Alonge et al., 2019).

Table 5: Mineral Composition and their formula obtained from the XRD results at **Igue** area (wt. %)

Mineral	Formula	IG1	IG2	IG3	IG4	IG5
Calcite	CaCO3	60	67	64	66.5	68
Quartz	SiO2	20.7	13	17	8	15
Orthoclase	KAlSi3O8	6.6	2	8.3	14	7.4
Lime	CaO	4.5	7	8.7	5.9	6.4
Illite	(KH3O)Al2Si3AlO10(OH)2	8	11	2	5.6	3.2
Others		0.2	0	0	0	0
Total		100	100	100	100	100

5.8 Ternary Plot of Mineralogical Samples

Figure 5 shows the ternary plot of $CaCO_3$-SiO_2-$KAlSi_3O_8$ which proves that the Igue marbles are largely calcitic marbles with a reasonable amount of quartz and low percentages of orthoclase. This is indicative of influx of Ca-rich minerals into the basin of deposition and this makes Igue marble suitable for several industrial applications such as cement production, fertilizers as well as lime production and sewage treatment. The presence of quartz indicates that the original composition of the rock (calcareous sedimentary rock) had presence of quartz before it was metamorphosed into marble. The high amount of calcite implies that the rock could be used in enhancing soil pH.

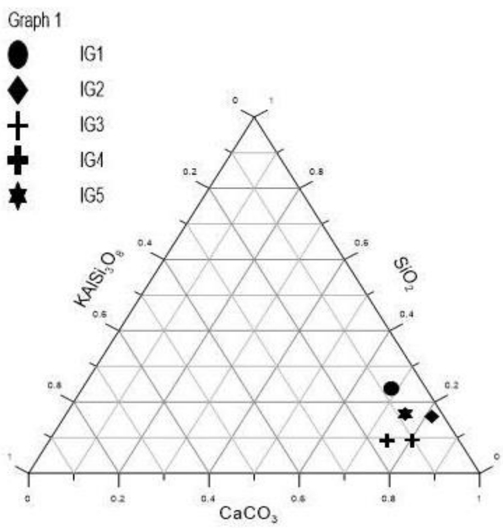


Figure 5: The Ternary Plot of $CaCO_3$-SiO_2-$KAlSi_3O_8$ Showing Positions of the Igue Samples.

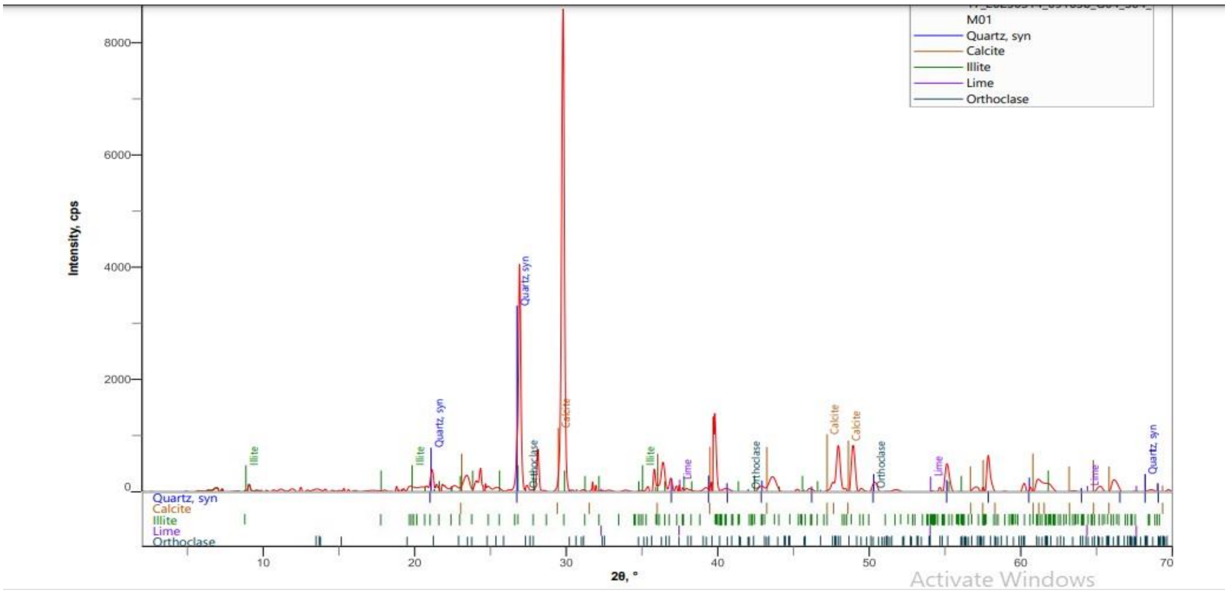
5.9 Spacing and 2θ Values

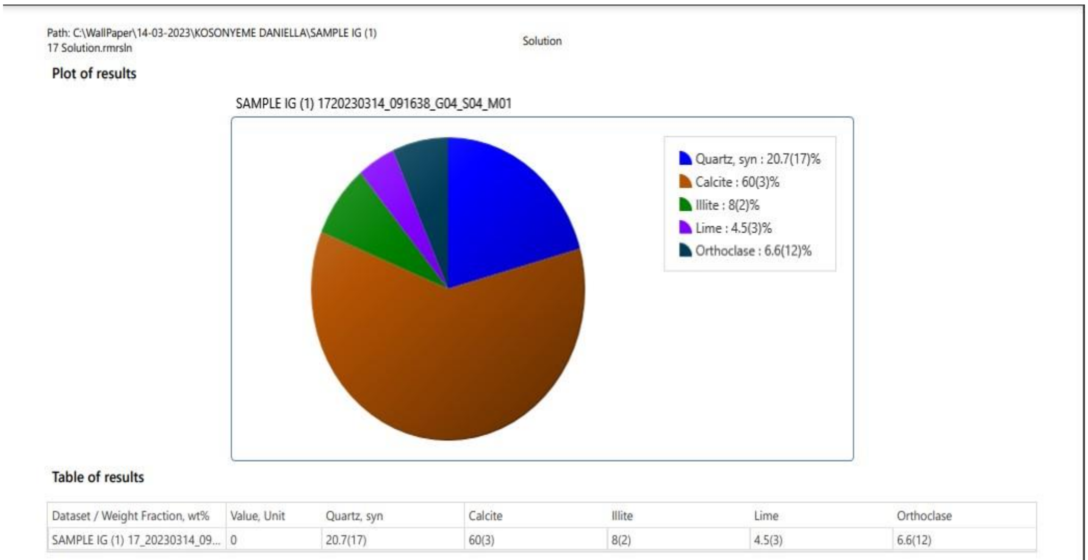
D-spacing is the interplanar spacing in a crystal lattice that represents the distance between consecutive planes of atoms within a crystal. The d-spacing is of utmost importance because these values are unique to the orders of the calcite. The 2θ value relays its relative abundance and intensity of the mineral. Table 6 illustrates the d-spacing and 2θ values of the dominant minerals. The unit of d-spacing is Angstrom units – 10^{-8} cm.

Table 6: D-spacing and 2θ values of the dominant minerals.

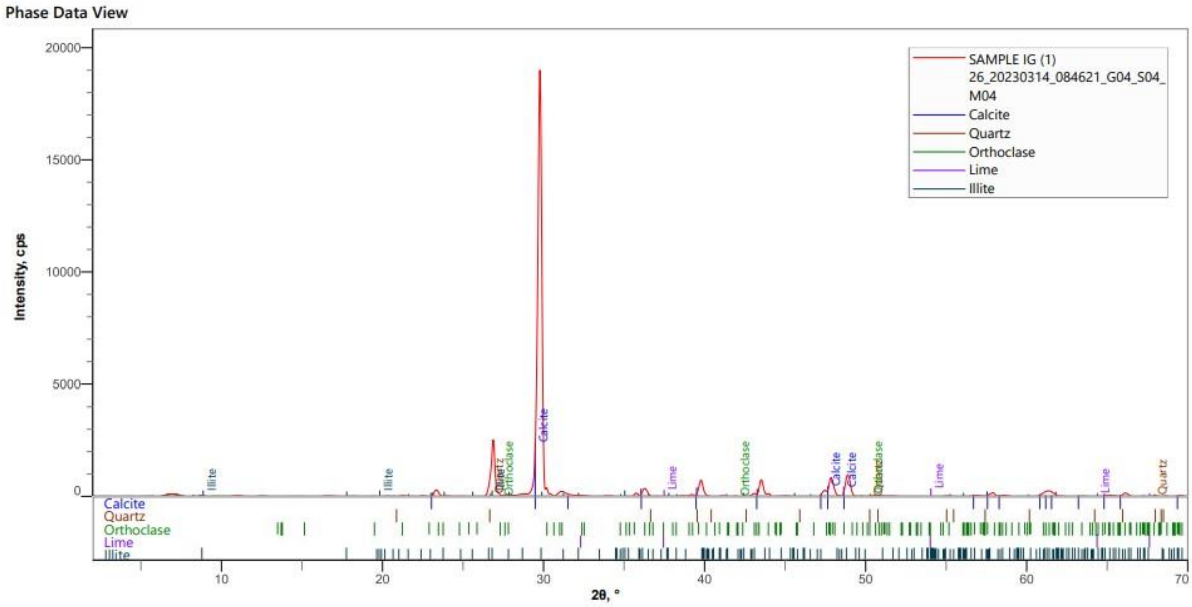
ORDERS	IG1	IG2	IG3	IG4	IG5
2θ (calcite)					
First order	29.75	31.08	29.7	29.7	29.72
Second order	43.56	43.48	47.87	47.42	47.5
Third order	47.93	47.42	48.84	47.78	47.89
D-spacing (Å)					
First order	2.99	2.86	3	3.01	3
Second order	2.08	2.07	1.89	1.91	1.91
Third order	1.89	1.92	1.86	1.9	1.89
2θ (quartz)					
First order	26.89	25.89	26.79	26.84	26.76
Second order	24.32	48.8	23.37	23.34	23.79
Third order	66.1	65.96	57.78	51.04	51
D-spacing (Å)					
First order	3.65	3.31	3.8	3.81	3.81
Second order	3.31	1.86	3.32	3.31	3.32
Third order	3.18	1.42	1.59	1.54	1.59

The results of the mineralogical analysis showing the diffractograms and pie charts are presented in Figures 6-10





Figures 6 and 4.3b: X-ray Diffractogram and Pie Chart for IG1



Plot of results

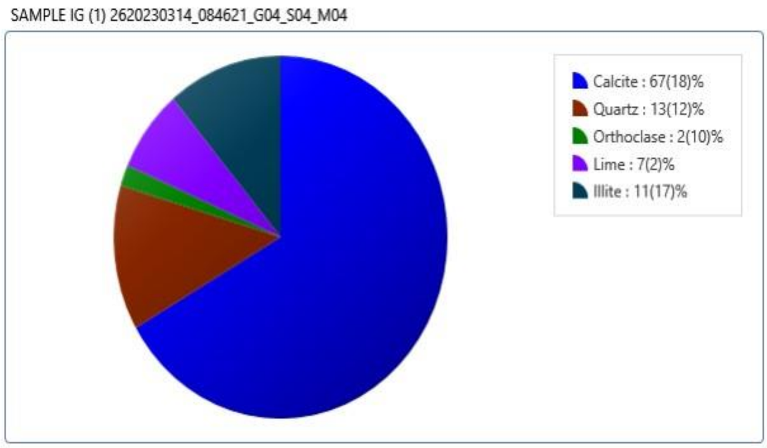
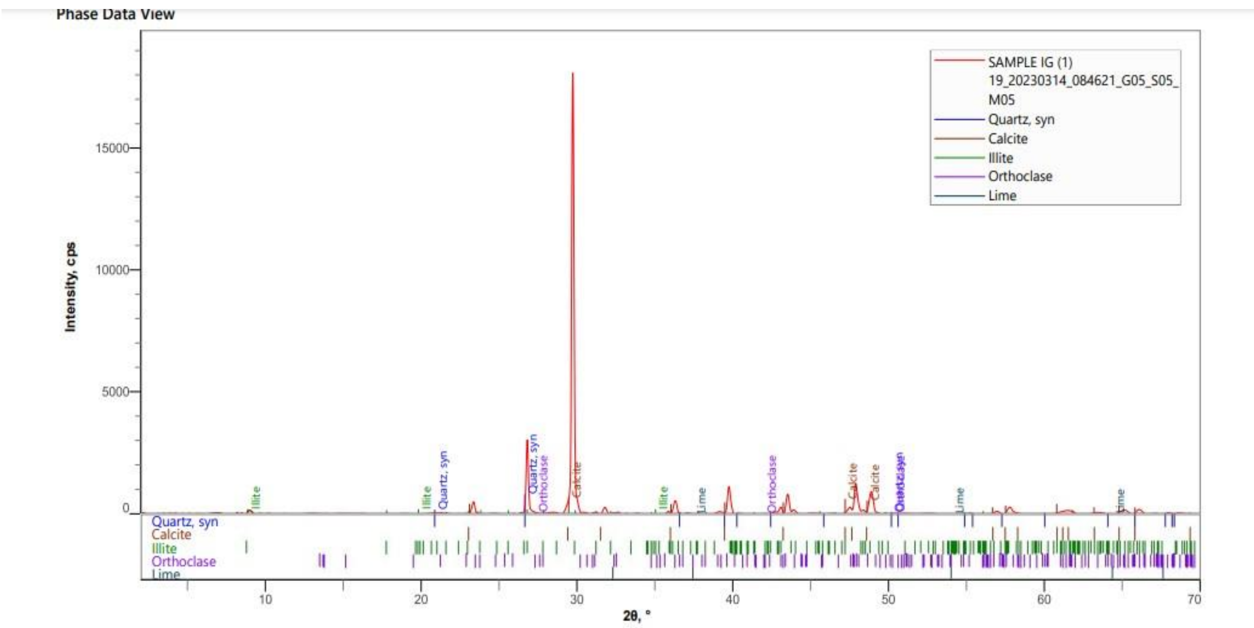


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Calcite	Quartz	Orthoclase	Lime	Illite
SAMPLE IG (1) 26_20230314_08...	0	67(18)	13(12)	2(10)	7(2)	11(17)

Figures 7: X-ray Diffractogram and Pie Chart for IG2



Path: C:\WallPaper\14-03-2023\KOSONYEME DANIELLA\SAMPLE IG (1)
19 Solution.rmrsln

Solution

Plot of results

SAMPLE IG (1) 1920230314_084621_G05_S05_M05

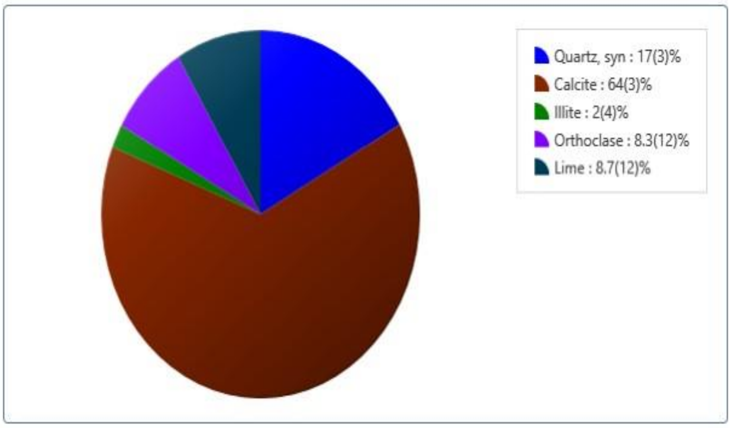
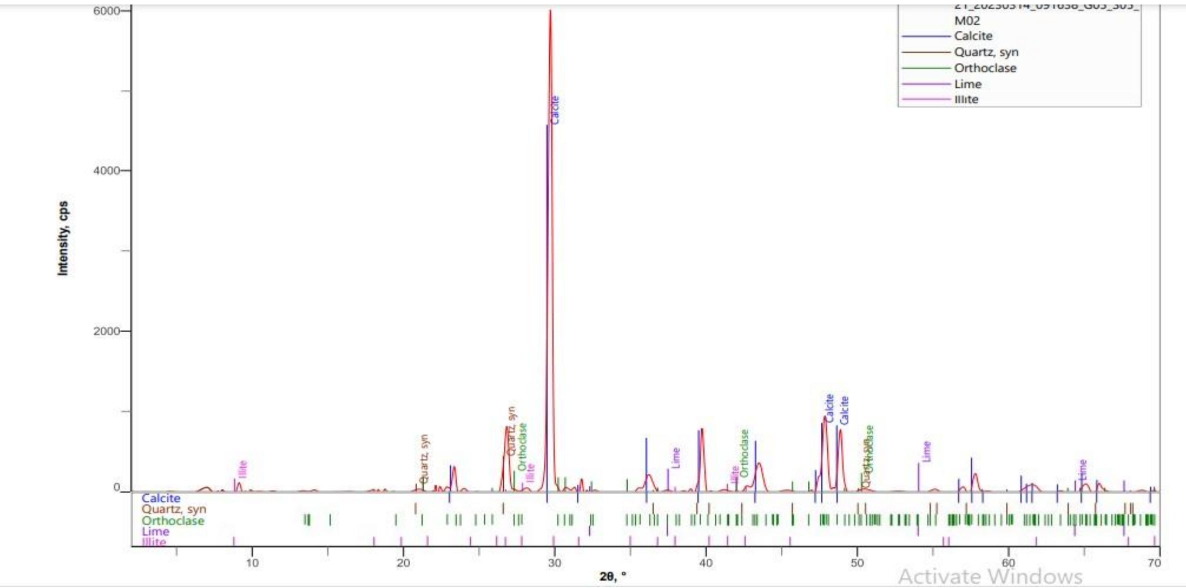


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Calcite	Illite	Orthoclase	Lime
SAMPLE IG (1) 19_20230314_08...	0	17(3)	64(3)	2(4)	8.3(12)	8.7(12)

Figures 8: X-ray Diffractogram and Pie Chart for IG3



Path: C:\WallPaper\14-03-2023\KOSONYEME DANIELLA\SAMPLE IG (1)
21 Solution.rmrsln

Solution

Plot of results

SAMPLE IG (1) 2120230314_091638_G05_S05_M02

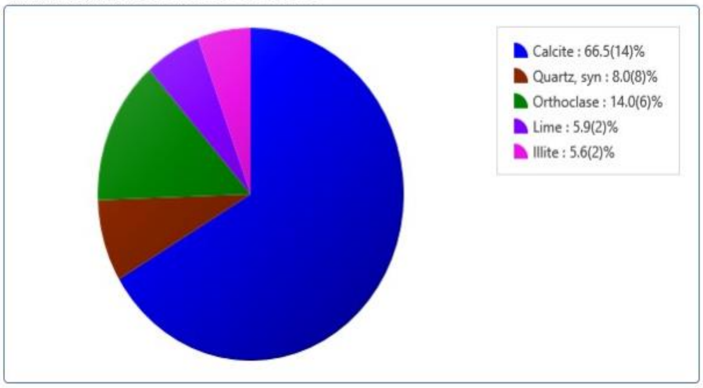
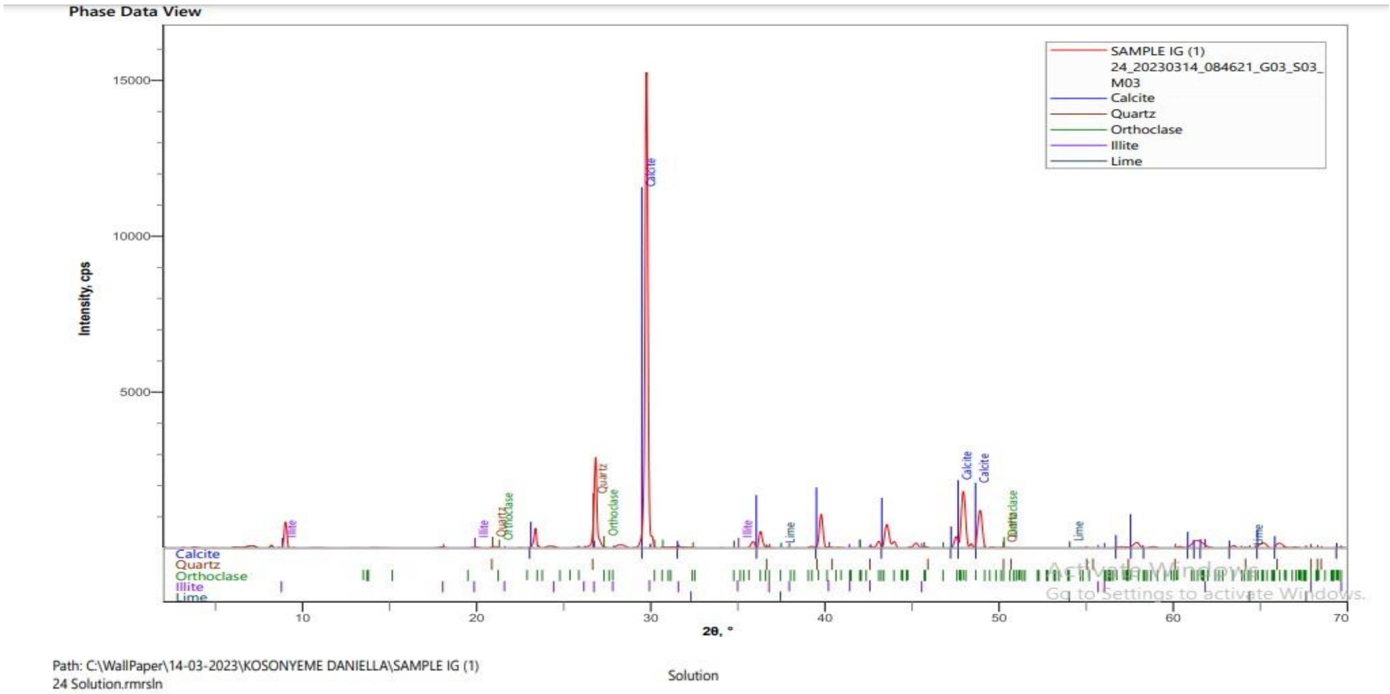


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Calcite	Quartz, syn	Orthoclase	Lime	Illite
SAMPLE IG (1) 21_20230314_09...	0	66.5(14)	8.0(8)	14.0(6)	5.9(2)	5.6(2)

Figures 9: X-ray Diffractogram and Pie Chart for IG4



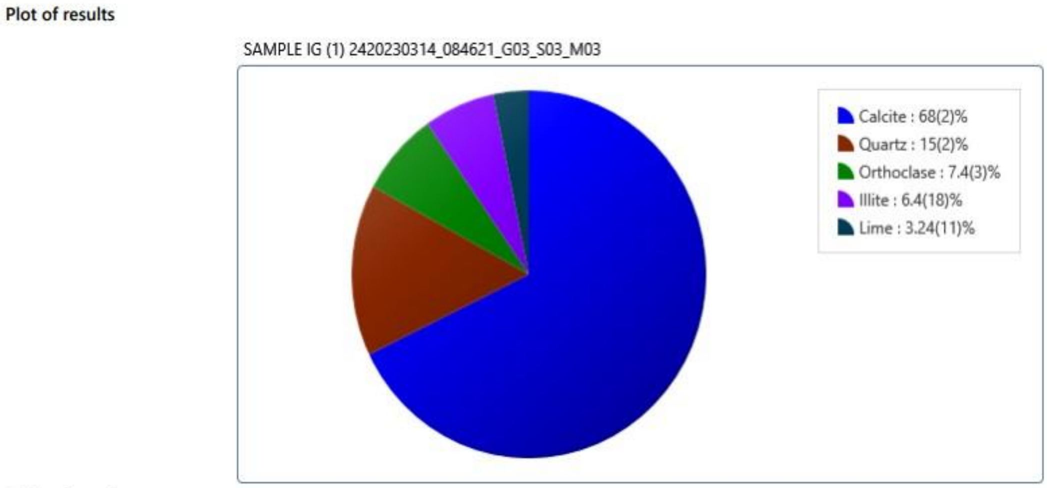


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Calcite	Quartz	Orthoclase	Illite	Lime
SAMPLE IG (1) 24_20230314_08...	0	68(2)	15(2)	7.4(3)	6.4(18)	3.24(11)

Figures 10: X-ray Diffractogram and Pie Chart for IG5

6. Conclusion

The Igue marble form a part of the Igarra Schist belt which is intruded by the Pan African Granites. The marble varieties at Igue and environs are highly calcitic and comprises rocks that were formed at low- medium grade metamorphism. Igue marble also do not meet the permissible limit for cement production because the LSF values exceeded the permissible limit but can be used if subjected to beneficiation. From the XRD analysis, calcite is the most abundant mineral (60% - 68%). Dolomite is not present in the sample, hence the Igue marble is a calcitic marble. Igue marble is used for the production of antacids, sculptures, tiles, chips and decorative uses.

References

Abaa, S.I., 1985. The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. Journal of African Earth Sciences, 3 (1-2), Pp. 107-113.

Black, R., Caby, R., Moussine- Pouchkine, A., Bayer, R., Betrand, J. M., Boullier, M.M.,Fabre, J. and Resquer, A., 1979. Evidence for late Precambrian plate tectonics in West Africa. Nature, 278, Pp. 223-227.

Blue Circle Industries Ltd. 1978. Cement Technology Course Volume. Blue Circle Industries Plc., 84 Eccleston square, London SW IV 1PX, United Kingdom.

Brownflow, A.H., 1996. Geochemistry (2nd Ed): Prentice Hall, pp. 350-351.

Clarke, F.N., 1924. The Data of Geochemistry: Washington Government Printing Office; Pp. 782.

Dada, S.S., 2006. Proterozoic evolution of Nigeria. The basement complex of Nigeria and its mineral resources (A tribute to Prof. MAO Rahaman). Akin Jinad & Co. Ibadan, pp. 29-44.

Davou, D.D., and Ashano, E.C., 2009. The geochemical characteristics of the marble deposits east of Federal Capital Territory (FCT), Nigeria. Global Journal of Geological Sciences, 7 (2).

Ekwueme, B.N., 1990. Rb-Sr ages and petrologic features of Precambrian rocks from the Oban Massif, southeastern Nigeria. Precambrian Research, 47 (3-4), Pp. 271-286.

Falconer, J.D., and Woods, H., 1911. The geology and geography of Northern Nigeria. Macmillan and Company, limited.

Gandu, A.H., Ojo, S.B., and Ajakaiye, D.E., 1986. A gravity study of the Precambrian rocks in the Malumfashi area of Kaduna State, Nigeria. Tectonophysics, 126 (2-4), Pp. 181-194.

Goldschmidth, J.R., Graff, L., and Joensu, O.I., 1955. The occurrence of magnesium calcite in nature. Geochimica et Cosmochimica Acta, 1, Pp. 212-230.

Munyanyiwa, H., and Hanson, R.E., 1988. Geochemistry of marbles and calc-silicate rocks in the Pan-African Zambezi belt, Zambia. Precambrian research, 38 (3), Pp. 177-200.

Obaje, N.G., 2009. The Basement Complex. Geology and Mineral Resources of Nigeria, Pp. 13-30.

Obasi, R.A., and Isife, F., 2012. Geochemistry and economic potential of marble from Ikpeshi, South-West, Nigeria. ARPN J. Eng. Appl. Sci., 7 (6), Pp. 1819-6608.

Obiora, S.C., 2005. Field Description of Hard Rocks, with examples from the Nigeria Basement Complex. Enugu (Nigeria).

Odeyemi, I., 1981. A review of the orogenic events in the Precambrian basement of Nigeria, West Africa. Geologische Rundschau, 70, pp. 897-909.

Odeyemi, I.B., 1988. Lithostratigraphy and structural relationships of the Upper Precambrian Metasediments in Igarra area, southwestern Nigeria. Precambrian geology of Nigeria. Publ. GSN, Pp. 111.

Odokuma-Alonge, O., 2019. A geochemical appraisal of some marble physiques in Ubo area and environs, southwestern Nigeria. Journal of Applied Sciences and Environmental Management, 23 (6), Pp. 1189-1193.

Odokuma-Alonge, O., Chibuzor, N.S., and Obarisagbon, I., 2021. Geochemical and Mineralogical Characteristics of some Marble Deposit around Ikpeshi Area Southwestern Nigeria. Nigeria journal of applied sciences, 39, Pp. 21-31.

Odokuma-Alonge, O., Chibuzor, N.S., and Ogbamikhumi, A., 2020. Geochemical Approach and Industrial Utilization of Some Marble Bodies from Ubo River Area and Environs, Southwestern Nigeria. Journal of Applied Sciences and Environmental Management, 24 (4), pp. 653-658.

Oluwatovin, O.A., and Olusola, A.O., 2021. Lithological features and Chemical Characterization of Metamorphosed Carbonate Rocks in Igue, Southwestern Nigeria. Journal, 13 (1), Pp. 11-20.

Ominigbo, O.E., 2022. Evolution of the Nigerian basement complex: current status and suggestions for future research. Journal of mining and Geology, 58 (1), Pp. 229-236.

Omoseebi, A.O., and Tanko, I.Y., 2021. Geochemistry and Determination of Mineral Properties of Dolomite Deposit in Ikpeshi Southern, Nigeria. European Journal of Environment and Earth Sciences, 2 (5), Pp. 41-46.

Onimisi, M., Ojonimi, I.T., Kolawole, M.S., and Ibimode, T.B., 2017. Field Occurrence, Chemical Composition and Industrial Application of Ekirin – Aade Marble Deposit, Kogi State, North Central Nigeria. Journal of environmental studies, 11 (2), Pp. 37-46.

Panda, H., 2016. The Complete Technology Book on Asbestos, Cement, Ceramics and Limestone.Asia Pacific Business Press Inc.

Pettijohn, F.J., 1975. Sedimentary rocks, 3, p. 628. New York: Harper & Row.

Rahaman, M.A., 1976. Review of the Basement Geology of Southwestern Nigeria. in:kogbe, C.A. (ed) Geology of Nigeria. Elizabeth Publishing Company Lagos. Pp. 41-58.

Rahaman, M.A., and Ocan, D., 1978. On Relationship in the Precambrian Migmatitic Gneiss of Nigeria. J. Min. Geol., 15, Pp. 23-32.

Talbot, C., 1982. Cement and the Geologist: In Course Note on Rocks as Construction Material. Published by AGID Headquarters, Bangkok, Thailand. Pp. 120.