

Research Article

The geochemistry, protolith, and tectonic settings of the Neoproterozoic Igarra-Ibillo-Ikpeshi meta-carbonate deposits, Southwest Nigeria

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Abstract

The geochemistry, provenance, protolith, and tectonic setting of Neoproterozoic meta-carbonate (marble) deposits in the Igarra-Ibillo-Ikpeshi area, southwestern Nigeria, were investigated using XRF on twenty-five samples from five quarry sites. The marbles are predominantly calcitic (average CaO = 46.62 wt.%, MgO = 7.14 wt.%) with subordinate dolomitic varieties and low silica and other impurities. Tectonic discrimination diagrams indicate deposition on a passive continental margin. Oxide ratios suggest a mantle-influenced shallow-marine carbonate protolith deposited in a saline, oxic to suboxic environment during the Neoproterozoic. These findings are consistent with pre-collisional carbonate platforms along the eastern margin of the West African Craton before the Pan-African orogeny. This study provides the first comprehensive trace and rare earth element constraints on the provenance, tectonic setting, and depositional history of meta-carbonates in the Igarra Schist Belt.

Keywords: Trace Elements, Passive Continental Margin, Igarra Schist Belt, Pan-African Orogeny

Introduction

Meta-carbonate rocks (marbles) are important indicators of ancient sedimentary environments and play a significant role in understanding crustal evolution during the Neoproterozoic Pan-African orogeny. In the Igarra-Ibillo-Ikpeshi terrains of southwestern Nigeria, marble deposits occur as massive bodies within the Igarra Schist Belt, associated with quartz-biotite schist, calc-silicate gneiss, and meta-conglomerates. Limited understanding of the tectonic setting and depositional conditions of these meta-carbonates hinders proper classification and correlation. This study investigates the geochemistry of Neoproterozoic meta-carbonate deposits in Igarra-Ibillo-Ikpeshi terrains to constrain their provenance, tectonic setting, and protolith. Marble, a major raw material for industries, results from the metamorphism of limestone, a carbonate sedimentary rock formed at the bottom of lakes and seas as silt and organic matter settle from the water body to the bottom. Calcite and dolomite are the major constituents of marble and often coexist in chemical equilibrium. Carbonate has been found to occur in anhydrous olivine and garnet in the upper mantle, where oxygen fugacity (partial pressure) is enough to stabilize carbonate minerals of magnesite, MgCO₃, and dolomite, Ca/MgCO₃. Marble is a granoblastic metamorphic rock resulting from the metamorphism of limestone or dolostone (carbonate rocks). This metamorphic process causes a complete recrystallization of the original rock into an interlocking mixture of calcite, aragonite, and/or dolomite crystals. It is white in its pure form, but mineral impurities such as clay, silt, sand, iron oxides, or chert can cause marble to appear in different colors.

The major influence on the chemistry and relative purity of a marble is the original composition of the carbonate sediment. Environments of carbonate deposition generally occur on a large scale, suggesting that the material will be consistent over a large, definable area. The studies of the trace and rare earth elements have been embarked upon by many scholars, such as Obasi et al. and Onimisi et al. to infer different tectonic environments and petrological affinities using diverse discriminant diagrams. This study is aimed at classifying the marbles in the study area geochemically in a bid to determine their provenance, tectonic settings, and protolith [1-6].

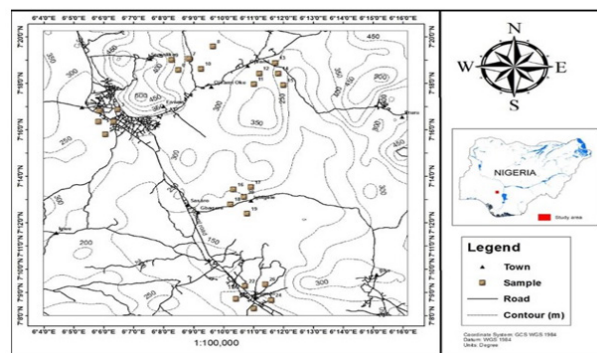


Figure 1: Location map of the Igarra-Ibillo-Ikpeshi study area showing sample locations.

Geological Settings

The Nigerian Basement Complex forms part of the Pan-African mobile belt between the West African and Congo Cratons. It records multiple orogenic events, with the Pan-African orogeny

(~600 ± 150 Ma) being the most pervasive [3]. The Igarra Schist Belt is one of the easternmost schist belts in southwestern Nigeria and is distinguished by abundant meta-carbonate and meta-conglomerate units. The study area is underlain by low- to medium-grade Neoproterozoic metasediments. Marble occurs as thick, lenticular to massive bodies within quartz-biotite schist, meta-conglomerate, and charnockite (Fig. 2). The meta-carbonates are medium- to coarse-grained, ranging in colour from white to pinkish-grey. They were subjected to Pan-African metamorphism and deformation. The Basement rocks are notably migmatitic gneiss complex, schist (metasediment), older granite, and late intrusives [2]. The schist occurs as a supracrustal cover on the Basement and consists of mica schist, meta-conglomerate, calc-gneiss, marble, and quartz biotite [7-13].

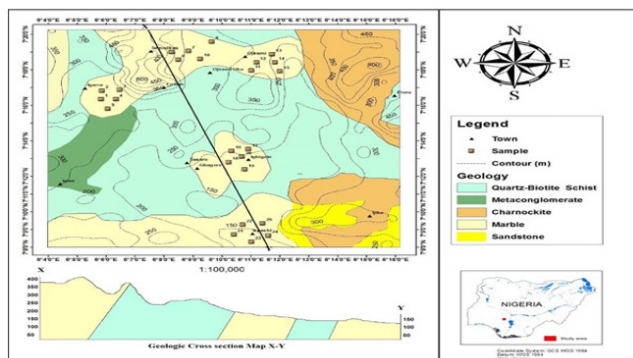


Figure 2: Geological map of Igarra-Ibillo-Ikpeshi showing meta-carbonate occurrences.

Materials and Methods

Twenty-five (25) fresh marble samples were collected from five quarry sites (Ojirami, Semolika, Sasaro, Igarra, and Ikpeshi). Samples were pulverized and analyzed for minor and major

oxides, trace elements, using X-ray Diffractometry (XRD) and X-ray Fluorescence (XRF) spectroscopy, Rigaku RIX 3000. The samples were collected with the aid of a geological hammer and a Global Positioning System (GPS) to locate and determine the coordinates of sampled locations. Collected samples were labeled and placed in sample bags. The samples were pulverized to reduce the larger size of the samples to smaller sizes (less than 1 mm) due to inhomogeneity and to increase the surface area. Various chemical reagents of analytical grade and instruments were used for the digestion of the samples. Quantitative and qualitative analyses were conducted to determine trace and rare elements, and major and minor oxides in powdered samples. Loss on Ignition (LOI) was determined gravimetrically.

Results and Discussion

Geochemical Composition and Classification of the Marbles

The major oxide composition (Table 1), shows high CaO (33.46–56.66 wt.%, avg. 46.62 wt.%) and variable MgO (0.75–19.97 wt.%, avg. 7.14 wt.%). SiO₂, Al₂O₃, and Fe₂O₃ contents are generally low, indicating high purity. CaO/MgO ratios (1.74–25.17) and calculated CaCO₃ (59.61–95.16%) and MgCO₃ (4.26–47.37%) contents classify the marbles as predominantly calcitic, with subordinate dolomitic varieties at Ikpeshi and Ojirami quarries Scott and Dunham [6]. Ternary diagram classification system (Fig. 3) for marbles by Storey and Vos, which presents the marbles as pure calcite and pure dolomitic calcite, with two samples plotting between pure calcitic dolomite and pure dolomite. According to Lippman (1973), pure carbonates should have a total carbonate content of 70% and above, while impure carbonates have between 40 – 70% [14]. Due to the presence of both calcitic and dolomitic carbonates in the marbles, the dolomites observed in the marbles were probably of precipitatory origin rather than replacement. Other oxides are regarded as impurities and are usually less than one (1) percent. The marbles have non-carbonate content ranging from 0.81% to 5.6%, with an average of 3.25%.

Table 1: Summary of major, minor oxides (%), and trace elements (ppm) geochemical data of marble deposits in the studied locations.

Oxides	Average	Min	Max	Trace Elements	Average	Min	Max
SiO ₂	1.947	0.47	7.3	V	10.516	4.11	26
Fe ₂ O ₃	0.369	0.03	1.23	Ba	89.52	15	169
Al ₂ O ₃	0.74	0.02	1.88	Cu	14.748	9.85	30
K ₂ O	0.239	0.01	0.67	Ni	21.002	19.84	21.9
MnO	0.085	0.01	1.19	Zn	39.133	29.8	90
CaO	46.62	33.46	56.66	Zr	11.477	3.85	39
MgO	7.143	0.753	19.97	Ag	1.119	0.4	3.41
Na ₂ O	0.225	0.01	0.63	Cr	21.417	19.8	30
P ₂ O ₅	0.073	0.02	0.21				
TiO ₂	0.058	0.01	0.21				
LOI	43.763	36.86	47.16				
CaCO ₃	82.66	59.61	95.16				
MgCO ₃	15.3	4.26	47.37				
CaO/MgO	14.961	1.74	25.17				
% Calcite	68.21	10.32	91.85				
% Dolomite	31.829	10.39	89.26				

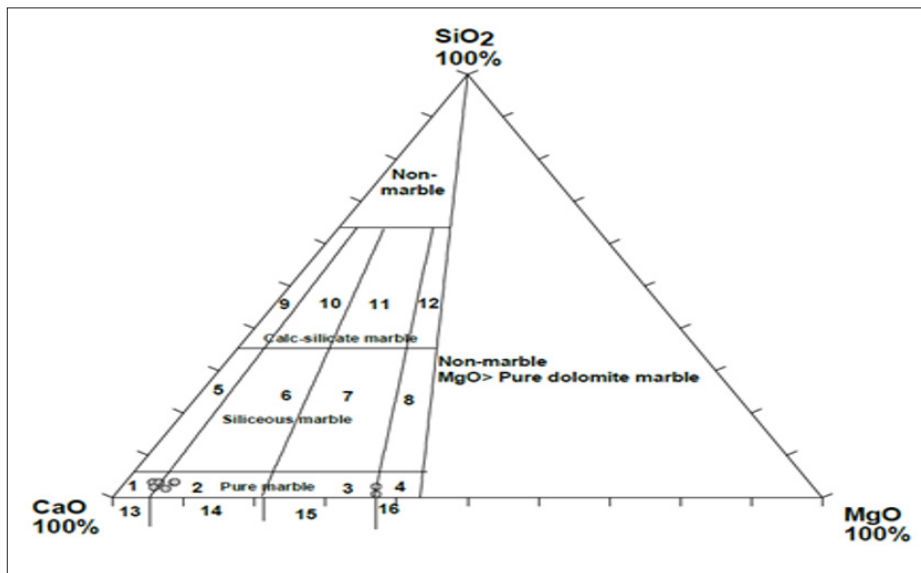


Figure 3: CaO-MgO-SiO₂ ternary diagram classification system for marbles [14].

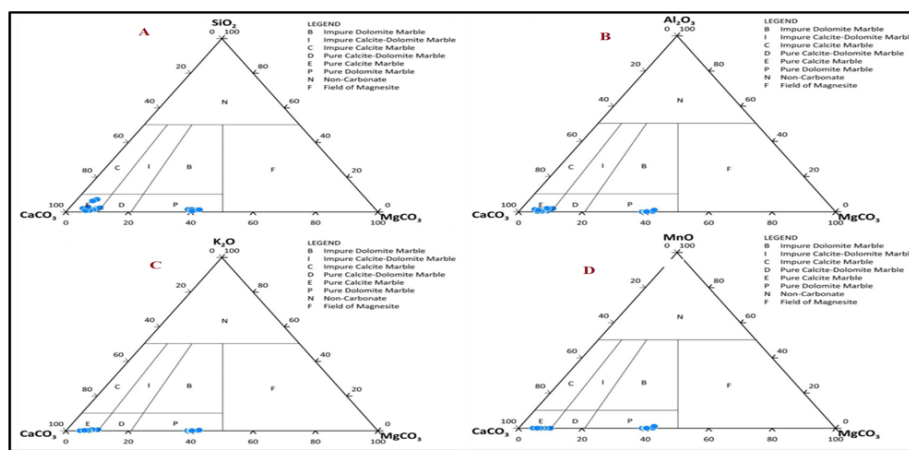


Figure 4: Ternary plots of (A): SiO₂-CaCO₃-MgCO₃, (B): Al₂O₃-CaCO₃-MgCO₃, (C): K₂O-CaCO₃-MgCO₃, (D): MnO-CaCO₃-MgCO₃.

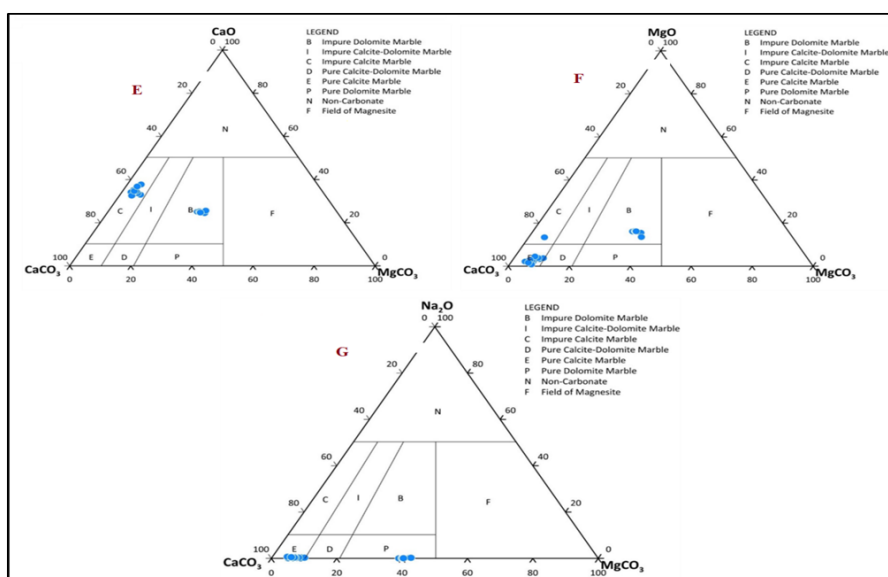


Figure 5: Ternary plots of (E): CaO-CaCO₃-MgCO₃, (F): MgO-CaCO₃-MgCO₃, and (G): Na₂O-CaCO₃-MgCO₃.

Tectonic Settings and Protolith

Bivariate and ternary discrimination diagrams were used to constrain the tectonic setting of the meta-carbonate protolith. The data consistently indicate deposition on a passive continental margin (Fig. 8). Figure 8A and 8B are bivariate tectonic discrimination plots of the marbles based on major oxides; both show the majority of the samples in the passive margin zone and a few in the active continental margin zone, reflecting limited detrital input from adjacent basement rocks. A discriminant plot of $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ vs. $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ Garrels and McKenzie of the marbles (Fig. 6) shows them plotting in the field of sedimentary and metasedimentary rocks [15]. To interpret the protolith of the marbles, a discriminant plot of $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ vs. $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ after Garrels and Mckenzie was done for marble deposits in the study area, shows that the marbles fall within the field of sedimentary and metasedimentary rocks, suggesting both contact and regional metamorphism due to the interbedding of the marble deposits with sandstone and quartz-biotite schist (Fig. 2), a characteristic used in determining types of metamorphism.

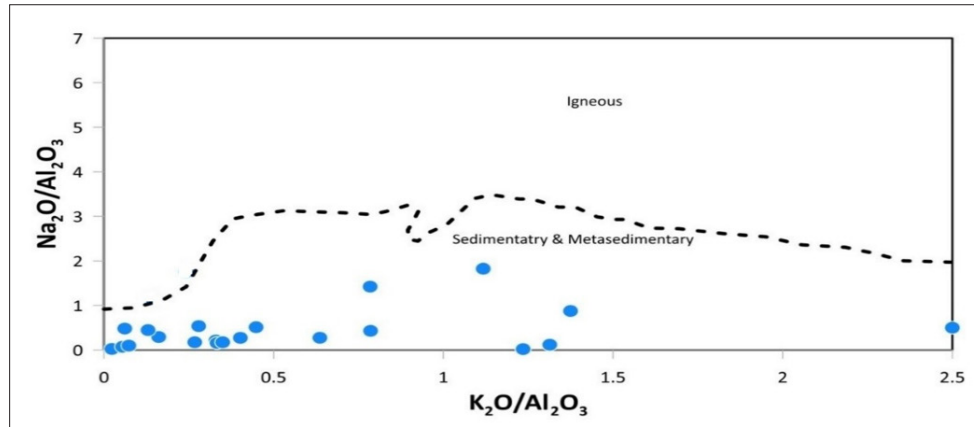


Figure 6: $\text{Na}_2\text{O}/\text{Al}_2\text{O}_3$ versus $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$ discrimination diagram [15].

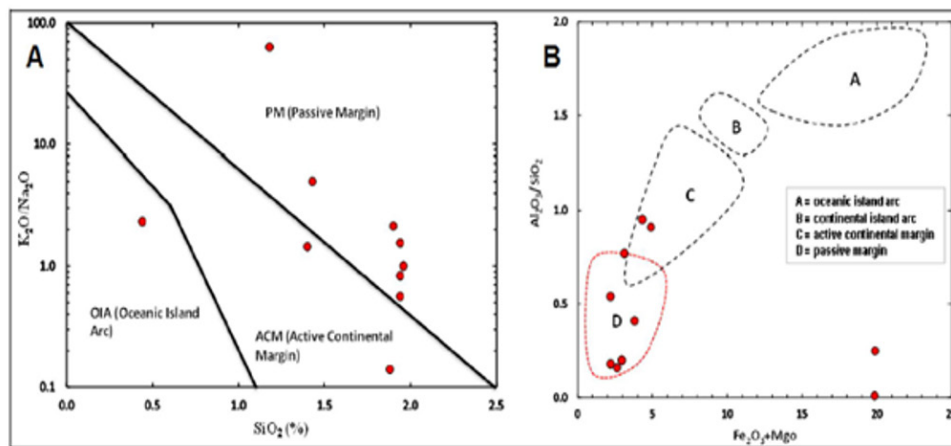


Figure 7: Bivariate plots of (A) $\text{K}_2\text{O}/\text{Na}_2\text{O}$ versus SiO_2 and (B) $\text{Al}_2\text{O}_3/\text{SiO}_2$ versus $\text{Fe}_2\text{O}_3+\text{MgO}$, confirming passive margin affinity.

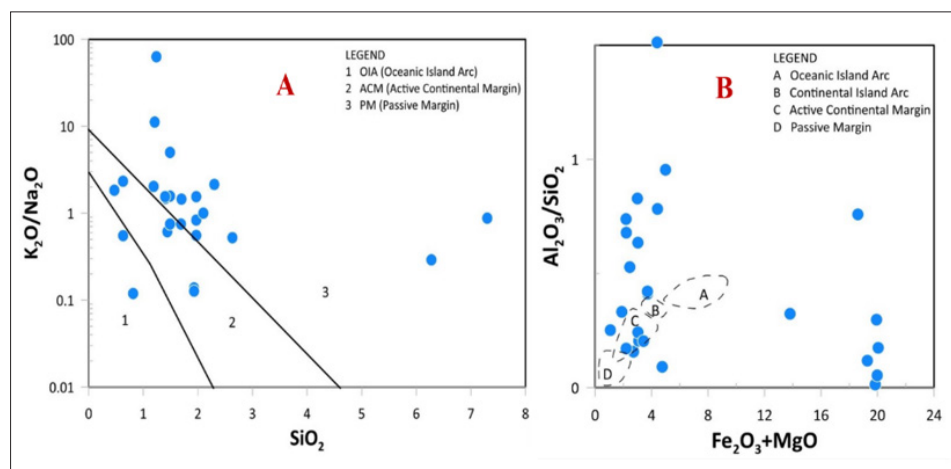


Figure 8: (A) Roser and Korsch and (B) Bhatia tectonic discrimination diagrams indicate a dominant passive margin setting [16].

Conclusion

The Neoproterozoic meta-carbonate deposits in the Igarra-Ibillo-Ikpeshi area are predominantly high-purity calcitic marbles with subordinate dolomitic varieties. Geochemical data reveal low impurity levels, indicating derivation from a shallow-marine carbonate protolith deposited on a passive continental margin. Tectonic discrimination diagrams consistently support this passive margin setting, consistent with pre-collisional sedimentation along the eastern margin of the West African Craton during the Neoproterozoic, before the main Pan-African collisional event. This study provides new insights into the provenance, tectonic setting, and petrogenesis of meta-carbonate rocks in the Igarra Schist Belt and contributes to the understanding of Neoproterozoic crustal evolution in southwestern Nigeria. Future work integrating stable isotope (C-O) geochemistry, zircon U-Pb dating, and detailed mineral chemistry is recommended to further constrain the depositional age and metamorphic history of these deposits [17].

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