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PETROGRAPHIC, MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF METACARBONATE (MARBLE) ROCKS FROM THE OREKE AREA, SOUTHWESTERN NIGERIA: IMPLICATIONS FOR INDUSTRIAL APPLICATIONS

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Abstract: Metacarbonate rocks from the Oreke area were investigated in order to study their mineralogical and geochemical characteristics and evaluate their industrial potential. Petrographic examination, X-ray diffraction, and inductively coupled plasma mass spectrometry were employed to characterize representative samples of the white, whitish-grey, and dark marble varieties. The marbles are predominantly dolomitic and contain subordinate calcite, tremolite, phlogopite, sylvite, and graphite. Geochemical analyses reveal appreciable compositional variations among the three varieties. The average oxide composition of the Oreke marbles is characterized by major CaO and MgO contents, accompanied by subordinate SiO_2, Al_2O_3, Fe_2O_3, MnO, Na_2O, K_2O, TiO_2, and P_2O_5, with mean values of 28.24, 17.84, 10.64, 2.39, 3.11, 0.058, 0.331, 0.527, 0.808, and 0.289, respectively. The average loss on ignition is 35.55 wt. %, reflecting the substantial carbonate fraction of the deposit. The integrated mineralogical and geochemical evidence demonstrates that the Oreke marble deposit constitutes a valuable industrial resource with promising applications in the production of magnesium metal and magnesia, as well as in agronomy and other carbonate-based industries.

Keywords: Oreke marble, mineralogical characterization, petrography, industrial and agronomic applications.

Introduction

Carbonate rocks are widely used as industrial raw materials because of their purity and favourable chemical composition. Nigeria is endowed with abundant mineral resources, including extensive metacarbonate deposits that provide essential materials for infrastructure development (Muotoh *et al*., 1988; Okunlola, 2001). Many of these carbonate deposits occur within the Nigerian schist belts, which have experienced multiple episodes of deformation and metamorphism. These belts are distributed across both northern and southern Nigeria and exhibit distinct structural, metallogenic, and petrological characteristics (Elueze, 1992). Major schist belts include the Zuru, Anka, Maru, Wonaka, Kazaure, Karaukarau, Kushaka, Zungeru, Iseyin–Oyan, Ife–Ilesha, and Igarra belts (Fig. 1, Elueze and Okunlola, 2003).

The growing demand for marble and other lime-rich rocks in construction, coupled with rapid urbanization and renewed interest in solid mineral development, has stimulated both local and international investment in Nigeria's carbonate resources. The suitability of carbonate deposits for cement manufacture, chemical production, and construction applications depends primarily on their physical and chemical properties. Consequently, comprehensive characterization is essential before industrial utilization. This study investigates the mineralogical and geochemical characteristics, as well as the economic and industrial potential, of the Oreke marble deposit in southwestern Nigeria. Petrographic observations, X-ray diffraction (XRD), and inductively coupled plasma mass spectrometry (ICP–MS) were employed to establish the mineralogical composition and assessing the suitability of the marble for various industrial applications.

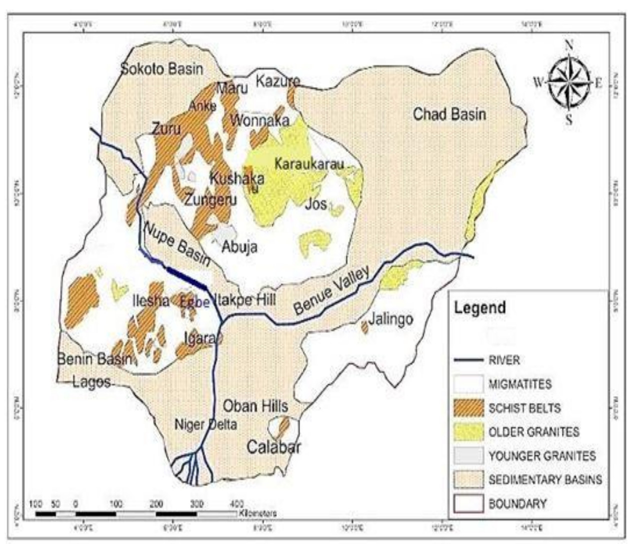

Fig. 1 Geological map of Nigeria showing the schist belts (adapted from Annor *et al*, 1996).

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Study Area Geology

Granite, marble, quartz schist, and banded gneiss constitute the principal lithological units in the study area. Most of the rocks are well exposed, although many outcrops exhibit deep weathering. Banded gneisses are widespread, and are locally intruded by pegmatitic veins. The marble bodies are extensively distributed throughout the Oreke region and occur in a range of colours, including white, whitish-grey, and dark varieties. Marble accounts for approximately 10% of the exposed rock units in the area.

These carbonate rocks are concentrated in the north eastern part of Oreke town, where they are bounded by banded gneisses and schists. The marble typically occurs as low-lying, lens-shaped bodies with a predominantly north–south orientation.

Materials and Methods

Ten representative marble samples were collected as fresh rock chips from active open pits within the Oreke area (08°29′16.4″N, 005°10′34.9″E) (Fig. 2), encompassing the white, whitish-grey, and dark varieties. Samples were prepared for petrographic, XRD, geochemical, and geotechnical analyses. For XRD, powdered samples (<2 µm) were analyzed at the Nigerian Geological Survey Agency, Kaduna, using a Pan alytical X'Pert Pro diffractometer with Cu Kα radiation over 5–70° 2θ. Mineral phases were identified with the PDF-4 Minerals database in X'Pert High Score Plus.

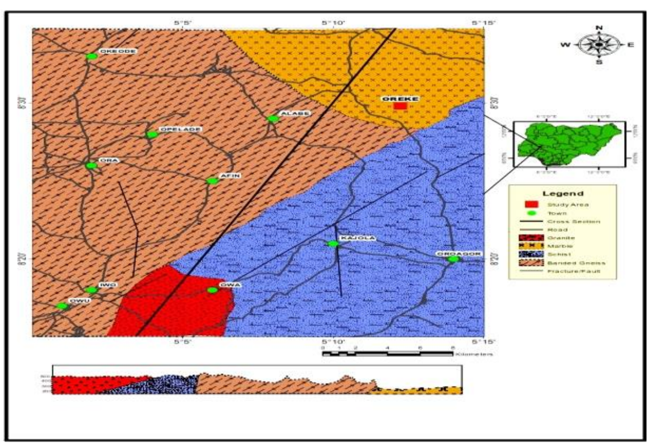

Fig. 2 Geological map of Oreke area.

Major and trace elements were determined at Activation Laboratories, Canada, following standard acid digestion and lithium metaborate fusion procedures, respectively, and analyzed by ICP–MS. Analytical precision was better than 0.4% for major oxides and 0.5 ppm for trace elements. Thin sections of representative samples were examined under plane- and cross-polarized light, and carbonate minerals were distinguished using the Alizarin Red S–potassium ferricyanide staining method. Physical and geotechnical properties were determined according to ASTM and BGS procedures. Replicate analyses were performed and mean values reported.

Results and Discussion

Petrographic and X-ray Diffraction Analyses

Petrographic examination and X-ray diffraction (XRD) analyses indicate that the carbonate rocks are composed predominantly of dolomite with subordinate calcite (Figs. 3 and 4). The XRD patterns of the representative samples are presented in Figures 5–7. Dolomite is the dominant mineral phase and occurs in all the samples analyzed. In addition, the white marble variety contains traces of tremolite, the whitish-grey variety contains minor sylvite and graphite, and the dark marble variety is characterized by traces of tremolite and phlogopite (Table 1).

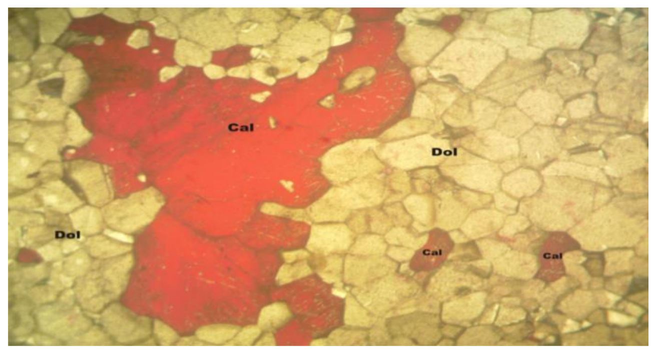

Fig. 3 Photomicrograph of the white marble variety (*crossed nicols*) showing calcite (Cal) and dolomite (Dol).

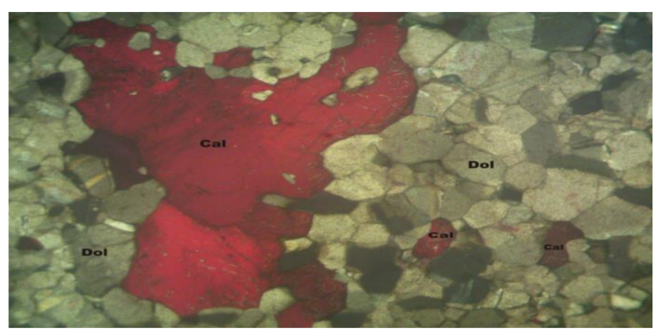

Fig. 4 Photomicrograph of white marble variety (*plane polarised*) showing calcite (Cal) and dolomite (Dol).

Geochemical Features

In general, the presence of MgO, CaO, Fe_2O_3, and SiO_2 is crucial for describing the marble material's quality. Table 2 provides the chemical makeup of the marble samples. The primary elements are expressed as a percentage (wt.%), while the trace elements are expressed as parts per million (ppm).The Oreke marble's SiO_2 concentration ranges from 2.2 to 24.07 (av. 7.71). MgO ranges from 12.02 to 21.11 (av. 19.01), Al_2O_3 ranges from 0.09 to 6.86 (av. 1.52), Fe_2O_3

Table 1. The X-ray diffraction results showing the quantitative relative mineral composition of the Oreke marble.

Samples	Major %	Minor %	Trace %
White marble (M1)	Dolomite (70)	Tremolite (30)	-
White-greyish marble (M5)	Dolomite (63)	Calcite (15)	Sylvite (14) Graphite (8)
Dark marble (M10)	Dolomite (53)	Tremolite (33)	Phlogopite (14)

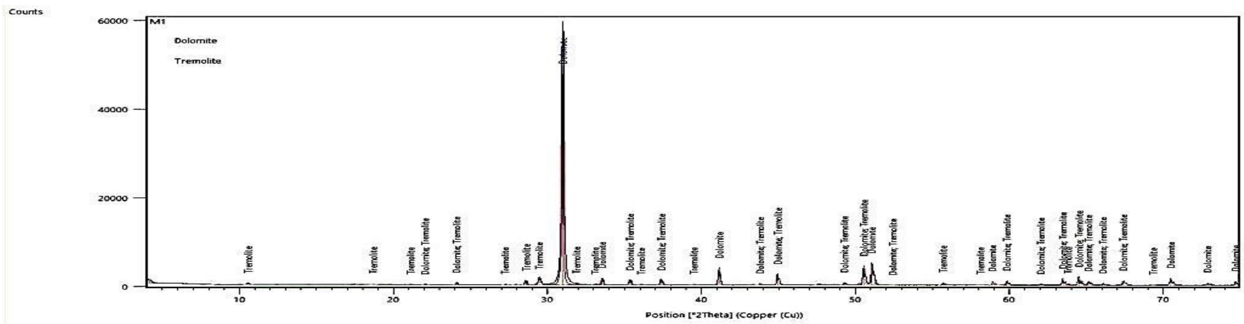

Fig. 5 X-ray powder diffraction analysis plot of marble sample (white marble).

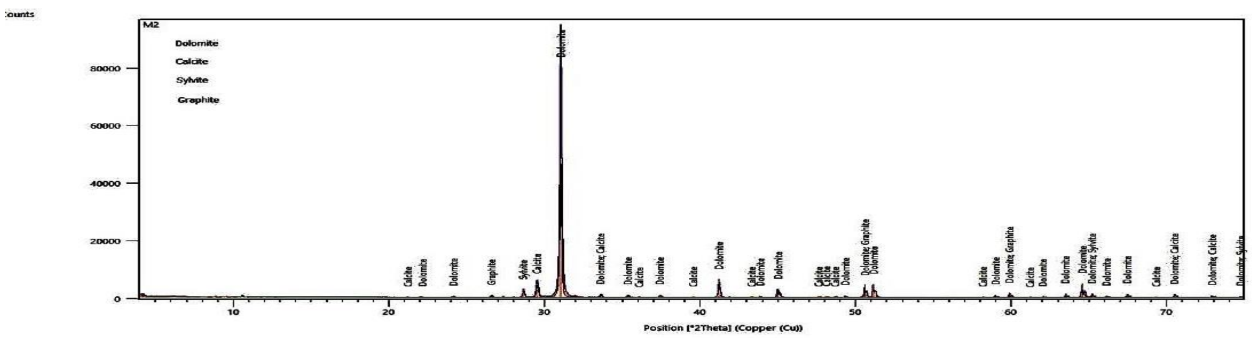

Fig. 6 X-ray powder diffraction analysis plot of marble sample (white-greyish marble).

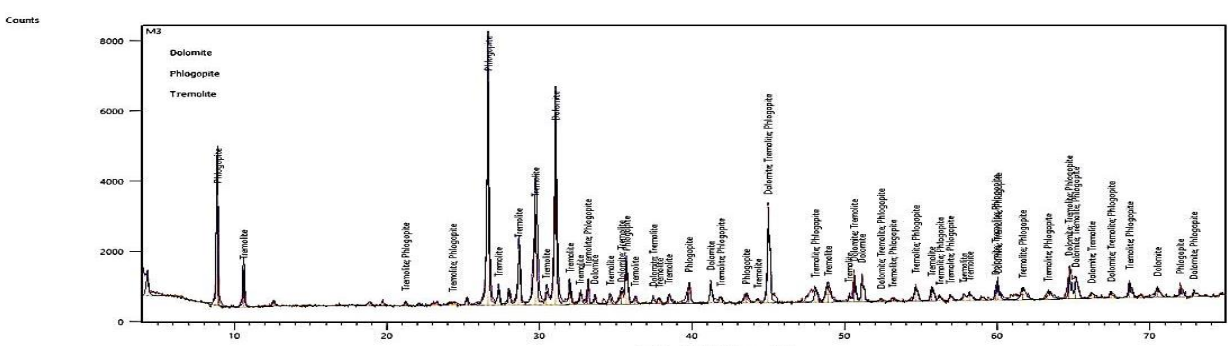

Fig. 7 X-ray powder diffraction analysis plot of marble sample (dark marble).

ranges from 0.08 to 9.19 (av. 1.92), and the average CaO content of marble is from 22.26 to 31.86 (av. 29.43). The samples loss on ignition (L.O.I.) ranges from 19.6 to 44.9 (av. 38.98). Other samples, like Na_2O, K_2O. MnO, TiO, and P_2O_5, have low average values of 0.03 to 0.9, 0.01 to 1.56, 0.005 to 0.165, 0.033 to 0.155, and 0.03 to 0.78, respectively. The white variety sample M1 has the greatest CaO content (31.55%) (Table 2). The samples with the lowest CaO concentrations, M9 and M10 (dark variety), have weight percentages of 22.26 to 22.76. The silica content of both samples is significant, at 23.70 and 24.07 weight percent. Sample M10 (24.07) had the highest SiO_2 concentration observed The samples had a comparatively high MgO value of 21.10–21.11 weight percent, and the results indicate that the rock is extremely rich in dolomite. The samples M8 and M4 (white-greyish variation) have the

Table 2. Chemical composition of Oreke marble.

Wt.%	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	Mean
SiO_2	4.86	4.59	2.2	2.3	4.98	4.75	2.73	2.88	23.70	24.07	7.706
Al_2O_3	0.15	0.16	0.09	0.09	0.35	0.32	0.21	0.23	6.72	6.86	1.518
Fe_2O_3	0.16	0.15	0.09	0.08	0.18	0.18	0.11	0.12	8.92	9.19	1.918
MnO	0.006	0.006	0.005	0.005	0.008	0.008	0.005	0.005	0.161	0.165	0.0374
MgO	20.82	20.27	20.22	21.11	20.65	20.39	21.09	21.10	12.02	12.38	19.01
CaO	31.55	30.46	30.85	31.69	30.73	31.59	30.56	31.86	22.26	22.76	29.43
Na_2O	0.04	0.05	0.03	0.03	0.06	0.06	0.05	0.05	0.86	0.94	0.217
K_2O	0.02	0.02	0.01	0.01	0.06	0.06	0.05	0.06	1.48	1.56	0.333
TiO_2	0.005	0.005	0.002	0.003	0.021	0.02	0.025	0.027	2.367	2.447	0.4922
P_2O_5	0.08	0.07	0.05	0.04	0.04	0.05	0.04	0.03	0.72	0.78	0.19
LOI	42.9	42.87	44.95	44.94	42.78	42.99	44.54	44.48	19.64	19.67	38.98
CaO/MgO	1.51	1.50	1.52	1.50	1.48	1.54	1.44	1.50	1.85	1.83	14.02
Calcite % in marble	4.66	4.19	5.00	4.16	3.69	5.87	2.27	4.44	15.26	14.89	6.44
Dolomite %in marble	95.34	95.81	95.00	95.84	96.31	94.13	97.73	95.56	84.74	85.11	93.55

Table 3. Oreke marble varieties chemical content in comparison to Obajana, Jakura, Ososo, Igbetti, and Burum marbles.

	Oreke white marble	Oreke whitish-grey marble	Oreke dark marble		Obajana (n=10)		Jakura (n=33)		Ososo (n=21)		Igbetti (n=7)		Burum (n=29)	
Oxide	Mean		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
SiO_2	4.73	3.30	23.89	2.2-24.07	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	0.155	0.215	6.79	0.09-6.86	0.243	0.08-0.52	00.7	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	0.155	0.127	9.055	0.08-9.19	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
MnO	0.006	0.006	0.163	0.005-0.165	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	20.55	20.76	12.2	12.02-21.11	1.09	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	31.01	31.21	22.51	22.26-31.86	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	0.045	0.047	0.9	0.03-0.94	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	0.02	0.042	1.52	0.01-1.56	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	n
TiO_2	0.005	0.013	2.407	0.002-2.447	0.029	0.01-0.08	N	n	n	n	n	n	0.17	n
P_2O5	0.075	0.0417	0.75	0.03-0.78	0.058	00.2-0.12	N	n	n	n	n	n	0.03	n
LOI	42.89	44.11	19.66	19.6-44.9	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	99.88	99.82	36.7-98.9	99.14	99.40-99.76	99.87	n	99.80	n	90.24	n	99.82	n

I. Oreke dark marble, Oreke white marble, and Oreke whitish-grey marble (this study)
II. Obajana marble (calcitic) [Elueze *et al*., 2015] n= not available
III. Jakura marble (calcitic) [(Emofurieta, and Ekuajeni. (1995)]
IV. Ososo marble (calcitic) [(Emofurieta, and Ekuajeni. (1995)]
V. Igbetti marble (dolomitic) [(Emofurieta, and Ekuajeni. (1995)]

highest MgO content. This implies that Mg^{2+} may have been ionically substituted for Ca^{2+} in the calcite structure. Because MgO, SiO_2, TiO_2, and Fe_2O_3 are associative minerals of the oxides, it is also highly probable that dolomite, quartz, titanium, and iron minerals are present in samples M4, M8, and M9. Additionally, the dark variant samples M9 and M10 only contain very modest amounts of K_2O. Oreke marble bodies' average and range of chemical data are similar to those of Burum and Igbetti marble. When compared to other marble rock samples from Obajana

(Elueze *et al*., 2015), Jakura (Emofurieta and Ekuajeni, 1995), Ososo and Igbetti (Emofurieta and Ekuajeni, 1995), and Burum (Okunlola, 2001). The SiO_2 concentration in the Oreke marble rocks exhibits a strong variation and can be considered a relatively siliceous rock. Compared to other marble sources, the Oreke marble variants have a comparatively high silica concentration (Table 3). The average SiO_2 content is 4.73 for the Oreke white marble variation, 3.30 for the white-greyish type, and 23.89% for the dark marble variety.

A certain amount of impurity in the parent rock is also indicated by the relatively low average values of Al_2O_3 and Fe_2O_3 of the white and white-greyish types (Al_2O_3: 0.155, 0.215; Fe_2O_3: 0.155, 0.127 %), and high levels of Al_2O_3 and Fe_2O_3 (6.79, 9.055 %) of the dark marble variety, respectively. Alkali (K_2O + Na_2O) is present in relatively small amounts in all Oreke marble types. Compared to comparable marble sources, these values have a slightly higher alkali concentration (Table 3). In general, the white 42.89 and white greyish 44.11 variants of Oreke marble have a higher average L.O.I. content than the dark variety (19.66%). This suggests that the Oreke marble deposit has a high volatile concentration. Comparing the Oreke marble deposit to the average and range of marble bodies from other published works (Table 3), it can be inferred from this analysis that the marble is dolomitic with some impurity since it contains alumino silicate minerals.

Table 4 displays the trace element composition of the rock samples taken from the study area. Sr exhibits a consistent dominance in value across all marble varieties, while Ce values decrease in the white and white greyish marble samples but also have a significant presence in the dark marble samples, whereas Co, Cu, Pb, Zn, Ba, Sr, and Rb have very high values in Oreke marble rocks, particularly in the dark variety.

In general, the marbles' trace element contents exhibit high levels and significant variation among the three kinds (Table 3). In comparison to marble samples from Obajana (ppm) (Ce: 4.1; Co: 1.1; Cu: 2.5; Pb: 6; Zn: 80) (Elueze *et al*., 2015) and Jakura (Ce: 3; Co: 17; Cu: 5; Zn: 13) (Emofurieta and Ekuajeni, 1995), the average values of the dark marble samples (Ce: 33; Co: 22; Cu: 20; Pb: 6; Zn: 80) are generally high, reflecting a high degree of impurity. Furthermore, the dark marble values are elevated compared to those from Ososo (Ce: 4; Co: 15; Cu: 6; Zn: 12) (Emofurieta and Ekuajeni, 1995), Burum (Co: 145; Cu: 4; Zn: 38) (Okunlola, 2001), and Igbetti (Ce: 3; Co: 14; Cu: 9; Zn: 23) (Emofurieta and Ekuajeni, 1995).

Potential Industrial Applications

Flux in steel making: Calcined marble used as a steelmaking flux facilitates the removal of phosphorus, silica, and sulfur from slag by converting them into calcium phosphate, silicates, and sulfides, respectively. According to the British Geological Survey (BGS, 1993), marble intended for use as a steelmaking flux should contain less than 5 wt. % SiO_2. The Oreke marble samples M2, M3, M7, and M8 satisfy this criterion and are therefore suitable for application as fluxes in steel production.

Other Applications: Magnesia (MgO) and magnesium metal, which are components of refractory bricks, are obtained from calcined dolomite. Hydrochloric acid can be used in a leaching process to extract magnesium from dolomite ores. The pH of the Oreke sample is 8.2, which makes it a good water softener (Boynton, 1980). It is beneficial for the potential creation of sculptures and decorative items since it is simple to sculpt.

Table 4. Comparison of trace elements of Oreke marble varieties with Obajana, Jakura, Ososo, Igbetti and Burum marbles.

	Oreke white marble	Oreke white-greyish marble	Oreke Dark Marble		Obajana (n=7)		Jakura (n=7)		Ososo (n=7		Igbetti (n=7)	Burum (n=7)	
	Mean		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Ce	0.7	1.0	33	0.5-33.6	4.1	1-13	3	3-6	4	3-6	3	3-6	n
Co	< 1	< 1	22	21-23	1.1	1-2	17	10-20	15	10-20	14	10-20	14
Cu	20	< 10	20	10-20	2.5	1-6	5	2-9	6	5-7	9	7-11	4
Pb	< 5	10	6	6-21	1.5	1-4	N	n	n	n	n	n	n
Rb	< 2	2	90	6-91	5.44	1-22	N	n	n	n	n	n	n
Sr	58	105	130	41-196	2740	1557-3678	N	n	n	n	n	n	n
Zn	< 30	< 30	80	30-80	2.5	1-10	13	13-19	12	10-15	23	15-29	38

I. Oreke white marble, Oreke whitish-grey marble, Oreke dark marble (this study)
II. Obajana marble (calcitic) [Elueze *et al*.2015]
III. Jakura marble (calcitic) [(Emofurieta, and Ekuajeni. (1995)]
IV. Ososo marble (calcitic) [(Emofurieta, and Ekuajeni. (1995)]
V. Igbetti marble (dolomitic) [(Emofurieta, and Ekuajeni. (1995)]
VI. Burum marble (dolomitic) [Okunlola 2001] n= not available

Conclusion

The Oreke marbles are predominantly dolomitic and comprise white, whitish-grey, and dark varieties distinguished by their mineralogical and geochemical compositions. Dolomite is the dominant phase, with minor calcite, tremolite, phlogopite, sylvite, and graphite. The white and whitish-grey marbles are relatively pure and enriched in carbonate minerals, whereas the dark variety contains higher silicate and accessory mineral contents. Comparison with other Nigerian marble deposits indicates that the Oreke deposit is a significant dolomitic resource with considerable potential for the production of magnesia and magnesium metal, refractory materials, agricultural amendments, and selected metallurgical applications. These findings provide a sound basis for the sustainable exploitation and value addition of the Oreke marble deposit.

Conflict of Interest

No conflicts of interest are disclosed by the authors.

Data Availability

They are included in the article

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