Full Length Research

Dimension stone: Exploration, evaluation and exploitation in southwest parts of Oban Massif
Southeastern Nigeria

N. Egesi* and C. A. Tse

Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria.

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Some igneous and metamorphic rocks in Oban Massif can meet requirements for the production of dimension stone. The thickness of lateritic deposits is thin in places, though the area is within the equatorial rain forest region subjected to extensive weathering. Pegmatitic granite and kyanite gneiss have been identified as of good quality in physical, chemical and mechanical properties to be a resource. Petrographic analysis of the rocks identified its mineralogy, grain size, texture, fabric and weathering states. Exploitation of these rocks could be as rough unprocessed dimension stone or better polished natural stones for a variety of uses. An integrated database and GIS for mapping and monitoring stone degradation can be useful in old stone construction. Nigeria can eliminate export tax rebate on dimension stone for a long-term significant production, exportation and usage. Small and medium-scale enterprises with appropriate technical know-how can be encouraged with soft loans to establish, as an effective production of dimension stone will reduce unemployment, diversify the quarrying industry and economy.

Key words: Dimension stone, rocks, petrographic analysis, quarrying, Oban Massif, Nigeria.

INTRODUCTION

The Oban Massif belong to the Precambrian Basement Complex of southeastern Nigeria and is surrounded by the younger sedimentary rocks of Cretaceous age, the northern part have boundary with Mamfe Embayment, the Benue Trough is on the west, the Cameroon Volcanic Line (CVL) on the east, while the Calabar Flank covers the southern part. The area is within the equatorial rain forest zone with thick vegetation Rahman et al. (1981, 1988); Ekwueme (1990) produced the first comprehensive geological map of Oban Massif in which the rocks have been differentiated into phyllites, schists, gneisses and amphibolites (Figure 1). Intrusives into these are charnockites, dolerites, granites, granodiorites, diorites, syenites, ademellites and pegmatites. Most of these rocks are being quarried into aggregates and used for construction purposes such as houses, roads and bridges.

Dimension stone is a natural stone or rock that has been selected and fabricated (trimmed, cut, drilled, ground) to specific sizes or shapes. Colour, texture, pattern, and surface finish of the stone are normal requirements. Another important selection criterion is durability, the time measure of the ability of dimension stone to endure and to maintain its essential and distinctive characteristics of strength, resistance to decay, and appearance. In the Oban Massif, there are several quarries over ten, that produce crushed stone used as construction aggregates for pavement. It is possible to convert a crushed stone quarry into dimension stone production. However, first the stone shattered by heavy and indiscriminate blasting must be removed (Figure 2). Dimension stone is separated by more precise and delicate techniques, such as diamond wire saws, diamond belt saws, jet-pieces, or light and selective

*Corresponding author. E-mail: ubaegesi@yahoo.co.uk.
blasting with Primacord, a weak explosive.

In this contribution, we present prospects for using the variety of igneous intrusives and metamorphic rocks that abound in the area in the production of dimension stone, use in construction of bathrooms vanities, countertops, tiles, monuments, exterior building components and flagstone, in addition to the present production of aggregates.
Geological setting

A detailed report on the geology of the area, can be found in Ekwueme (1985, 1987, 1990); Ekwueme and Onyeagocha (1986). The rock units in the area are phyllites, schists, gneisses, migmatites and amphibolites. Intrusive into these rocks are granodiorites, pegmatitic granites and olivine dolerites (Figure 1). Phyllite is a regional metamorphic rock characterized by weak foliation, lustrous, often undulating, well developed cleavage surfaces intermediate between slate and mica schist. Schists have well developed parallel orientation of minerals. Three groups of fine-grained, medium-grained and coarsed-grained schists have been identified by Ekwueme (1987) and consist dominantly of quartz, mica and chlorite. The chlorite schist which is green shows well developed schistosity.

The gneisses quartzo-feldspathic type, occur in the area. They are medium to coarsed-grained biotite-hornblende gneiss, kyanite gneiss and migmatitic gneiss. The migmatitic gneiss occur as lit-par-lit type. The dominant intrusive rocks in the area are granitoids rocks consisting of pegmatitic granite and granodiorite which are coarsed-grained. The intrusive rocks are non-foliated and display sharp contact relationships with the metamorphosed rocks. There is a gradational contact between the phyllites, schists and gneisses, while these rocks have sharp contact relationships with the amphiboles.

Polydeformation has resulted in multidirectional orientations of planar and linear structures in the gneisses, schists and quartzites. Porphyroblastic, granoblastic, xenoblastic textures are observed on metamorphic rocks, while the igneous rocks display porphyritic, xenomorphic, granular and mortar features.

Petrography

In assessing of a rock for use as a dimension stone, the first requirement is petrographic study to identify its mineralogy, grain size, texture, fabric and weathering states. All these processes are in turn determined by the geological processes which formed the rock. A good understanding of these processes and effects, will enable one to determine a rock’s suitability, availability and consistent production. The rocks of interest are the pegmatitic granite and granodiorite from igneous rock, while gneiss from metamorphic rock. The leucocratic pegmatitic granite at Njahachang area shows quartz, mica, orthoclase, hornblende and accessories (Figure 2). Granodiorite which shows a mortar structure in hand specimen consist of quartz, k-feldspar, plagioclase, biotite, hornblende and accessory magnetite opaque minerals (Figure 3).

Kyanite gneiss was mapped at Old Netim and consists of minerals like hornblende, magnetite and light-blue
crystals of kyanite. The light colour components are quartz and feldspar, and garnet containing inclusions of quartz and mica in schist (Figure 4). Table 1 is showing the mineralogical modal averages of rocks in the study area. While common colours used in major applications may be mentioned, there is an extra-ordinarily wide range of colours available in thousands of patterns. These are created by geological phenomena such as mineral grains, inclusions, veins, cavity fillings, blebs, and streaks as was observed in the thin sections of the petrographic analysis (Figure 4). Igneous, metamorphic and sedimentary rocks are used in dimension stone production. Evolution in building technology over the past 60 years has dramatically changed the way in which granite and others are used in building construction.

Advances in granite processing technology, particularly developments in diamond sawing and computer control systems over the last decade or so, have reduced the relative cost of granite for use in domestic applications such as benchtops. As a consequence granite has become an international commodity of some importance, with ~ 16 Mt/year being mined around the world. The stone used in these applications usually have certain properties, or meet a standard specification. The American Society for Testing and Materials (ASTM) has such specifications; granite, marble, limestone, quartz-based dimension stone (C616), slate (629), travertine (1527), serpentine (1526). Other national standards organization are for example, the British Standard Institution BS and German DIN. These specifications can relate to any one or a combination of chemical, physical and mechanical properties. They are sometimes not
Table 1. Modal averages of minerals in some rocks of southwest Oban Massif southeastern Nigeria.

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Granodiorite A</th>
<th>Granodiorite B</th>
<th>Kyanite gneiss A</th>
<th>Kyanite gneiss B</th>
<th>Pegmatitic granite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>21.0</td>
<td>23.0</td>
<td>26.8</td>
<td>25.0</td>
<td>27.0</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>23.0</td>
<td>25.0</td>
<td>24.0</td>
<td>26.0</td>
<td>35.0</td>
</tr>
<tr>
<td>K-feldspar</td>
<td>11.3</td>
<td>10.0</td>
<td>9.7</td>
<td>10.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Biotite</td>
<td>22.0</td>
<td>20.0</td>
<td>20.0</td>
<td>14.0</td>
<td>11.0</td>
</tr>
<tr>
<td>Muscovite</td>
<td>6.2</td>
<td>6.0</td>
<td>0.6</td>
<td>-</td>
<td>3.0</td>
</tr>
<tr>
<td>Garnet</td>
<td>-</td>
<td>-</td>
<td>0.6</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Kyanite</td>
<td>-</td>
<td>-</td>
<td>7.0</td>
<td>10.0</td>
<td>-</td>
</tr>
<tr>
<td>Sillimanite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chlorite</td>
<td>-</td>
<td>4.0</td>
<td>4.0</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>Epidote</td>
<td>2.3</td>
<td>-</td>
<td>1.6</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Hornblende</td>
<td>9.6</td>
<td>6.0</td>
<td>5.0</td>
<td>9.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Sphene</td>
<td>4.0</td>
<td>3.0</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Calcite</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Zircon</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Opaques</td>
<td>0.6</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Olivine</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>-</td>
</tr>
</tbody>
</table>

* A compiled from Ekwueme (1985); B and others present study.

Table 2. Physical parameters of some basement rocks (mean values, with ranges in brackets) (Elueze, 1995).

<table>
<thead>
<tr>
<th>Rock type</th>
<th>Specific gravity</th>
<th>Standard strength Index</th>
<th>Water absorption capacity (%)</th>
<th>Oil absorption capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean range</td>
<td>Mean range</td>
<td>Mean range</td>
<td>Mean range</td>
</tr>
<tr>
<td>Gneisses and migmatites</td>
<td>2.64 (2.48-2.80)</td>
<td>7.65 (4.30-10.50)</td>
<td>0.39 (0.29-0.51)</td>
<td>0.13 (0.08-0.22)</td>
</tr>
<tr>
<td>Quartzites and schists</td>
<td>2.52 (2.42-2.70)</td>
<td>5.49 (3.20-8.80)</td>
<td>0.56 (0.36-0.72)</td>
<td>0.23 (0.17-0.30)</td>
</tr>
<tr>
<td>Amphibolites</td>
<td>2.79 (2.73-2.89)</td>
<td>7.16 (5.40-10.07)</td>
<td>0.34 (0.28-0.42)</td>
<td>0.06 (0.05-0.08)</td>
</tr>
<tr>
<td>Granites and granodiorites</td>
<td>2.67 (2.53-2.78)</td>
<td>7.13 (3.75-10.85)</td>
<td>0.36 (0.23-0.58)</td>
<td>0.08 (0.06-0.09)</td>
</tr>
<tr>
<td>Syenites and charnockites</td>
<td>2.79 (2.62-2.90)</td>
<td>9.38 (7.30-11.77)</td>
<td>0.31 (0.13-0.59)</td>
<td>0.09 (0.08-0.10)</td>
</tr>
<tr>
<td>Gabbros and dolerites</td>
<td>2.86 (2.72-2.93)</td>
<td>10.91 (6.75-14.50)</td>
<td>0.26 (0.18-0.32)</td>
<td>0.08 (0.06-0.12)</td>
</tr>
</tbody>
</table>

easily attainable because of variations of rock materials from one location to other. Table 2 is the physical parameters of some basement rocks (mean values, with range in brackets).

From the various test results carried out at the Quality Control Department (laboratory) of Setraco Nigeria
Table 3. Test result of the rock samples in the study area.

<table>
<thead>
<tr>
<th>Rock samples</th>
<th>AAV in %</th>
<th>ACV in %</th>
<th>AIV in %</th>
<th>Absorption in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotite-Granite</td>
<td>22.0</td>
<td>23.2</td>
<td>18.5</td>
<td>0.54</td>
</tr>
<tr>
<td>Granite-Gneiss</td>
<td>27.0</td>
<td>26.1</td>
<td>22.8</td>
<td>0.73</td>
</tr>
<tr>
<td>Greenstone</td>
<td>45.2</td>
<td>55.9</td>
<td>49.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Acceptable standards (BS, AASHTO, ASTM)</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
<td>&lt; 35</td>
<td>&lt; 1.0</td>
</tr>
</tbody>
</table>

Table 4. The role of the geologist in dimension stone production.

<table>
<thead>
<tr>
<th>Roles</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market research</td>
<td>Advise on the technical properties of rock, specifications and suitability for each application.</td>
</tr>
<tr>
<td>Exploration</td>
<td>Find rock of quality required in the market and in sufficient quantity.</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Assess quality of rock to establish suitability for market.</td>
</tr>
<tr>
<td>Mine or quarrying planning</td>
<td>Consider shape and position of rock in relation to environment, method and ease of extraction. Advise on quality variation, which could be any physical, chemical or mechanical property.</td>
</tr>
<tr>
<td>Production</td>
<td>Advise on effects and methods to counter sudden and long term variations in quality of rock material.</td>
</tr>
<tr>
<td>Technical sales</td>
<td>Advise customers on nature of rock impurities in product and their likely consequences during use, long term supply position and effects of quality changes.</td>
</tr>
<tr>
<td>Research and development</td>
<td>Examine potential for new products and improvement of manufacturing techniques in which the rock is used, new methods of processing and quality improvement. Nature of transformation of rock constituents particularly in silicate and oxide systems.</td>
</tr>
</tbody>
</table>

Limited, in accordance with British Standard (BS), American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO). The granite pegmatite has Aggregate Abrasion Value (AAV) of 22.0%, Aggregate Crushing Value (ACV) of 23.3%, Aggregate Impact Value (AIV) of 18.5% and water absorption 0.54%. Kyanite gneiss has 27.0, 26.1, 22.8 and 0.73% while greenstone has 45.2, 55.9, 49.6 and 3.7% respectively (Table 3). The high resistance of the granite and its low water absorption could be attributed to its mineralogical composition of quartz, feldspar, biotite and accessory minerals. It is an intrusive igneous rock formed as a result of slow cooling with grain boundaries interlocked.

Exploration and production

Reasonable deposits of pegmatitic granite occurred at Aiyebam and Njahachang area (Figure 2) and kyanite gneiss at Old Netim which are of good quality for dimension stone production (Figure 4). The geologist have active involvement in most stage of dimension stone industrial activity. His participation certainly needs to go beyond exploration, mine planning and development stage. Table 4 illustrates the nature of the tasks of a geologist with adequate training in dimension stone production and should be able to undertake in an organization extracting, processing and marketing of dimension stone. Brazil, China, India, Italy, and Spain are the major producers of dimension stone, each having annual production levels of 9 to over 22 million tons. Other producers include Portugal and Australia, Nigeria can join the later group if interests in the quarry industry direction, a non-oil product is maintained.

According to the USGS (2006), U.S. dimension stone production was 1.33 million tons valued at $265 million, compared to 1.36 million tons (revised) valued at $269 million in 2005. Of these, granite production was 428,000 tons, valued at $105 million in 2006 and 416,000 tons...
valued at $106 million in 2005, and limestone was
559,000 tons valued at $96.1 million in 2006 and 581,000
tons valued at $95.8 million (revised) in 2005. The World
Demand for (finished) Granite Index showed a growth of
15% annually for 2000 to 2006 period, compared to 14%
annually for the period 2000 to 2005 period. The DSAN
U.S. Ceramic Tile Demand Index shows a growth of 5.0%
anually for the period, compared to the 5.5% annually
for the 2000 to 2005 period. In Nigeria, there is no
reliable statistics on production of dimension stone.

However, demand has been on increase as can be
observed in use at public places like the Federal
Secretariat Abuja, oil producing and services companies
offices, commercial houses like banks and even
individual residential homes, as preference to the use of
rug carpets on floors. Major ceramic tile suppliers, Italy
and Spain, have been losing markets to new entrants
Brazil, China and India. Nigeria can join the new entrants
if government policy is enhanced, even if it means
exporting the unprocessed or rough dimension stone. For
example, the Chinese Government has made a policy
shift of long-term world-wide significance for dimension
production, by eliminating the 15% export tax rebate on
all dimension stones. So far, it has not replaced it with an
export tariff on it, as it has on other industrial minerals. In
addition, the Chinese Government sometimes strongly
discourages its domestic firms from buying rough
dimension stone from overseas.

Evaluation, use, recycling and reuse

The need for evaluation of rocks for dimension stone
production cannot be over-emphasized. Regional aero-
magnetic survey of the area has been carried out, other
exploration geophysical survey like gravity with more
direct boring will be most effective for ground truthing. In
the study area, the companies producing aggregates
seems to be interested on surface exposure as observed
at Aiyebam pegmatitic granite which was sampled and
abandoned. The lateritic overburden is less than 1 m for
example, at Njahachang (Figure 2) if compared to the
over 25 m overburden removed at Ugwuele Uturu,
Setraco dolerite quarry at a nearby location. Although,
production of aggregates in the study area is going on,
there is need to convert part of the products to dimension
stone or in parts were future mining of these rocks will be
established.

Environmentally friendly construction with natural
materials is an idea that has been around for decades,
especially with the recent global warming problems.
Educational institutions are often requiring new building
to be green and few cities have some rules pushing
green building. Also, for environmentally friendly concept,
dimension stone has advantage over concrete, aluminum
and steel whose productions are all energy intensive
and create much air and water pollution. As an entirely
natural product, dimension stone also has an advantage
over quartz surface artificial products. Dimension stone
rates very well in terms of the criteria on the ASTM
checklist for sustainability of building products: there are
no toxic materials used in processing, there are no
greenhouse gas emissions during processing, the dust
created is controlled, the water used is almost completely
recycled and it is a perpetual resource, can last many
generations and even centuries depending on rate of
production and consumption.

Recycling dimension stone can occur when structures
are demolished. The material most likely to be recycled is
concrete, and this represents the largest volume of
recycled construction materials. Presently, in Nigeria not
too many structures incorporate dimension stone. Stone
recycling is usually done by specialists that monitor local
demolition activity, looking for stone-containing houses,
builtings, bridge abutments, and other dimension stone
structures scheduled for demolition. The recycled dimen-
sion stone is used in old stone buildings being renovated,
benches, or landscaping. Dimension stone can also be
reused. Buildings immediately spring to mind. The old
stone work may only need cleaning or sandblasting, but it
may need more. Firstly, the building exterior needs to be
first inspected for unsafe conditions. Next, the building
walls need to be inspected for water leakages. Deteriorated
pieces of stone work are replaced with pieces of stone that match the original as much as possible. The exterior parts of dimension stone will often
change colour after exposure to weather over time.
Interior dimension stone can sometimes change its shade
a little over time too. It may not be possible to find an
exact match, even from the original quarry. A rock iden-
tified for dimension stone production will often change its
appearance from location to location in the same quarry.
If the dimension stone renovationist is truly fortunate, the
original builder may put aside some spare pieces of the
stone for future need.

Stone selection, cleaning and degradation

The selector of dimension stone begins by considering
stone colour and appearance, and how the stone will
match its surroundings. In addition, the suitability of its
properties for the intended use must be considered.
Stone being used in tiles should be sealed in order to
resist stains, and be heat and impact resistant. Stone
being used for flooring, paving, or surfaces subject to foot
or vehicular traffic ought to have a semi-abrasive finish
for slip resistance, such as bush-hammered or thermal.
Dimension stone requires some specialized methods for
cleaning and maintenance. Abrasive cleaners should not
be used on a polished stone finish because it will wear
the polish off. Acidic cleaners cannot be used on marble
or limestone, because it will remove the finish. Textured finishes can be treated with some mildly abrasive cleaners but not bleach or an acidic cleaner if marble or limestone. Stains are another consideration, stains can be organic or metallic, this requires some special removal techniques, such as the poultice method.

Assessment of in-service performance of both traditional and modern building materials (dimension stone) also requires a consistent and long-term structured programme of analysis. The complicated character of weathering system of any individual building makes developing such a programme problematic. Field assessment of weathering and development of classification schemes based on this assessment are essential in understanding and predicting building stone degradation. Laboratory studies are limited in their reductionist view of degradation (Inkpen et al., 2004; Hacking, 1983), whilst computer simulations are at present, too limited in their modeling capabilities to provide anything other than partial view of degradation (Dorsey et al., 1999). At the highest level, weathering features are grouped into 1 of 4 classes: loss of stone material, deposits, stone detachment and fissures/deformation. The classification should follow the principles of simplicity of use, ease of transferability, flexibility and should not assume process/form relationships. An integrated database and GIS for mapping and monitoring stone degradation may be useful.

CONCLUSIONS

The petrographic analysis of the rocks indicated some of the rocks have interlocked grain boundaries, particularly the pegmatitic granites which is an important property in economic evaluation of a rock for dimension stone production. This probably makes granites, most suitable for the production of dimension stone in the area. Mining of these rocks usually results in environmental degradation, this can be reduced by integrating Environmental Impact Assessment (EIA) report to include land reclamation at the end of the life of the quarry. Nigeria can benefit from dimension stone mining and production, the rock boulders can be exported as raw block, or finished products as bathroom vanities, countertops, tiles, monuments, exterior building components and flagstone. Small-and-medium scale enterprises (SMEs) can be effective in dimension stone production, since the rocks in places are not massive. Dimension stone production can be incorporated into the recent entrepreneur skills acquisition programme of Universities curricula.

REFERENCES