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Economic evaluation of Burum-Takalafia marble deposit, Federal Capital Territory, Abuja, Nigeria

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ABSTRACT

The physical and chemical properties of the Burum - Takalafia marble and lime products derived from it are documented in this study with a view to evaluating their suitability in various industrial applications such as improving soil quality. The marble has 31.04wt% and 20.75wt% CaO and MgO, respectively and very low SiO_2 of 3.08wt%. The marble has $CaCO_3$ content of 43% and $MgCO_3$ content of 44.3%. The slaked lime prepared from the raw marble has 59.17wt% and 33.25wt% MgO content respectively. The physical tests show average apparent porosity of 0.68%, hardness of 3, bulk density of 2.66g/cc, specific gravity of 2.70, colour brightness of 85% and compressive, tensile and shear strengths of 92.83N/m^2, 3.8 N/m^2 and 13.63 N/m^2 respectively for the raw marble samples. Agronomic tests show that there was an increase in Ph from 5.40-6.80, Ca (0.5-0.84%), Mg (0.1-0.13%), K (0.12-0.14%), CEC (2.36-2.76%) and organic matter content (0.52-1.03%). The results were compared with those of other workers and they revealed that the Burum- Takalafia raw marble and its lime products can be used in agriculture as acid soil ameliorants and nutrients status enhancers, building and construction materials and refractory lime in the manufacturing of chemicals. The deposit also finds application in the paper, paint and plastic industries were they are used as fillers/extenders.

INTRODUCTION

A variety of marble deposits is found within the Nigerian basement terrain,e.g. Burum-Takalafia in the Federal Capital Territory (FCT). Abuja; Kwakuti in Niger State; Etobe, Ajaokuta and Jakura in Kogi State; Muro in Nassarawa State; Igbetti in Oyo State; Ukpilla in Edo State and Elebu in Kwara State (Oluyide and Okunlola, 1995; Elueze, 1993; Emofurieta and Ekuajemi, 1995; Ofulume, 1993, Okunlola, 2001. Ako, 2006). These deposits have various morphologies within the schist belts and exhibit different physico-chemical characteristics that render them economically attractive.

Nigeria's marble reserves are put in excess of 5 billion tonnes of proven, indicated and inferred categories, Burum-Takalafia marble inclusive (Oluyide and Okunlola, 1995). Despite his abundant reserve, not very much of the country's marble has been properly utilised. This is partly due to lack of comprehensive and reliable recent geochemical and physical data on the marble deposits, which are very important to the choice of any deposit for a particular purpose. This is an important issue especially at this period when the Federal Government of Nigeria is placing bans on the importation of some products to give room for the production of such products locally. Also, the harsh economic situation in the country has forced Nigerians to look more and more inwards for raw materials to meet the demand of the rapidly growing industries and for exports.

Marble finds application in many industries, such as cement manufacturing, agricultural lime for soil enrichment, fluxes in steel, chemical products, ceramic whiting, sewage/water treatment, fillers/extenders in paints, plastics and paper manufacturing, as dimension stones and construction purposes (Okunlola, 2001).

The use of marblel or its product for any of the purposes mentioned above is a function of particular physico-chemical characteristics which are exhibited by the deposit. These physic-chemical characteristics must meet International Standard or specification for each usage. Boynton and Gutschick (1990) revealed that for a carbonate rock to be good raw material for lime manufacture, the total carbonate content must be at least 97%. According to Kogel et, al., (2006) for a carbonate to meet the standard for use for Portland cement production, it should have MgO content not exceeding 10% and CaO content above 43% and both pyrite and free silica should be absent.

In this study of the Burum-Takalafia marble is investigated with a view to reveal their geochemical and geophysical characteristics as well as suitable industrial applications such as in agriculture.

REGIONAL GEOLOGICAL SETTING

The Precambrian basement complex of Nigeria is categorised into three main subdivisions and occurs within the Pan African (ca.O.6Ga) province east of the Archean to Early Proterozoic West African Craton. These subdivisions include the migmatite-gneiss-quartzite complex, the schist belts and the Pan-African Plutonic series referred to as Older Granite Suite. The migmatite gneiss-quartzite suite contains rocks that are as old as 3Ga and those that are as young as 600 Ma (Ajibade, 1982; Jones and Hockey,(1964; Grant, 1969; McCurry; 1976 and Rahaman, 1976). These rocks recorded at least four major tectonic cycles of deformation, metamorphism and remobilization in the Liberian (2700± 150 Ma), Eburnean (2000 ± 200 Ma), Kiberian (1100 ± 200 Ma) and Pan-African (600 Ma), confirming the polycyclic nature of the Nigerian basement. However, older ages (> ca. 3.0 Ga) have been indicated for the Kaduna migmatites (Dada and Briqueu, 1996) and this reinforces the view that this migmatite-gneiss complex may belong to an Archean protoshield subjected to Proterozoic thermotectonic processes (Elueze, 1992). The schist belts consist of north-south trending rocks which occur prominently in the western part of the country and these include Iseyin, Igarra-Okene and Egbe-Isanlu schist belts. The Toto-Gadabuike schist belt which hosts the Burum-Takalafia marble (Muotoh et al., 1988; Okunlola, 2001; Elueze and Okunlola, 2003; Ako, 2006 Ekwueme, 1985; 1986 and 1987) are other occurrences mentioned in the country. The belts are composed of metamorphosed pelitic and psammmitic assemblages. Secondary lithologies such as ferruginous, (banded iron formation), carbonate and mafic to ultramafic bodies are often used in discriminating them. These belts are considered to be upper Proterozoic supracrustal rocks which have been infolded into the migmatite-gneiss complex (Ajibade, 1976). Pan-African granites which range in composition from true granites to granodiorites tonalites and synites (calc-alkaline intrusive bodies) commonly intrude the migmatite-gneiss assemblages and the lithologies of the schist belt, (Elueze and Okunlola, 2003).

GEOLOGY OF THE BURUM-TAKALAFIA AREA.

In the Burum-Takalafia area, two main groups of rocks occur. These include rocks of the migmatite-gneiss complex and the metasedimentary rocks (Fig.1)

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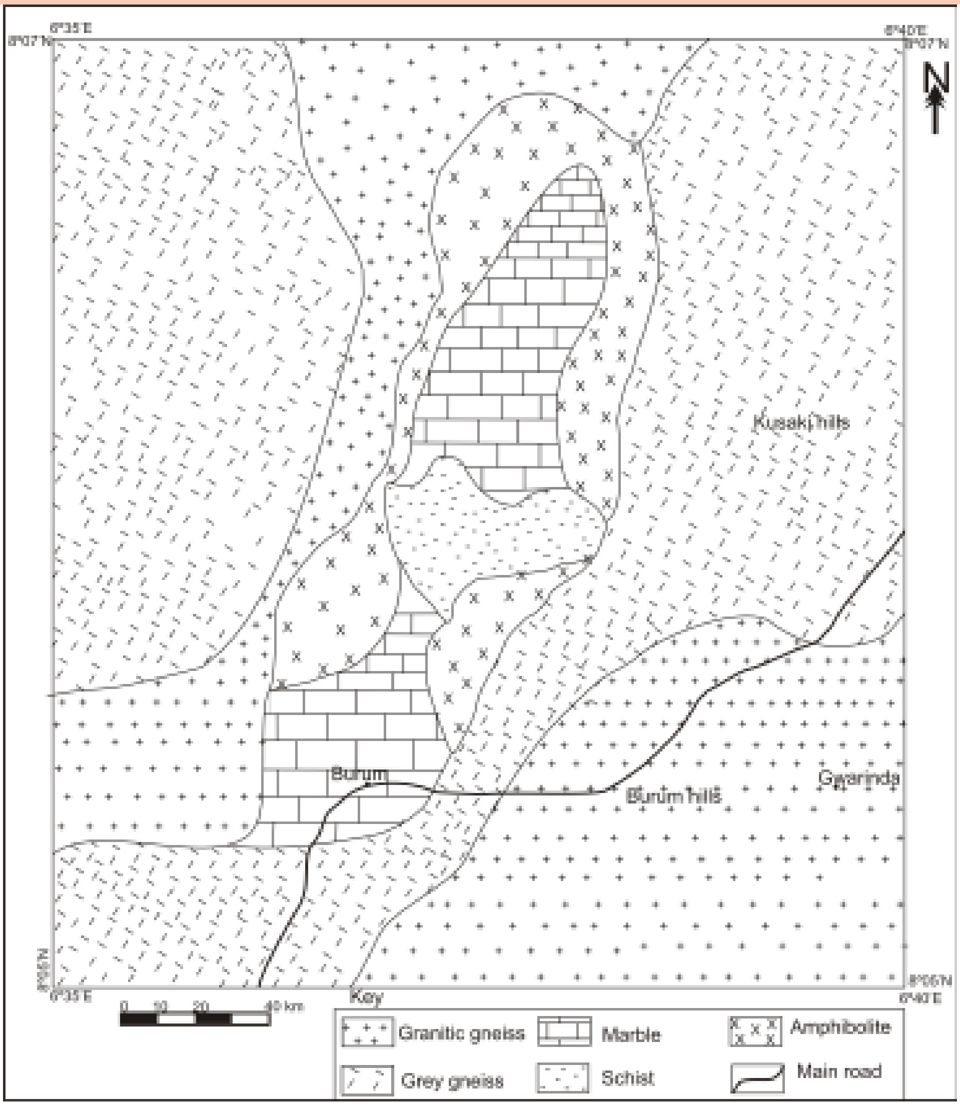

Fig.1. Geological map of Burum-Takalafia area.

The gneisses occur as hilly, massive and low-lying outcrops and where they have contacts with other rocks, such contacts are marked by the development of the cataclasites and mylonites. The grey gneiss is dark in colour with a gneissic foliation defined by felsic and mafic minerals, medium grained in texture with the development of pinch and swell structures in some places. The granite gneiss is light in colour, medium to coarse grained with a very poor gneissic foliation. Generally, the gneissic rocks consist of a heterogeneous group predominantly of granitic composition, varying degree of foliation. . The rocks are variable in colour depending largely on the nature and proportion of feldspars and the ferromagnesian minerals. The textural variation in these rocks is due to varying size and K-feldspar porphyroblast content. In some places, the feldspar porphyroblasts are numerous and fairly large (up to 2-3 cm), well lineated augen-shaped grains. Hand specimens of the rock show that they contain feldspars, quartz and biotite. The metasedimentary rocks (amphibolites, schists and marble) occupy the central part of the study area and are bordered by approximately N-S trending units of the migmatite-gneiss complex. They occur as low-lying outcrops and discontinuous ridges. The schists form extensive bodies characterised by abundance of quartz rubbles and disaggregated mica “books” over the area they occupy. They are usually whitish to light grey in colour, coarse grained with large cobbles of quartz and intergranular large muscovite plates prominently displaced. The quartz-mica schists are the most extensive metasediments and have been intensively weathered in some places. They are largely pelitic and contain very little feldspathic constituents.

The amphibolites occur as lenticular and ovoid- shaped outcrops and occupy a N-S position like other metasediments within the study area. They occur in association with the marble which outcrop as discontinuous lenses. A careful look at the amphibolite samples shows two petrographic varieties based on the textural and structural characteristics. They include the banded and the massive varieties. The banded variety is a fine-medium grained, strongly foliated dark grey variety which is foliated and the foliation is marked by a fine mineralogical banding of a few millimetre and preferred orientation of elongated crystals of amphibole. The dark colour bands are composed of greenish black amphibole (hornblende) while the light colour bands are rich in grey to white feldspar. In some places, they occur as lenses and bands which are sometimes interlayered with marble, greenish in colour, fissile and are weathered in most cases. A streaky alternation of bands of dark coloured minerals and less developed bands of quartz and feldspar marks the foliation. The massive variety of amphibolites is medium-grained, dark grey to black in colour with a weak foliation and occurs as dyke-like bodies. Mineralogically, it consists of hornblende, plagioclase, biotite, quartz and little pyroxene and epidote.

The Burum-Takalafia marble is interlayered with the amphibolites which occur as lenses and bands. Like other metasediments they outcrop on the right side of the River Tarkwai and form sharp contacts with other rock types particularly the amphibolites. The deposit is well exposed at the quarry pits and the river channel where the over burden has been removed. On careful observation of samples from the quarry pits, two petrographic varieties can be distincguished on the basis of colour and texture. These are the white and grey varieties. The white variety which occurs at the flanks of the quarry pits is coarse grained with characteristic interlocking rhombohedral calcite crystals. The grey variety occurs at the centre of the pits and is very fine - grained. They consist dominantly of equigranular granoblasts of calcite which show mutually interlocking grain boundaries. Mineralogically, both varieties are made up of calcite, dolomite, graphite and little quartz.

MATERIALS AND METHODS

To test for the industrial applications of the marble both the raw marble samples and its lime products (calcined products) were used for chemical, physical and agronomic analyses. The raw marble samples were collected from quarry pits where the marble is being extracted in the study area. The raw marble samples were selected to be representative of the two petrographic varieties.

For the chemical analyses, six fresh samples each weighing about 4kg were obtained and analysed for the major and trace elements. The lime products of the marble samples used for the analyses, were prepared by heating about 500kg of powdered marble samples at a temperature of 950-1100˚C in a muffle furnace. The quick lime (CaO) that resulted from the heating was quickly slaked in water to form hydrated lime. Determination of the major and trace element concentrations in both the raw marble and the lime products was done using the X-Ray Fluorescence (XRF) analytical technique at laboratory of Geological Survey of Nigeria, Kaduna according to the method described by Okunlola (2001). The chemical data for the representative samples for the raw marble are shown in tables 1 and 2 while that of the lime products in table 3.

The physical properties of the raw marble samples were determined in the Civil Engineering Laboratory of Admadu Bello Univesity, Zaria. The physical properties determined include: apparent porosity, bulk density, pH, colour, loss on ignition, hardness, compressive, tensile and shear strengths. Apparent porosity, bulk density, colour, hardness, compressive, tensile and shear strengths were determined by procedures contained in Gokhale et al., (1984). In pH measurement, 5gm of the powder of the six samples selected was thoroughly stirred in a conical flask and the pH determined using a pH meter while loss on ignition was determined by heating 100g of powdered sample in muffle furnace at 1000˚C till a constant weight is obtained. Agronomic analyses were made by mixing 100g of acid soil with 40g of powdered raw marble samples in clay pots. Evaluations of soil properties were made at 4 weeks intervals for 12 weeks. The following parameters were determined: pH, Al, Ca, Mg, Na, K, Mn, Fe, Cu, Zn, cation exchange capacity (CEC), organic matter content and total N_2.. These tests were carried out at the Institute for Agricultural Research, Admadu Bello University. Zaria, according to the method obtained in Okunlola (2001).

RESULTS

The analytical results of the raw marble samples show average CaO and MgO contents of 31.03wt% and 20.75wt% respectively. Apart from SiO_2 which has an average content of 3.80wt%, the other oxides have less than 1wt% each. The total average content for the oxides is 98.88%, and the average content for L.O.I. for the sample is 42.4wt%. For trace elements, Li content is 80ppm, followed by Cr and Ga 15ppm each, Cu, 8 ppm and Zn, 6 ppm (Table I).

Average $CaCO_3$ content for the marble samples is 43% while average $MgCO_3$ content is 44.5%. The greater value of $MgCO_3$ than $CaCO_3$ shows that the marble is dolomitic. The total carbonate content in the marble is 87.5% (Table 2).

The results of the calcined marble samples (slaked lime) show an average CaO content of 59.17wt%, which is greater than that of the raw marble (31.03wt%). (Fig 3) In the same manner, the average MgO content in the lime product of 33.25wt% is greater than that of the raw marble samples. Apart from SiO_2 which has an average content of 3.51wt%, other oxides have average contents of less than 1wt% with Al_2O_3, MnO and Na_2O having the least values of 0.03wt% each. The range of the CaO contents is 52.1-61.3wt% while that of MgO is 32.15% - 36.13wt%. The highest value for the trace elements was recorded for Zn (38 ppm) followed by Ni (20 ppm), Co (14ppm) Cu and Cr 4ppm each. A range of 6 – 52 ppm was recorded for Zn, 18 – 36ppm for Ni, 6 – 18ppm for Co, 2 – 5ppm for Cr and 3 – 5ppm for Cu respectively (fig 3).

Table 1. Major and trace elements chemical data for Burum-Takalafia raw marble samples.

Major Elements (%)	BTL 1	BTL 2	BTL 3	BTL 4	BTL 5	BTL 6	average
SiO_2	3.51	3.40	3.89	3.44	3.40	5.12	3.80
TiO_2	ND*	ND	ND	ND	ND	ND	ND
Al_2O_3	0.65	.048	0.75	0.72	0.60	0.75	0.61
Fe_2O_3	0.18	0.19	0.26	0.23	0.34	0.42	0.72
FeO	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01
MgO	20.52	21.00	20.04	20.70	21.04	21.20	20.75
CaO	30.90	30.90	30.92	30.92	30.92	31.61	31.03
Na_2O	0.04	0.04	0.07	0.05	0.03	0.07	0.05
K_2O	0.05	0.05	0.03	0.02	0.05	0.08	0.12
P_2O_5	0.03	0.01	0.02	0.02	0.03	0.01	0.02
L.O.I.	44.06	44.06	42.62	42.00	42.67	42.65	42.40
TOTAL	99.96	98.72	98.00	98.79	99.00	101.93	98.88
Trace elements (ppm)							
Cr	22	18	15	12	13	10	15
Cu	14	6	8	6	6	8	8
Ga	12	12	8	10	16	22	15
Li	50	63	57	60	156	94	80
Zn	5	6	5	5	9	6	6

Table 2. Calcium and Magnesium carbonates percentages for Burum – Takalafia raw marble samples.

Carbonate percentage	BTL 1	BTL 2	BTL 3	BTL 4	BTL 5	BTL 6	Average
$CaCO_3$	42.5	42.8	43	42.5	44.4	42.8	43
$MgCO_3$	42.5	43.8	43.2	43.8	43.5	45.2	44.5
TOTAL	85	86.6	86.2	86.3	87.9	88	87.5

Table 3: Summarized chemical data for calcined marble samples of Burum – Takalafia.

Major elements (%)	Average	Range
SiO_2	3.51	0.9 - 4.11
TiO_2	0.04	0.02 – 0.06
Al_2O_3	0.03	0.01 – 0.04
Fe_2O_3	0.05	0.03 – 0.06
MnO	0.03	0.02 – 0.04
MgO	33.25	32.15 – 36.13
CaO	59.17	52.1 – 61.3
Na_2O	0.03	0.01 – 0.04
K_2O	0.05	0.04 – 0.06
L.O.I.	3.65	1.5 – 5.1
Trace Elements (ppm)		
Cu	4	3-5
Zn	38	6-52
Ni	20	18-36
Cr	4	2-5
Co	1	6-18

The results of the physical properties of the raw marble samples show on average an apparent porosity value of 0.68% with a range of 0.48 – 0.92%, hardness of 3, bulk density of 2.67g/cc and a specific gravity of 2.70 (Table 4).

Colour which is a measure of the visual brightness is 85 and this is slightly lower than values for British whiting and Indiana marble (Boynton, 1985). Compressive strength (92.83N/m^2), tensile strength (3.8N/m^2) and shear strength (13.63 N/m^2) values for the raw marble are within the range for most marbles (Scott and Durham, 1984).

Agronomic determinations show that after 12 weeks of application of the powdered raw marble samples on acid soil, there was an increase in pH from 5.40 – 6.80, Ca (0.5 – 0.84%) Mg (0.1 – 0.13%), K (0.12 – 0.14%), CEC (2.36 – 2.74%) and organic matter (0.52 – 1.03%).

DISCUSSION

The use of marble and its lime products as raw materials in various industries is a function of the physico-chemical properties of the raw materials which must meet manufacturing specifications. In deciding the suitability of marble for a particular process or use, the first thing to bear in mind is the calcium and magnesium contents. The higher the concentration of these elements, the better. Secondly, what impurities are deleterious to the process concerned or its end product and what concentration can be tolerated and thirdly, the physical properties of the marble. The suitability of the Burum – Takalafia marble in various industrial applications is discussed below.

Agriculture

Soil liming is one of the oldest used of marble and its lime product (Ojo et al., 1998). The marble or lime functions to provide readily assimilable food for plant life, to transform natural soil substances into more soluble states, to neutralize unhealthy acidity or alkalinity, supply substances originally lacking in the soil and improve soil texture and structure.

Results of chemical analysis of the Burum-Takalafia raw marble and lime product show abundant major and trace elements which have important positive implication in agriculture. This coupled with pH > 8, low grittiness, low content of acid insolubles and high CaO (31.03%) and MgO (20.75%) are requirements (Ofulume, 1993). Results of determinations have shown therefore that the Burum-Takalafia raw marble and lime product are very useful as acid soil ameliorants and nutrient status enhancer. Another use of marble in agriculture is in animal production. It is used as a source of calcium in cattle cake and shell-forming material in poulty grit. In fish farming, it is employed in liming of fish ponds. Any type of marble is suitable, that is, composition is relatively immaterial but the most important point is its neutralizing value and must be in grounded form (Stowell, 1963). Based on this, the Burum-Takalafia marble can thus be used for cattle, poultry and fish production.

Environmental Uses

Raw marble and their lime pruducts have found applications for environmental purposes, (Baynton, 1980). For water treatment puroses, a combination of lime with sodium carbonate is employed for water softeneing to remove the temporary bicarbonate hardness. It is also used for purification, coagulation, neutralization of acid water and removal of Si, Mn, Fe, F from water. High pH> 11, produced by lime kills most types of bacteria (Boynton and Gutshick, 1975). The specifications of lime for water softening and purification are CaO > 65%, pH > 10, MgO < 2%, SiO_2 < 0.01%, absence of Co, Hg and Pb. Burum-Takalafia marble is thus not suitable for these purposes as it does not meet the above specifications. Lime is also useful in sewage treatment, neutralization of acid water and removal of silica and phosphate from sewage effluents. The specifications are similar to those for water softening and purification. Thus the Burum-Takalafia marble does not meet the requirements.

Chemical productions

One of the largest uses of raw marble and its lime products is in the productions of sodium Carbonate, bicarbonate and hydroxide by the Solvay (ammonium – soda) process. The basic requirement is a total carbonate ($MgCO_3$, $CaCO_3$) content of more than 70wt%, and low values of trace elements. The Burum-Takalafia marble meets these specifications as it has a total carbonate content of 87.5% and low values of Co, Cu, Ni and Zn for both the raw and its lime products.

In the production of calcium carbide, acetylene, quick lime is mixed with coke and heated in electrical furnaces to 2000˚c. Molten carbide is removed from the furnace and crushed upon solidifying and is then ground for uses (Okunlola, 2001). The requirements are high CaO (> 90wt %), low pH (<0.02%) and MgO (<0.5wt%). The deposit does not meet the standard because its CaO content is less than 90wt% (31.03wt %), pH (8.3%) and MgO (20.75wt %).

In calcium arsenate (a pesticide) productions, arsenic acid is reacted with milk of lime to form calcium arsenate. The requirement is a lime (CaO) content of > 65wt%. The Burum-Takalafia marble does not meet the requirement for pesticide production because its CaO is 59.17wt%. Lime (CaO) plays the role of absorbent for chloride in calcium hypochlorite and chloride of lime in the production of bleaches. The specifications are CaO > 80wt%, MgO < 1wt% and SiO_2 < 2wt%. Based on these the Burum-Takalafia lime products do not meet the specification and thus cannot be used for the production of bleaches. This is because its CaO content is 59.17wt% less than 80%, MgO content 33.25wt% which is greater than the 1wt% required and its SiO_2 content of 3.51% is greater than the required 2wt%.

In the paper, paints and plastics industries, grounded marble (in powder form) is used as fillers/extenders. The requirements are Al_2O_3, Fe_2O_3t and P_2O_5 contents of less than 1wt% coupled with high colour purity, smoothness and lack of grits in the final crushing quality. The deposit contains 0.61 wt% Al_2O_3, 0.73 wt% Fe2O3t and 0.02 wt% P2O5. A colour purity of 83wt% and lack of grits in its powdered samples therefore qualify the deposit for these uses.

Portland cement production

The requirements for Portland cement production are total carbonate content of at least 97 %, $MgCO_3$ 6-7 %, MgO 3-3.5 wt%, CaO > 43 wt% and a silica content of less than 5wt% (Boynton and Gutschick, 1983). The Burum-Takalafia marble deposit has a total carbonate content of 87 .5 %, MgO (20.75 wt %), CaO (31.03wt%) and $MgCO_3$ (44.5 %) and is therefore not suitable for Portland cement production.

Building and construction

Marble finds application as decorative and ornamental stones. It is valued for flooring in form of tiles, (Ofulume, 1991) slabs, aggregates and making of paladiana. The requirements include CaO and MgO content of more than 60%, compressive, tensile and shear strengths greater than 20 N/m^2, 5 N/m^2 and 7 N/m^2 respectively (Scott and Durham, 1984). Addition of hydrated lime made from marble to soil at the base stabilizes it. Lime actually alters the physical characteristics of clay-bearing soil, transforming the soils into more stable materials to improve road durability. The requirement is in addition low porosity and low water and oil absorption capacities. The deposit meets more than 80% of these requirements and can thus be used as building and construction materials.

Metallurgy

One of the numerous applications of raw marble and its lime product is in the metallurgical industry, especially for fluxing steel (Ofulume, 1993). The value of lime for most of its uses depends mainly on its content of "available lime" (calcium oxide or calcium hydroxide). Magnesia is frequently the impurity that affects lime in manufacturing, so the use of marble or its lime product for any purpose is based on the contents of $CaCO_3$ and $MgCO_3$.

Requirements for metallurgical lime include CaMgO or CaO greater than 65%, high reactivity, L.O.I of 1-2wt% and SiO_2, 1-1.5wt%. From the results of the chemical analyses, (Table 3), the Burum-Takalafia lime product does not meet the requirements for use as fluxes in steel production. In steel productions, lime acts as flux in purifying steel by promoting fusion of the slag and assisting in the removal of phosphorus, silica, sulphur and other impurities (Okunlola, 2001).

Lime is also used as refractory lime in the metallurgical industries where it is used for lining open hearths. The requirements are total MgO and CaO greater than 58wt%, SiO_2, 2-4wt% and high reactivity. Based on these, the Burum-Takalafia lime product meets the requirements and can thus be used as refractory lime in the metallurgical industry.

CONCLUSIONS

The Burum-Takalafia marble deposit displays distinctive chemical and physical and characteristics which have a bearing on their industrial uses as defined by their measured major and trace elements contents and physical properties. Results of these measured parameters show that both the raw marble and its lime product can be used in agriculture as acid soil ameliorants and nutrient status enhancers, as building and constructional materials refractory lime and in the manufacture of chemicals. They also find application in the paper, pint and plastic industries where they are used as fillers/extenders.

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