Compositional appraisal and quality implications of a metacarbonate deposit occurring in parts of southeastern Nigeria

Presoja sestave in njenega vpliva na kakovost metakarbonatne kamnine iz nahajališča v jugovzhodni Nigeriji

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Received: October 11, 2011 **Accepted:** December 19, 2011

Abstract: Metacarbonate deposits occurring in Nsofang and environs in the Ikom area of southeastern Nigeria are low grade dolomitic marble. Field and compositional attributes of the marble have been used to establish the material's suitability for identified end-product uses. Thin-section optical microscopy, X-ray powder diffraction and bulk rock chemistry agree with the fact that carbonate phases dominate the modal mineralogy of the rock. Dolomite is clearly the dominating phase and calcite the subordinate, while silicates constitute the accessory phases. The mineralogical composition reflects the possible attainment of peak metamorphic conditions that is equivalent to, at most, the greenschist facies metamorphism. Geochemical and comparative data show that the Nsofang marble displays lower CaO and elevated MgO, LOI and trace elements compositions, compared to similar carbonate – bearing rocks occurring in other parts of Nigeria and elsewhere. Also, computed CaO/MgO ratio of the marble appears relatively lower and some of the trace elements display significant positive relationships with the insoluble residue contents of the Nsofang marble. All these attributes degrade the quality of the marble, making it unsuitable for many conventional applications. However, certain compositional features, such as elevated MgO composition and low total sulphur contents can impact positively on the applicability of the Nsofang marble. Accordingly, the marble can be relied upon as compensators for magnesium deficiencies in the agricultural

Original scientific paper

industry, and in the sourcing of magnesium oxide for the chemical industry as well as when used as dimension stones. Furthermore, with adequate beneficiation, the Nsofang marble can also be adapted for use as MgO + C refractories for electrical arc furnace (EAF) linings.

Izvleček: Metakarbonatna kamnina v nahajališčih Nsofanga in okolice na območju Ikoma v jugovzhodni Nigeriji je dolomitni marmor nizke stopnje metamorfoze. Na podlagi terenskih in kemičnih lastnosti tega marmorja je bila opredeljena njegova primernost kot surovina za določene namene. Rezultati preiskave zbruskov pod optičnim mikroskopom, rentgenske difrakcijske analize prahu in kemijske analize kamnine pričajo o tem, da prevladujejo v mineraloški sestavi kamnine karbonatne faze. Prevladujoč glavni mineral je dolomit, stranski pa kalcit, medtem ko so silikatni minerali akcesorni. Mineraloška sestava nakazuje verjetnost pogojev metamorfoze, ki ustreza vsaj faciesu zelenih skrilavcev. Geokemijski in primerjalni podatki pričajo o tem, da se sestava marmorja iz Nsofanga odlikuje po nižjem CaO in visokih MgO, LOI in slednih prvinah v primerjavi s podobnimi karbonate vsebujočimi kamninami iz drugih delov Nigerije in od drugod. Tudi izračunani količnik CaO/MgO tega marmorja je razmeroma nizek, medtem ko so nekatere sledne prvine statistično značilno pozitivno korelirane z vsebnostjo netopnega ostanka v Nsofanškem marmorju. Vse navedene lastnosti slabo vplivajo na kakovost marmorja, ki zato ni ustrezen za marsikatero običajno uporabo. Vendar pa nekatere lastnosti sestave, tako visoka vsebnost MgO in nizka celotnega žvepla utegnejo ugodno vplivati na njegovo uporabnost. Tako ga je mogoče uporabljati kot protisredstvo ob pomanjkanju magnezija v kmetijstvu, kot vir magnezijevega oksida v kemični industriji in kot arhitektonski kamen. In slednjič, marmor iz Nsofanga je mogoče uporabiti po ustrezni predelavi tudi za izdelavo MgO + C ognjevzdržnih materialov za obloge v električnih obločnih pečeh (EAF).

Key words: metacarbonate, composition, geochemistry, Nigeria
Ključne besede: metakarbonat, sestava, geokemija, Nigerija

Introduction

Although metacarbonate deposits, such as marble, occur abundantly in Nigeria, and furnish the raw material needed for the rapidly expanding building and other industries, their compositional features have not been widely investigated and documented. The few contributions on compositional and quality attributes of marble deposits in Nigeria, include those of Age (2008), Danladi (1993), Davou & Ashano (2009), Emofurieta & Ekuajemi (1995) and Emofurieta et al. (1995). On the other hand, much more work appears to have been done on investigations of dimensional properties of prospects. Ojo et al. (2003) focused on the determination of the lateral and depth extents of the Takalafia marble, situated close to the Federal Capital Territory of Nigeria. Odeyemi et al. (1997) considered ground gravity and magnetic surveys in an effort to evaluate the economic significance of the Ikpeshi marble. Folami & Ojo (1991) worked on the geophysical study of the southern part of Igarra with the intent of mapping concealed Ore deposit in the form of marble.

Much as the dimensional features of metacarbonate bodies are important, the compositional properties are also required, especially in the economic valuation of a prospect. The relevance of mineralogical and chemical investigations cannot be overemphasized when assessing the suitability of metacarbonate rocks for specific usage.

In southeastern Nigeria, metamorphosed carbonate deposits was recently discovered in Nsofang and environs in the Ikom area, and no published data exist yet on this deposit. There is the need to explore the deposit in sufficient details, and such investigation should normally include physical evaluation, compositional assessments, and geophysical exploration. The present contribution focused on the compositional appraisal of the metacarbonate rock, and the intension is to reveal the industrial quality of the material, based on available compositional data. However, no effort is made in the present study to interpret the compositional features of the rock to reflect petrogenetic history of the deposit since this aspect constitutes another area of research. The impetus for the present research was derived from the need to be actively involved in the growth and development of the hitherto dormant solid minerals sector of Nigeria.

Description of Study Area

The area of investigation is situated southeast of Ikom in the southeastern region of Nigeria (Figure 1), and delimited by latitude 5°40′ and 6°00′ North and longitude 8°35′ and 8°50′ East within the Nigerian topography sheet 315 (Ikom NW). Geologically, most parts of the area can be classified as parts of the Mamfe embayment, a predominantly sedimentary deposits comprising sandstones, mudstones, shales, limestones, micro-conglomerates, polygenic conglomerates having thickness of about 2000 m (Olade, 1975) associated with basic volcanic and undifferentiated basement rocks (Figure 1). In recent times, metacarbonates, which occur as lensoid bodies within the low to very low grade metamorphosed and unmetamorphosed sedimentary sequences near Nsofang village, have also been revealed as parts of the lithologic components of the embayment. The metacarbonate body is delimited by latitude 5°44′ and 5°47′ North and longitude 8°38′ and 8°42′ East. The deposits are generally low-lying, with slightly elevated portions in some locations, while their surfaces are rugged, possibly due to the influence of weathering. Some of the exposure appears foliated with steep dips and variable strike orientation. Also, joints are common and assume cross or east – west orientations.

Methods of Study

Both petrographic and chemical analyses were undertaken in the study of the Nsofang metacarbonates. The petrographic study comprised both thin section optical microscopy and X–ray diffraction investigations. Unweathered rock samples collected during fieldwork and traversing of various metacarbonate outcrops, within the prospect region, were utilized for the various

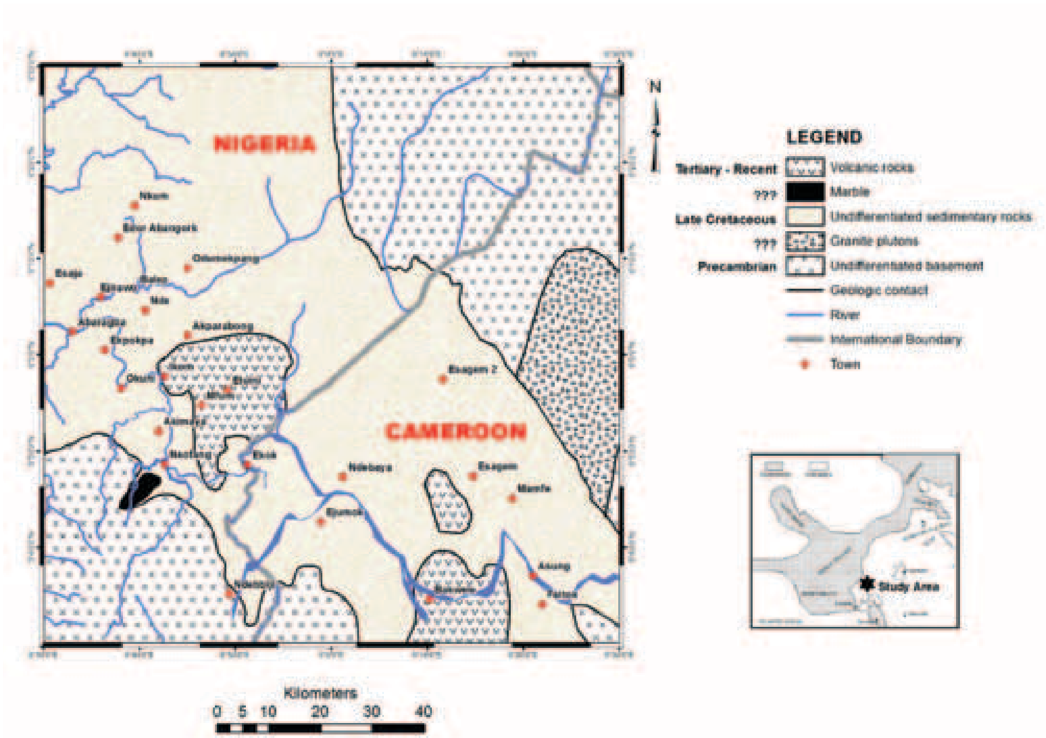

Figure 1. Geologic map of Southeastern Nigeria and Western Cameroon, showing the location of Nsofang marble within the Mamfe embayment of southeastern Nigeria

analyses. Systematic sampling was hampered by irregular exposure of the rocks, weathering and thick forestation. Nevertheless, a total of eleven representative metacarbonate rock samples were considered fresh and appropriate for the analysis. The rock samples, weighing 0.5–1.5 kg, were reduced and finely chipped. The sample chips were thoroughly cleaned, crushed with a "jaw-crusher", split by quartering and finely ground. All sample preparations and treatments were done at the Thin–Section Workshop of Department of Geology, University of Calabar, Calabar- Nigeria. Thin sections were also prepared in the same venue.

Data thus obtained from the thin section examinations were supported with X-ray diffraction (XRD) information. The XRD analyses were carried out on powdered samples, and the XRD patterns were obtained under the following conditions: $CuK_{\propto 1}$ radiation (0.154059 nm) with 30 kV, 30 mA energy and graphite monochromatic. XRD study was considered most useful in the discernment of individual mineral components of cryptocrystalline phases and in differentiation of calcite and dolomite since this was almost impossible with the thin sections.

The chemical analysis was done at Acme Analytical Laboratories, Vancouver BC, Canada under the analysis code 4A4B, a lithium metaborate/tetraborate fusion ($LiBO_2/Li_2B_4O_7$) ICP/ES whole – rock package and trace element ICP/MS package which is unique for the scope of elements and detection limits. The two packages are combined for Code 4A02 and Code 4B02. Essentially, the prepared samples were mixed with $LiBO_2/Li_2B_4O_7$ flux, and the crucibles fused in a furnace. The cooled beads were dissolved in ACS grade nitric acid. Loss on ignition (LOI) was determined by igniting a sample split before measuring weight loss. Total carbon and total sulphur were analyzed by high temperature (LECO) combustion. Each analysis was done in duplicate, and reproducibility found to be within ±2 %. Also, analyses of standard materials indicate that the methods adopted give results that are generally accurate to within ±10 %.

Results and Interpretations

Mineralogy and petrography

In hand specimen, the carbonate rock is characterized by a fairly homogeneous texture, uniform hardness and good resistance to abrasion. The investigated samples, which are mostly unweathered, commonly exhibit off – white to greyish colour, unimodal grain size distribution pattern and distinct linear and planar fabric produced by variation in coloration. The grain sizes are mostly fine to medium.

Table 1. Mineralogical compositions, based on XRD data, of metacarbonate rocks of Nsofang, Ikom area of Southeastern Nigeria

	Major	Minor	Trace
L_{11}	dolomite	calcite	quartz – phlogopite – talc
L_{21}	dolomite – calcite	–	quartz – phlogopite – talc
L_{31}	dolomite	calcite	quartz – phlogopite – talc

The microscopic features, as observed through optical microscopy and XRD (Table 1) show a dominantly carbonate mineralogy. The various carbonate phases could not be differentiated during microscopic examinations, because the investigated thin sections were not stained with alizarin or other relevant chemical. However, the XRD data (Table 1) revealed that the metacarbonate is predominantly dolomitic with calcite as subordinate in most cases, and quartz, talc, phlogopite and probably muscovite constituting the accessory phases. The microscopic study also shows that the rock is heteroblastic with grains of different sizes forming mortar fabric. Most often, medium grained (≈1.0–2.0 mm) calcite or dolomite, having deformed twinning lines, are observed surrounded by fine grained (<1.0 mm) dolomite or calcite crystals. The boundaries of the medium crystals are usually sutured to minerals, particularly phlogopites and occasionally muscovite, formed hypidioblastic to idioblastic weakly – deformed flakes that occur mostly as small inclusions within the medium grained calcite and dolomite grains. However, it must be emphasized that all the accessory phases, put together, exhibit an abundance that rarely exceeds 1 %.

Geochemical compositions and comparisons

The chemical compositions of the metacarbonate rocks are listed in Table 2, together with relevant statistical data. Characteristic is the high content of CaO (29.85–51.67 %, av. 35.79 %), MgO (3.88–21.25 %, av. 16.70 %) and LOI (40.8 %–46.50 %, 44.41 %). Very high is also the total carbon concentration (11.31–12.97 %, av. 12.28 %) while the total sulphur concentrations are generally below detection limit of 0.02 %. The SiO_2 contents range from 0.82–6.21% with a mean value of 2.31 %, the Al_2O_3 contents from 0.03–1.01% and an average value of 0.22 %. The contents of TiO_2, MnO, Na_2O and probably K_2O are all low. Fe_2O_3 and P_2O_5 contents range from <0.04–0.36 % and from 0.02 –0.1 % respectively. The data clearly fall within the limiting values known for carbonate rocks (CHERNEVA et al., 2009; DAVOU & ASHANO, 2009; DEELMAN, 2008; EMOFURIETA et al., 1995; LEAKE et al., 1975).

Table 2. Geochemical composition and relevant data of metacarbonate rocks of Nsofang, Ikom area of Southeastern Nigeria

	L_{11}	L_{12}	L_{13}	L_{21}	L_{22}	L_{23}	L_{31}	L_{32}	L_{41}	L_{42}	L_{43}	**Statistics**	
												Mean	**St. Dev.**
Major elements oxides, total C, total S and estimated mineral compositions in mass fractions, wt/%													
SiO_2	6.21	4.08	3.26	1.08	2.74	0.82	1.6	1.43	1.03	1.37	1.82	*2.31*	*1.649*
TiO_2	0.06	<0.01	<0.01	0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	<0.01	*0.01*	*0.015*
Al_2O_3	1.01	0.03	0.03	0.24	0.15	0.15	0.3	0.25	0.14	0.06	0.06	*0.22*	*0.278*
Fe_2O_3	0.36	<0.04	<0.04	0.08	0.08	0.08	0.08	<0.04	<0.04	<0.04	<0.04	*0.08*	*0.094*
MnO	0.01	0.01	<0.01	0.01	0.02	0.02	0.02	<0.01	0.01	<0.01	<0.01	*0.01*	*0.005*
MgO	20.42	21.25	20.56	12.6	21.09	20.14	18.43	11.43	3.88	16.35	17.52	*16.70*	*5.415*
CaO	30.26	30.1	30.94	41.09	29.85	31.67	33.78	41.88	51.67	36.94	35.55	*35.79*	*6.793*
Na_2O	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.04	0.02	<0.01	<0.01	<0.01	*0.01*	*0.009*
K_2O	0.49	<0.01	<0.01	0.03	0.06	0.06	0.03	0.02	0.02	0.03	0.03	*0.07*	*0.140*
P_2O_5	0.05	0.05	0.06	0.02	0.15	0.14	0.14	0.13	0.02	0.04	0.02	*0.07*	*0.054*
LOI	40.8	44.1	44.8	44.6	45.4	46.5	45.2	44.5	43.1	44.9	44.6	*44.41*	*1.459*
TOTAL	99.68	99.69	99.73	99.77	99.56	99.6	99.63	99.72	99.93	99.76	99.67	-	-
Total C	11.31	12.16	12.17	12.46	12.18	12.97	12.37	12.61	12.14	12.45	12.21	*12.28*	*0.407*
Total S	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	*<0.02*	*0.000*
CaO/ MgO	1.48	1.42	1.50	3.26	1.42	1.57	1.83	3.66	13.32	2.26	2.03	3.07	-
Calcite	3	1	4	42	1	7	15	46	83	25	20	-	-
Dolomite	93	97	94	58	96	92	84	52	18	75	80	-	-
<u>Trace elements in</u> μg/g													
Ba	190	22	6	33	78	70	37	37	19	57	52	*55*	*49.91*
Cs	3.9	0.2	<0.1	0.2	0.4	0.3	0.2	0.2	0.1	0.3	0.4	*0.6*	*1.11*
Rb	17.8	0.5	0.3	0.8	2.7	2.2	0.9	0.7	0.6	1.2	1.5	*2.7*	*5.08*
Sr	59.1	53.8	60.1	167.7	97.4	95.6	100.1	181.4	552.3	115.8	112.6	*145.1*	*141.16*
Nb	1.5	0.2	0.1	0.3	0.2	0.3	0.2	0.2	0.1	<0.1	<0.1	*0.3*	*0.40*
Pb	0.9	0.4	0.5	0.7	0.6	0.5	0.7	0.8	1.1	0.3	0.5	*0.6*	*0.23*
Zr	35.7	4.1	6.7	7.7	14.9	15.1	7.8	12.4	3.8	5.4	12.8	*11.5*	*9.03*
Cd	0.2	0.2	0.7	0.3	0.2	0.1	0.3	0.3	0.1	0.3	0.3	*0.3*	*0.16*
Cu	0.9	0.7	1.6	0.6	1	0.6	2.7	1.5	12.1	0.2	0.2	*2.0*	*3.42*
Ni	0.3	<0.1	0.8	3.9	1.2	1.7	1.3	3.5	1.6	1.1	1	*1.6*	*1.19*
U	0.5	1.3	3	0.8	0.3	0.3	0.6	0.6	2.3	2.3	1.8	*1.3*	*0.95*
Y	5.7	2.7	2	1.8	0.6	0.7	1.4	2	1	0.7	0.6	*1.8*	*1.49*
Zn	9	5	6	8	4	5	7	6	3	5	4	*5.6*	*1.80*

The major elements geochemical and relevant data of the metacarbonate rocks have been compared with average values of carbonate – bearing rocks occurring in Nigeria and elsewhere in Table 3. As shown in Table 3, the CaO composition of the investigated metacarbonate rock is low, compared to that of Mfamosing limestone (EKWUEME, 1995), Ashaka limestone (Tadco Consulting Engineers, 1989), Jakura marble (OFULUME, 1993), Ososo marble, Akure marble (EMOFURIETA & EKUAJEMI, 1995), metacarbonate rocks from the Zambezi mobile belt of Zambia (MUNYANYIWA & HANSON, 1988), Jabal Farasan marble deposit of Saudi Arabia (QADHI, 2008), Dalradian Connemara marble in western Ireland (YARDLEY, 1977), metacarbonate rocks of northwest Konya in Turkey (EREN, 1993) and marble with carbonatite-like geochemical signature of the Bohemian Massif in Czech Republic (HOUZAR & NOVAK, 2002). It is only in the Guyuk limestone of northeastern Nigeria (GABAKO & TEDRA, 1994), marble occurring east of the Federal Capital Territory (DAVOU & ASHANO, 2009) and the Igbeti marble (EMOFURIETA & EKUAJEMI, 1995) that comparatively lower CaO values are observed. Ironically, these are the only deposits having MgO concentration that are higher than that of the Nsofang rocks. All other deposits displayed relatively lower MgO concentration (Table 3). SiO_2 and LOI components of the investigated rocks are comparable to those of Ashaka limestone (Tadco Consulting Engineers, 1989) and metacarbonate rocks of northwest Konya in Turkey (EREN, 1993) while the Jakura marble (OFULUME, 1993) only differ by its slightly depleted SiO_2 composition. No other LOI values are lower than that of the metacarbonate rocks of Nsofang and environs.

Generally, the overall major elements geochemistry data of the Nsofang marble is comparable to those of marble occurring east of the Federal Capital Territory (DAVOU & ASHANO, 2009) and the Igbeti marble of EMOFURIETA & EKUAJEMI (1995), both in southwestern Nigeria.

The concentrations of trace elements in the rock, also shown in Table 2, are not as low as expected, and values for Sr and Ba are highly variable. Interesting are the relatively high concentrations of Ba (6–190 × 10^{-6}, av. 55 × 10^{-6}), Sr (53.8–552.3 × 10^{-6}, av. 145.1 × 10^{-6}), Rb (0.3–17.8 × 10^{-6}, av. 2.7 × 10^{-6}) and probably Zr (3.8–37.7 × 10^{-6}, av. 11.5 × 10^{-6}) at a markedly predominance of Sr. Other components, notably, Zn (av. 5.6 × 10^{-6}), Pb (av. 0.6 × 10^{-6}), Cu (av. 2.0 × 10^{-6}), Cd(av. 0.3 × 10^{-6}), Ni (av. 1.6 × 10^{-6}), U (av. 1.3 × 10^{-6}) and Y (av. 1.8 × 10^{-6}) show moderate concentrations.

Table 3. Comparison of averages chemical data of metacarbonate rocks of Nsofang in Ikom area of southeastern Nigeria with carbonate – bearing rocks occurring in other part of the world and MgO/CaO ratio values

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	2.31	0.38	16.20	7.30	2.40	0.50 .5	0.49	1.18	0.44	1.98	11.69	10.61	1.91	11.18
TiO_2	0.01	0.004	0.17	–	0.01	0.00	–	–	–	0.01	0.01	0.07	0.04	0.05
Al_2O_3	0.22	0.07	0.43	2.78	0.92	0.07	0.03	0.10	0.07	0.83	0.09	4.30	7.33	0.65
Fe_2O_3	0.08	0.1	12.5	1.18	0.04	0.04	0.07	0.07	0.04	0.26	0.02	2.97	0.01	1.10
MnO	0.01	–	–	–	0.009	0.00	0.002	0.003	0.002	0.01	0.00	0.22	–	0.02
MgO	16.70	0.3	26.89	–	19.60	0.42	20.70	1.75	0.32	2.75	4.38	2.01	8.78	5.36
CaO	35.79	54.87	8.78	47.70	31.82	54.92	28.94	53.64	55.33	50.89	48.71	41.90	45.39	45.30
Na_2O	0.01	0.03	–	–	0.05	0.02	0.01	0.02	0.03	0.06	0.00	1.38	0.26	0.13
K_2O	0.07	0.03	–	–	0.007	0.03	0.03	0.01	0.001	0.01	0.01	0.56	–	0.29
P_2O_5	0.07	–	–	–	0.045	0.00	–	–	–	0.01	0.15	0.21	–	0.04
LOI	44.41	–	32.05	38.66	44.09	43.37	–	–	–	–	35.74	–	42.66	35.56
CaO/MgO	3.07	182.90	0.33	–	1.62	130.76	1.40	30.65	172.91	18.51	11.12	20.85	5.17	8.45

1. Average chemical data of metacarbonate rocks of Nsofang, ikom area of southeastern Nigeria (present work).
2. Average chemical data of Mfamosing limestone, (Ekwueme, 1995)
3. Average chemical data of Guyuk limestone, northeastern Nigeria (Gabako & Tedra, 1994)
4. Average chemical data of Ashaka limestone, (Tadco, 1989)
5. Average chemical data of marble, east of the Federal Capital Territory (Davou & Ashano, 2009)
6. Average chemical data of Jakura marble, southwestern Nigeria (Ofulume, 1993)
7. Average chemical data of Igbeti marble, southwestern Nigeria (Emofurieta & Ekuajemi, 1995)
8. Average chemical data of Ososo marble, southwestern Nigeria(Emofurieta & Ekuajemi, 1995)
9. Average chemical data of Akure marble, southwestern Nigeria (Emofurieta & Ekuajemi, 1995)
10. Average chemical data of metacarbonate rock from the Zambezi mobile belt of Zambia (Munyanyiwa & Hanson, 1988)
11. Average chemical data of Jabal Farasan marble deposit in Saudi Arabia (Qadhi, 2008)
12. Average chemical data of marble in the Dalradian Connenera of Western Ireland (Yardley, 1977)
13. Average chemical data of metacarbonate rocks in northwest Konya, Turkey (Eren, 1993)
14. Average chemical data of marble with carbonatite-like geochemical signature of the Bohemian massif, Czech Republic (Houzar & Novak, 2002)

Discussions

Characterization and quality implications

The results of the chemical analyses (Table 2) reflect the paragenesis determined by X-ray powder diffraction (XRD) (Table 1), and observed by optical microscopy on thin sections. In particular, the very high concentrations of LOI, CaO, MgO and total carbon (Table 2) corroborate mineralogical observations that the carbonate phases are the dominating phases in the investigated rock, which agree with the broad classification of the rock as a carbonate. Dolomite is clearly the dominating phase, with calcite as subordinate while silicates, notably quartz, talc and phlogopite constitute the accessory phases of the rock (Table 1). The mineralogical composition of the metacarbonate rock indicate that peak metamorphic conditions equivalent to, at most, the greenschist facies (Blatt & Tracy, 1995) was most likely attained. Given the overall field, petrographic, mineralogical and geochemical data, the metacarbonate rocks of Nsofang in Ikom area of southeastern Nigeria can best be classified as low grade dolomitic marble.

The quantitative identification of CaO, Fe_2O_3, MgO and SiO_2 in the Nsofang marble is important in the characterization of the quality and hence the usability of the material. Technically, following Rosen et al. (2005, 2007), Nsofang marble qualify as pure marble. However, the fact that CaO and LOI composition of the marble, taken together, constitute less than 80 % in most cases (Table 2), points to the presence of significant concentration of components and phases that are not compatible with the purity required of marble for various important applications. Cherneva et al. (2009) observed that most of the marble of the Arda Tectonic unit in the Central Rhodope in Bulgaria classified as pure marble are calcite dominated, low in MgO content and display high CaO/MgO ratio. In contrast, the Nsofang marble is dolomite dominated with an MgO contents that are relatively high, reaching a peak of 21.25 % in sample L_{12} and displaying an overall average of 16.62 % (Table 2). Furthermore, the computed CaO/MgO ratio values of the marble (Table 2), which vary between 1.42–13.30 with a mean of 3.07, is quite low when compared to those of deposits of other localities (Table 3), notably, those of Mfamosing limestone, (Ekwueme, 1995), Jakura marble (Ofulume, 1993), Ososo marble (Emofurieta & Ekuajemi, 1995), Akure marble (Emofurieta & Ekuajemi, 1995), metacarbonate rock from the Zambezi mobile belt of Zambia (Munyanyiwa & Hanson, 1988), Jabal Farasan marble deposit in Saudi Arabia (Qadhi, 2008), Dalradian Connenera in western Ireland (Yardley, 1977), metacarbonate rocks in northwest Konya in

Turkey (Eren, 1993) and marble with carbonatite-like geochemical signature of the Bohemian massif, Czech Republic (Houzar & Novak, 2002) (Table 3).

In considering these attributes, indication is that the Nsofang marble is tainted, and MgO appear to be the major component that reduces the purity of the marble. SiO_2 also constitute a source of contamination, even though, its concentration in the marble is frequently less than 2 %. Other contaminants, notably Fe_2O_3, Al_2O_3, Na_2O and K_2O are present in small proportion with overall average values that is often less than 1 % (Table 2). The “impure” nature of the Nsofang marble can also be sufficiently mirrored by the slightly elevated abundance of trace elements (Table 2) since, according Chernerva et al., (2009), impure marbles of the Arda Tectonic unit in the Central Rhodope in Bulgaria are richer in trace elements than the pure marbles.

Economic aspects

High chemical purity of >97 % $CaCO_3$ compositions and LOI values <3 % are required for a carbonate materials to be considered suitable for used in the manufacture of lime (Boynton, 1980; Ofulume 1993; Ofulume et al., 2009, Power, 1985), and lime that is manufactured for fluxing in steelmaking is expected to exhibit at least 52 % CaO (about 92.8 % $CaCO_3$) (British Standard Institute, 1982). Similarly, materials to be adopted for use as fillers suitable for the production of paper coatings, paints, rubber and plastics are expected to be of high chemical purity and to display maximum possible calcium carbonates content and minimum acid insoluble composition (Howse, 1994; Qadhi, 2008).

In the light of the foregoing, the Nsofang marble fall short of the specifications of materials to be used as flux and also lack the requirements for its application as raw material in the manufacture of lime and fillers. In particular, the relatively low CaO contents (mean concentration of 35.79 %) of the Nsofang marble, together with the presence of acid insoluble minerals (such as quartz with a maximum content of 6.21 %) fall short of the requirements for adoption of the marble for these usages. Also, the high LOI values of between 40.8 % and 46.5 %, exhibited by the Nsofang marble is considered unacceptable, since LOI of materials to be processed for lime or flux in the Basic Oxygen Furnace (BOF) is expected to be less than 3 % (Ofolume, 1993). Excessive LOI values can have significant effects in reducing potential for scrap melting which may lead to uncontrolled foaming or stopping (Anderson & Vernon, 1971).

Furthermore, a simple comparison of the chemical data of Nsofang marble with the compiled chemical specification of a number of industries that consume raw marble (Emofurieta & Ekuajemi, 1995) indicate that the Nsofang marble may also not be appropriate for application in the cement, ceramics and glass industries. Nevertheless, despite these shortcomings, the Nsofang low grade dolomitic marble can be adapted for a variety of other uses, notably, as aggregate in mortar and concrete of the construction industry and as an abrasive product for the polishing of certain metals. Most importantly, the elevated concentration of MgO in the marble can be exploited for use as compensators for magnesium deficiencies in the agricultural industry, especially for neutralizing acidic soils for farming purposes, and may also be relevant in the sourcing of magnesium oxide for the chemical industry as well as in the production of chrome-based products. In addition, with appropriate beneficiation, the elevated MgO, moderate total carbon, and low Al_2O_3 and SiO_2 composition of the Nsofang marble can be harnessed for application as MgO + C refractories for electrical arc furnace (EAF) linings.

Impurities, such as pyrite and marcasite are undesirable in marbles to be used as dimension stones because on oxidation they can produce stains which is of particular concern for exterior work (Howse, 1994). Thus, the low total sulphur composition of the marble, which most likely reflects the absence of sulphur-bearing minerals such as pyrite and marcasite (FeS_2) can be exploited in the application of the marble as dimension stones. Also, with favorable physical attributes, the marble could be considered as a potential source of terrazzo chips and landscaping material and may be suitable for use as a decorative stone. Furthermore, when pulverized and ground to specified mesh size, the Nsofang marble can also be used as low grade carbonate fillers, for use in putty, caulking, sealing, venyl floor covering, carpet backing, asphaltic products and adhesives.

Conclusion and Recommendations

Metacarbonate deposit occurring in Nsofang area of southeastern Nigeria has been classified as low grade dolomitic marble, based on inherent compositional, petrographic and field attributes. The marble is characterized as tainted because of its relatively low CaO contents and CaO/MgO ratio, and elevated MgO, LOI and trace elements composition. The observed compositional features of the marble have suggested a number of applications for the marble, but these are by no means exhaustive. More uses would still be revealed when physical attributes, notably bulk specific gravity and bulk density, water absorption, apparent porosity, reflectance/chromaticity, including brightness, decrepitation, mechanical strength tests, notably principle schmidt hammer rebound, uniaxial compression strength test and strength point load index as well as surface area and reactivity, are determined. Subsequent research should also incorporate geophysical techniques so that the extent of the prospect can be adequately defined for reserve estimation purposes.

Acknowledgements

The Chiefs and people of Nsofang community in present–day Etung Local Government Area of Cross River State in southeastern Nigeria are gratefully acknowledged for their hospitality during the field aspects of this work. This work has also benefited immensely from contributions and assistance from Mr. Okokon Ndaw, the Director, Regional Geology Unit of the Nigerian Geological Survey Agency (NGSA) and Mr. Ajenikpa, an Assistant Director in the Nigerian Geological Survey Agency (NGSA). Furthermore, appreciation is due my three graduate students, Charles Umagu, Columbus Edet and Festus Uduma for the roles they played towards the successful completion of this work. Finally, I give special thanks to all the people who were involved at the sample preparation and analysis stage of the work at both the Department of Geology, University of Calabar – Nigeria and Acme Analytical Laboratories, Vancouver BC, Canada.

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