FIELD GEOLOGIAL AND GEOCHEMICAL ASPECTS OF MARBLE OCCURENCES IN OSOSO, SOUTHWESTERN NIGERIA

By

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Abstract

Previous geological investigations in Ososo did not combine subsurface and outcrop data to determine lithostratigraphic relationship, and did not ascertain potential uses of marble bodies in the area. Yet, these are part of the considerations in assessing the economic value of marble deposits. For that reason, this study integrated outcrop and core data to establish the spatial distribution and relationship of the rock types in the area. It also aimed to classify the marble bodies and evaluate their potential uses from X-Ray fluorescence and X-Ray diffraction data. In upward younging order, the rocks found are granite-gneiss and gneiss, calc-silicate gneiss, whitish and gray marble, garnet-biotite-muscovite schist, quartzite, intrusive granite and gabbro. Folds, pinch and swell structures, and boudinages deform leucosomes within the granite-gneiss. They indicate a change from compressional regime to extensional regime. They also indicate more than one deformational phase. In the whitish marble, CaO ranges from 50.79 to 52.13 wt %, and MgO ranges from 0.01 to 0.25 wt %. They are high purity calcitic marble, and are useful in manufacturing sugar. The gray marble contains 20.10 wt % CaO and 40.75 wt % MgO. They are pure dolomite, and useful as suitable flux material in steel plants.
Keywords: Core data, outcrop data, X-Ray fluorescence, X-Ray diffraction, boudinage

Introduction

Marbles are dynamo-thermally metamorphosed sedimentary carbonate rocks (Odukume-Alonge, 2019; Ailegbo *et al., 2021*). They are raw materials for diverse industrial products, and are utilized in driving numerous industrial processes. Because of this virtue, marbles are now included among the group of strategic economic minerals (Romanus and Frederick 2012; Sumarmi and N Wahyuningtyas, 2021). In Nigeria, marbles are found within the basement complex that constitutes the Pan-African mobile belt sandwiched between the West African Craton on the west and the Congo Craton east (Turner,1983; Wright *et al.*,1985; Udi *et al.*,*2023*)

However, it is the supracrustal schist belts of the basement complex (Fig.2- in the Appendix) that host economic deposits of marble (Akinola and OlaOlorun, 2020). Among the schist belts is the Igarra Schist belt. The three major rock groups in the Igarra Schist belt are (1) migmatite, biotite and hornblende-biotite gneiss (2) low grade metasediments comprising schists, calc-silicate gneiss, marble, polymict metaconglomerates, and quartzites (3) syn-tectonic to late-tectonic porphyritic biotite and biotite-hornblende granite, granodiorite, adamellites, charnokites, gabbros, diorites, pegmatites, aplite and syenites (Rahaman, 1988; , Udi *et al.*,*2023*). A provisional lithostratigraphic column for the Igarra Schist belt consists of (1) migmatite-gneiss complex at the base, followed upwardly by (2) quartz-biotite schist formation (3) calc-gneiss formation (4) metaconglomerate (5) mica schist formation intercalated with quartzites (Odeyemi, 1988). Granite–gneiss is included among the complex of migmatites and gneisses [8]. The marble bodies in the schist belt occur as lenses (Odukume-Alonge, 2019; Akinola and OlaOlorun, 2020). Parts of the Igarra Schist belt where marble deposits have been established are Okpella, Ibillo-Mangongo, Igarra, Ikpeshi, Ubo and Obajana. Some past researchers on these areas are (Odukume-Alonge, 2019; Odeyemi,1988; Obasi and Isife, 2012; Elueze *et al.*, 2015; Sanni *et al*., 2018; Oluwajana *al.*, 2018). They conducted geological mapping at scales that vary between 1:50000 and 1:100000. At such a small-scale level of mapping, rock outcrops are recorded at a few isolated places and many marble lenses are unlikely to be captured. Inferred lithologic boundaries are over generalised and do not accurately reflect lithostratigraphic relationship among the rock bodies. Furthermore, coring was not conducted to support outcrop data in ascertaining spatial lithostratigraphic relationship (Oluwajana *et al.*, 2018).

None of the works extended to the recently discovered marble occurrences in parts of Ososo geographically defined within Latitudes 7°22'N to 7°23'N and Longitudes 6°19'E to 6°20'15"E. This is in the northeastern part of the Igarra Schist belt, where all rock bodies are recorded as porphyritic granite on small scale geological map (Fig. 3- in the Appendix). Many of the lately identified marble bodies in Nigerian have remained unevaluated or partially evaluated discoveries in terms of areal extent, reserve estimate, spatial relationship with associated rocks, geochemical characterisation and potential utilities (Akinola & OlaOlorun, 2020; Elueze *et al.*,2015). In spite of the fact that these parameters are critical data for developing mineral deposits, the Ososo marble occurrences remains among the unevaluated discoveries. For these reasons, this study was conducted to classify and delineate the marble bodies, ascertain their stratigraphic relationship with associated rocks, determine their deformation pattern, produce a geological map on a scale of 1:12000, and appraise their potential industrial uses on the basis of their major oxide content. The determination of the potential industrial uses of any mineral deposit is of foremost interest in economic geology (Prasad, 2017).

Methodology

The materials employed are Auchi topographic Sheet 266NE, four fresh samples of carbonate rock outcrops and drilled core samples. The equipment employed are GARMIN Geographic Positioning System (GPS), sledge hammer, hand lens, geological compass-clinometer, digital camera, field notebook, calico sample bag, core drilling machine, core boxes, X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) instruments. The software employed are *Mapinfo*, *Datamine Discover 3D, Mapsource, Global Mapper, Surfer 3.2.* The regional geological map of Edo State in Nigeria was purchased from the Nigerian Geological Survey Agency (NGSA), and Auchi topographic Sheet 266NE (1:50000 scale) was purchased from the Office of the Nigeria Surveyor General. Literature review was conducted on Nigerian Basement Complex and Igarra schist belt, core drilling, XRD analysis, XRF analysis, and major oxides constituents of marbles with respect to their potential industrial uses. The field mapping base map was produced by cropping out a part of Auchi topographic Sheet 266NE that lies within Latitudes 7°22'N to 7°23'N and Longitudes 6°19'E to 6°20'15"E. Preliminary visits to the area were conducted to acquire necessary permits required for access, followed by reconnaissance surveys to get acquainted with the terrain.

Surface lithological mapping was combined with vertical and inclined core drilling data to specify the rock types, their lateral extent and subsurface depth intervals. The lithological mapping involved searching for outcrops along dip direction, strike direction, and along direction inclined to the strike. Fresh samples were collected from the outcrops. The lithology of the samples and recovered cores were inferred on the basis of Mafic Colour Index (MCI), foliation type, crystal size texture, and effervescence with dilute hydrochloric acid. The geographic coordinates of the outcrops were obtained with the GPS, and plotted on the field base map. Compass-clinometer was used to measure foliation strike, foliation dip direction and foliation dip angle. Directions of joints, faults, and fold axis were also measured. The geological map was then produced on a scale of 1:12000. The samples were broken to smaller particles using geological hammer, and then powdered using pestle and mortar at the engineering geology laboratory of the Federal University of Technology in Minna. Thereafter, they were taken to NGSA laboratory in Kaduna for XRF and XRD analysis.

Results

Field Geological Aspects

The field geological aspect comprises the rock types together with their associated structures, and the lithostratigraphy of the area. The outcrops found are medium grained granite-gneiss, garnet-biotite- muscovite-schist, whitish marble, gray marble, calcium- silicate gneiss, quartzite, medium-grained biotite granite, and medium-grained gabbro. In hand specimen, the granite-gneiss is medium grained, with distinct to fairly distinct alternating dark and light coloured foliations. Much of the dark foliation consists of dark shining flakes with pearly lustre, and is interpreted to be biotite. Thus, the specimen consists partly of biotite melanosome. The light foliations consist of a mixture of pink to pinkish white colour and vitreous to porcelaneous lustre. This defines quartzo-feldsphatic leucosome. The rock is thus named granite gneiss. Many of the leucosome is differentially folded into ptygmatic folds (Fig. 4), recumbent folds with associated pinch and swell structure (Fig. 5), and isoclinal folds (Fig. 6).

Figure 4. Ptygmatic folds

Figure 5. Recumbent folds with pinch and swell structure

Figure 6. Isoclinal folds

Some of the leucosome foliations are also deformed into boudinages (Fig.7 and Fig.8).

Figure 7. Boudinage

Figure 8. Boudinage

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ISSN 2756-4444
E-ISSN 2756-4452

Their foliation trend NW and dip westward and eastward with average value of 40°. The lithostratigraphic units penetrated in some of the drilled coring holes is shown in Fig. 9.

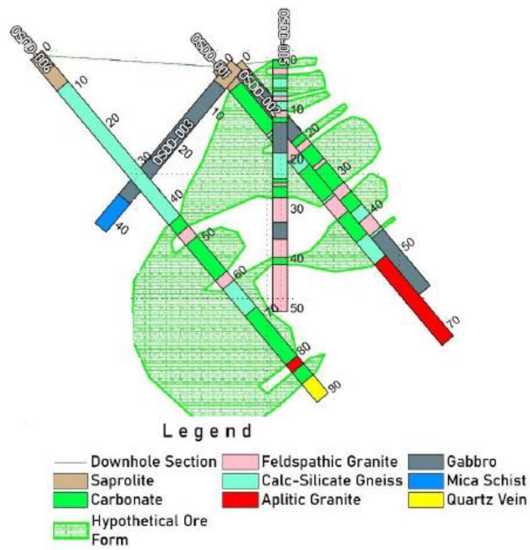

Figure 9. Cross-section of the of lithologic units penetrated in the coring holes

Table 1 is the lithologic column penetrated in OSDD_28. It shows gneiss directly overlain by calc-silicate gneiss in the deepest part of the hole, from 20 m to 49 m depth. The gneiss lies within 49 m to 61 m depth interval.

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E-ISSN 2756-4452

Table 1. Lithologic column inferred from coring hole OSDD_028

ID	DEPTH FROM (in m)	DEPTH TO (in m)	LITHOLOGY
OSDD_028	0.00	16.00	Saprolite
OSDD_028	16.00	17.00	Carbonate
OSDD_028	17.00	19.00	Calc-silicate gneiss
OSDD_028	19.00	20.00	Carbonate
OSDD_028	20.00	21.00	Calc-silicate gneiss
OSDD_028	41.00	43.00	Calc-silicate gneiss
OSDD_028	44.00	49.00	Calc-silicate gneiss
OSDD_028	49.00	61.00	Gneiss

The calc-silicate gneiss outcrops within the central part of the area (Fig. 10). It is weakly foliated, medium grained, and weakly effervescent with dilute HCl acid. Their colour varies from dark grey to greyish green.

Figure 10. Boulder of calc-silicate gneiss with weak foliation

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ISSN 2756-4444
E-ISSN 2756-4452

The calc-silicate rock intercalates with the carbonate body upwardly until it becomes solely a carbonate that underlies saprolite (Table 1).

The carbonate rock comprises whitish and dark gray to grayish green types (Fig. 11).

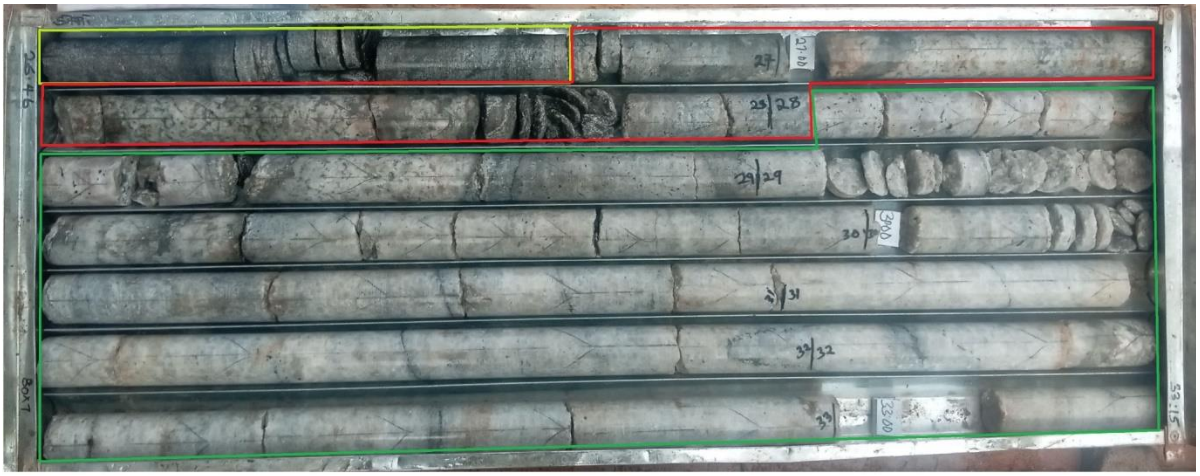

Figure 11. The dark gray marble (highlighted with the block) and whitish marble

The dark gray marble outcrops as low-lying bodies on the west of the whitish ones. They trend NW and have no discernible dips. The whitish marble is phaneritic to granoblastic and contains calcite crystals that are effervescent with dilute HCl acid (Fig. 12 and Fig. 13). Small amounts of graphite are found in them. They trend NW and averagely dip 40°E.

Figure 12. Whitish marble

Figure 13.Whitish marble with calcite crystals

The garnet-biotite- muscovite schist is deeply weathered and low lying in the central part of the area (Fig. 14). In areas where it is fairly fresh, it is dark grey to black in colour, medium grained in texture with garnet porphyroblasts. Quartz, biotite, orthoclase and plagioclase feldspars are found in hand specimen. It strikes NE and dip 40°E. The garnet porphyroblasts are 3 cm in size, vitreous in luster, and reddish rounded crystals. The muscovite is silvery white, vitreous in luster, and flaky.

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E-ISSN 2756-4452

Figure 14. Garnet-biotite-muscovite schist

Table 2 is the lithologic units penetrated by core hole OSDD_022. It shows the muscovite schist sandwiched between saprolite and calc-silicate gneiss.

Table 2. lithologic units penetrated in coring hole OSDD_022

ID	DEPTH FROM (in m)	DEPTH TO (in m)	LITHOLOGY
OSDD_022	0.00	17.00	Saprolite
OSDD_022	17.00	49.00	Mica schist
OSDD_022	49.00	50.00	Cal-silicate gneiss

Table 3 shows quartzite overlying garnet-biotite-muscovite schist coring hole OSDD_015. The quartzite outcrops in the NW and NE parts of the area.

Table 3. Lithologic units penetrated in coring hole OSDD_015

ID	DEPTH FROM (in m)	DEPTH TO (in m)	LITHOLOGY
OSDD_015	0.00	3.00	Saprolite
OSDD_015	3.00	5.00	Quartzite
OSDD_015	5.00	37.00	Mica schist
OSDD_015	37.00	45.00	Calc-silicate gneiss

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E-ISSN 2756-4452

Table 4 shows the lithologic units penetrated in coring hole OSDD_004. Granite is found in the lower part of the hole, while gabbro is found in the upper part, under saprolite. The granite is light gray to pinkish, medium-coarse grained, and sometimes porphyritic. In hand specimen, most of the mineral constituent is biotite. Hence, they are biotite granite.

Table 4. Lithologic units penetrated in coring hole OSDD_004

ID	DEPTH FROM (in m)	DEPTH TO (in m)	LITHOLOGY
OSDD_004	0.00	14.20	Saprolite
OSDD_004	14.20	24.19	Gabbro
OSDD_004	24.19	24.70	Calc-silicate gneiss
OSDD_004	24.70	25.92	Carbonate
OSDD_004	25.92	26.97	Calc-silicate gneiss
OSDD_004	26.97	28.51	Carbonate
OSDD_004	28.51	29.38	Feldspathic granite
OSDD_004	29.38	30.21	Carbonate
OSDD_004	30.21	32.39	Calc-silicate gneiss
OSDD_004	32.39	38.32	Carbonate
OSDD_004	38.32	56.20	Feldspathic granite

They outcrop as intrusive plutons in the NE and NE of the area, and intruded the granite- gneiss (Fig.15), the schist, marble and the quartzites.

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E-ISSN 2756-4452

Figure 15. Light grey to pinkish granites intrusive into granite-gneiss. 6°19'33"E; 7°22'30"N

The granite is extensively fractured, giving conjugate NW trending and NE trending joint sets.

Figure 16. NW trending joint set.

Figure 17. NW trending joint set. 7°22'37"N, 6°19'33"E

7°22'37"N, 6°19'33"E

The youngest rocks are the gabbroic plutons (Fig. 18). They intruded into all the rocks in the area. They are dark gray in colour and medium grained.

Figure 18. Exposed gabbro at 6°19'30'E. 7°22'37''N

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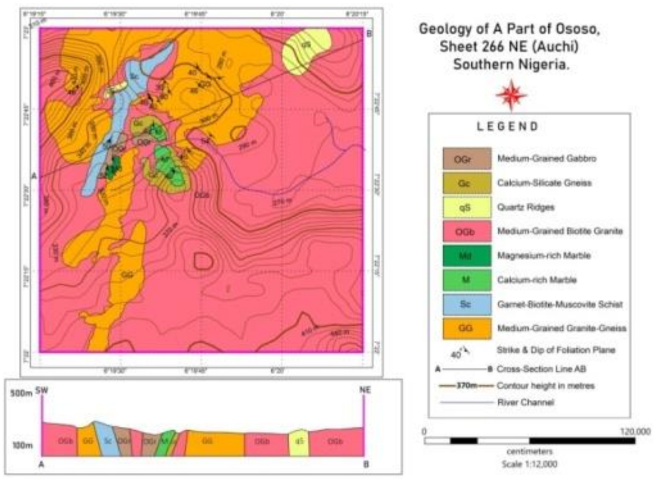

Figure 19. Produced geological map for the study area, on 1:12000 scale

Aspects on XRF and XRD

Table 5. Major oxides values for whitish marble, given in per cent weight

Sample ID	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Cl	H_2O
OR-700-C	2.24	0.05	0.95	52.13	0.11	0.02	0.04	0.29	0.005	43.20
OR-800-C	1.26	0.46	1	51.84	0.01	0.01	0.01	0.01	0.005	42.50
OR-1127-C	3.5	0.11	1.19	50.79	0.25	0.05	0.01	0.21	0.005	42.10
OR-1128-C	3.08	0.11	0.98	51.22	0.08	0.01	0.01	0.01	0.005	42.40
Average	2.52	0.1825	1.03	51.495	0.1125	0.0225	0.0175	0.13	0.005	42.55

The percentage weight of CaO in the whitish marble ranges from 50.79 % wt to 52.13 % (Table5). The percentage weight of $CaCO_3$ (that is of calcite) in the whitish samples ranges from 86.30 % wt to 89.00 % wt. This is a high purity carbonate. Table 6 is the values of Ca and Mg for the whitish marble in weight percentage. The Ca value ranges from 36.30 wt % to 37.26 wt %. The Mg value ranges from 0.01 wt % to 0.15 wt %.

Table 6. Percentage weight of Ca and Mg in the whitish marble

SAMPLE ID	CaO (wt %)	Ca (wt %)	MgO (wt %)	Mg (wt %)
OR-700-C	52.13	37.26	0.11	0.07
OR-800-C	51.89	37.09	0.01	0.01
OR-1127-C	50.79	36.30	0.25	0.15
OR-1128-C	51.22	36.61	0.08	0.05

The XRD results for whitish marble sample QR-700-C is Fig. 20. The identified minerals are given in Table 7.

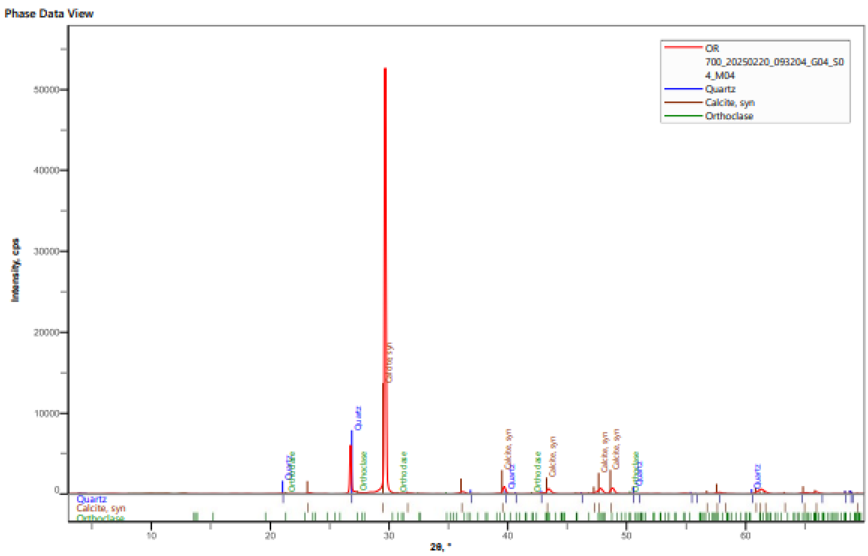

Figure 20. XRD results for QR-700-C (Whitish marble sample)

Table 7. Minerals in whitish marble sample OR-700-C

Sample ID	Mineral Phase		
	Calcite (wt.%)	11Quartz (wt.%)	Orthoclase (wt.%)
OR-7OO-C	86.3	11.4	2.26

The XRD results for whitish marble sample QR-800-C is Fig. 21. The identified minerals are given in Table 8.

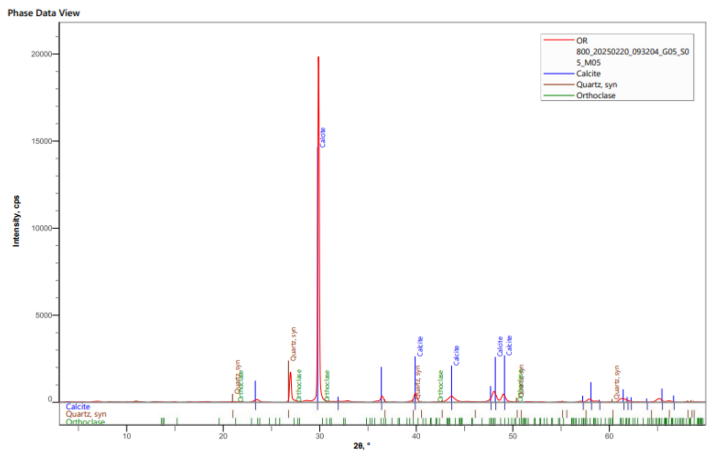

Figure 21. XRD results for QR-800-C (Whitish marble sample)

Table 8. Minerals in whitish marble sample OR-800-C

Sample ID	Mineral Phase		
	Calcite (wt.%)	Quartz (wt.%)	Orthoclase (wt.%)
OR-8OO-C	88.8	11.1	0.1

The XRD results for whitish marble sample QR-800-C is Fig. 22. The identified minerals are given in Table 9.

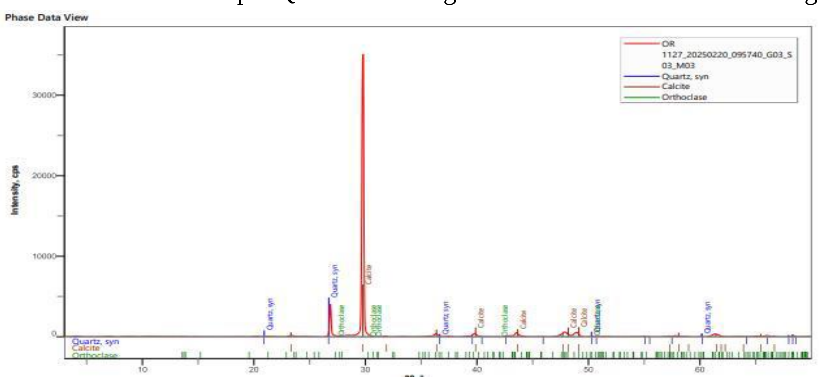

Figure 22. XRD results for whitish marble sample QR-1127-C

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E-ISSN 2756-4452

Table 9. Minerals in whitish marble sample OR-1127-C

Sample ID	Mineral Phase		
	Calcite (wt.%)	Quartz (wt.%)	Orthoclase (wt.%)
OR-1127-C	89.00	10.20	11.00

The whitish marble ranges from 86.3 wt % to 89.00 wt % in $CaCO_3$. Comparing them with 97 – 99 wt % for pure marble given by [19], the whitish marble contains some impurities.

Table 10 contains the major oxides in the gray marble in percentage weight. It contains 20.10 wt % CaO and 40.25 wt % MgO.

Table 10. Major oxides in sample OR-1096-C (gray sample) in wt %

Sample ID	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_2	Cl	H_20
OR-1096-C	14.23 Wt %	2.24 Wt %	3.49 Wt %	20.1 Wt%	40.25 Wt%	0.34 Wt%	0.47 Wt %	0.07 Wt %	0.005 Wt %	13.10 Wt %

Since the amount of its MgO doubles that of CaO, and wt % Mg is 24.30, the gray marble is considered magnesium rich.

Discussion

The differential deformation of the leucosomes in the granite-gneiss (some into different fold types, others into pinch and swell structures, as well as boudinages) indicates that the granite-gneiss suffered at least two different phases of deformation. Since folds result from long duration compressional forces, and boudinages result from extensional forces, the granite-gneiss probably experienced a change in tectonic regime in its geological history. Since the boudinages associate with some of the folds (Fig. 4 and Fig. 5), the compressional stress regime that resulted into the folds appears to predate the extensional stress regime that produced the boundinages. This follows the stratigraphic Law of Cross-Cutting Relationship. The association of boudinages with granite-gneiss typically indicates middle to upper amphibolite metamorphic facies. This singular criterion classifies the granite-gneiss among rocks of the basement complex sensu stricto. Granite granite-gneiss has been included among rocks of the basement complex sensu stricto of the Igarra Schist belt (Ogunyele et al.,2018). The NW trend of their foliation appears to be relict of pre- Pan African trend in the basement.

Applying stratigraphic Law of Superposition to core data in borehole OSDD_28 (Table 1), the gneiss predates the calc-silicate gneiss. The pattern of intercalation of marble with calc-silicate gneiss in borehole OSDD_28 (Table 1) shows that marble overlies the calc-silicate gneiss. Thus, the calc-silicate gneiss constitutes a gradational

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E-ISSN 2756-4452

intercalation boundary between the gneiss and the marble. Calc-silicate gneiss predates mica schist (which is the garnet-biotite-muscovite schist) while the mica schist predates quartzite in coring hole OSDD_015 (Table 3). It has been reported that quartzites overlie garnet-biotite-muscovite schist in Igarra area (Odeyemi, 1988). The combination of garnet with muscovite indicates greenschist metamorphic facies (Wright *et al.*,1985). This attribute groups them with the Younger Metasediments (Turner, 1983; Wright *et al.*,1985). Deformed veins and secondary lineation are not observed on the granites. Such granites are late orogenic plutons (Bilings, 1986). Thus the granites are late Pan African granites. It can be inferred from the produced map (Fig. 19) that late Pan African intrusive activity caused fracturing and dextral displacement of marble bodies in the central part of the study area, and sinisterly displacement of granite gneiss in the SE part. Since the theoretical maximum percentage weight of CaO in pure $CaCO_3$ is 56 % wt, the range of CaO in whitish marble makes it a high purity calcitic marble. This is supported by large white marble crystals seen in some of the marble outcrops as in Fig. 13. Value range of Ca in whitish marble is at least a hundred times that of its Mg values. Comparatively, the whitish marble is rich in Ca. On the whole, whitish marble is fairly rich in Ca because Ca theoretical value in 100 wt % CaO is 71.47 %. The gray marble meets the requirement of pure dolomite (maximum of 30.40 wt % CaO and minimum of 24.80 wt % MgO) given by (Bilings, 1986). Thus the gray marble is a pure dolomite. Since the amount of its MgO doubles that of CaO, and wt % Mg is 24.30, the gray marble is considered magnesium rich. The requirement for considering carbonate bodies to be used as flux material is 28 wt % CaO minimum and 18 wt % MgO maximum (Boynton, 1980). The gray marble meets these requirements for use as a flux material in steel plants. The requirement for using carbonate rocks in sugar manufacturing is minimum of 80 wt % CaO and a maximum of 1.00 wt % MgO (Boynton, 1980). The whitish marble meets the requirements.

Conclusion

The rock types in Ososo area, in order of relative age, starting with the oldest first, are gneiss and granite-gneiss, calc-silicate gneiss, Mg-rich marble, Ca-rich marble, garnet-biotite-muscovite schist, quartzite, late Pan-African intrusive granites and gabbros. Geological structures of the granite-gneiss are folds, pinch and swell structures, and boudinages. The area has been affected by at least two phases deformation, and experienced compressional stress regime that predated extensional stress regime. The Ca-rich marble is suitable for use in manufacturing sugar. The Mg-rich marble is pure dolomite, and can be used as flux material.

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E-ISSN 2756-4452

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Appendix

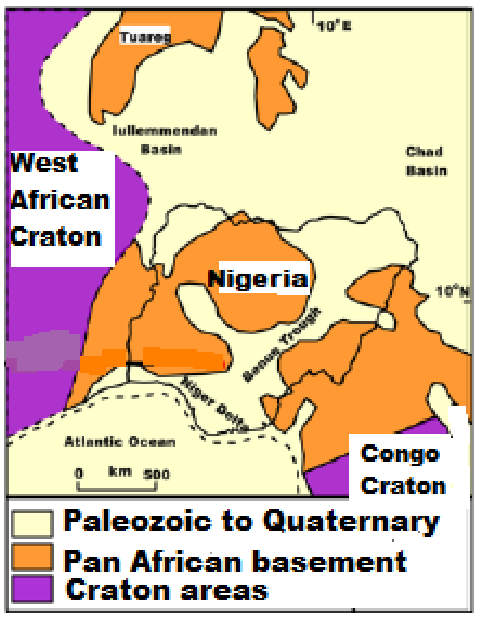

Figure1. Nigerian Pan-African Basement Complex
(Ogunyele *et al.*,2018)

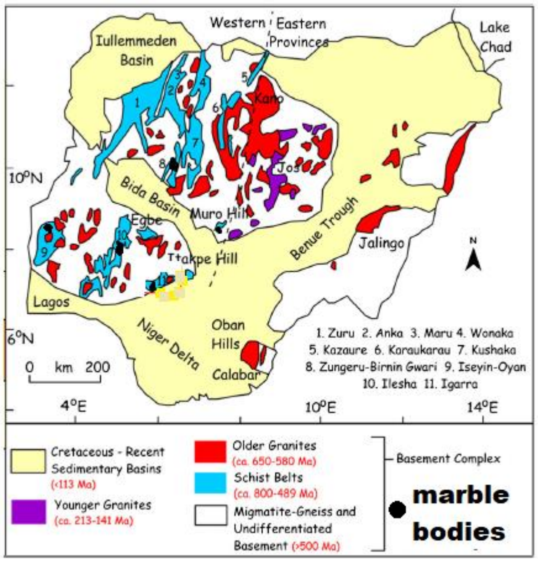

Figure 2. Supracrustal schist belts within the Nigerian Basement Complex (Woakes *et al.*,1987)

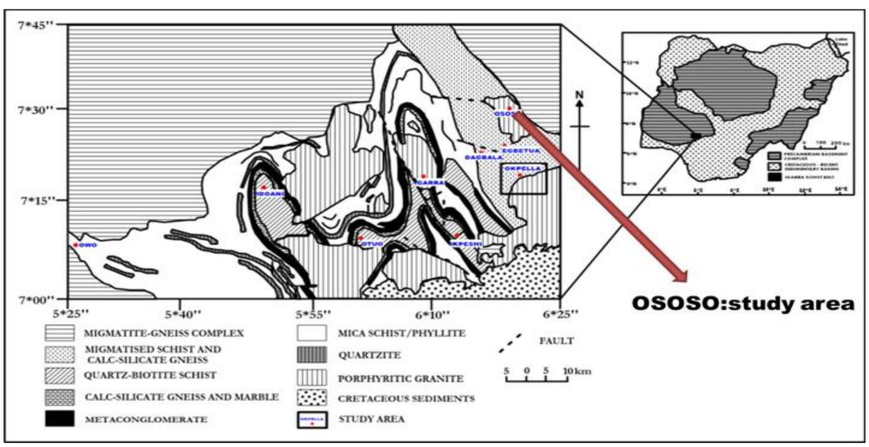

Figure 3. Modified after Ogunyele *et al.*,2018