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<td>OBIORA, S. C.</td>
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<td>Author 2</td>
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Petrography of some altered intrusive rocks from the Lower Benue Trough, Nigeria

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Abstract

Some intrusive rocks of doleritic to dioritic compositions from the Ejekwe-Wanikande and Okgwe-Ishiagu districts in the Lower Benue Trough have been studied using thin section microscopy and X-ray (powder) diffraction method. The rocks have intruded pre-Santonian sedimentary rocks which are predominantly calcareous shales. The exposures of these intrusive rocks generally have widths ranging from about 40 m to 228 m. The intrusive rocks are generally melanocratic to mesocratic (dark-to-light grey) and medium-to coarse-grained. They commonly contain well crystallized calcite which often appear as amygdaloids or cavity-fillings. Randomly oriented crystals of plagioclase feldspars with interstitial to ophtic clinopyroxene showing high degree of alteration are recognizable. The alteration assemblages in the dolerites consist of calcite, tremolite, chlorite (thuringite), epidote, analcime, serpentine, pyrite, with relic primary constituents of oligoclase and diopside. The dolerites contain the same alteration assemblages as the dolerites with exception of serpentine, but with apatite and relict primary constituents including andesine and diopside. The assemblage: tremolite, epidote, chlorite and analcime(a diagenetic zeolite) represents a metamorphic alteration still at the lower part of the greenschist facies. The alteration assemblages are most probably the result of fluid/rock interaction.

Introduction

The Benue Trough is an intra-continental rift (ca. 1000 km long and 80 km wide) regarded as a failed arm of a triple junction whose centre is occupied by the Niger Delta (Grant, 1971; Burke et al., 1972). The most suitable mechanism of formation of such a rift as the Benue Trough involves asthenospheric uplift or mantle plume, crustal stretching and thinning, and emplacement of igneous bodies in the lithosphere, and block-faulting (Olade, 1975; Bott, 1976; Ofoegbu, et al., 1990). Thus, the origin of the Benue Trough was attended by magmatism the age of which spans from the Jurassic to Early Cretaceous (Valanginian) times (Umeji and Caen-Vachette, 1983, 1991), up till the Tertiary times (Umeji, 2000). The igneous rocks in the southern (lower) Benue Trough occur in essentially four districts which, from the north to the south, include southwest of Gboko, Ejekwe-Wanikande, Abakaliki and Okgwe-Ishiagu districts (Obiora, 2002). Various accounts of the igneous rocks in the Lower Benue rift have been given by Gunthert and Richards (1960), Okezie (1957, 1961), Olade (1979), Hossain (1981), Hoque (1984), Umeji (1985, 2000), Benkheilil (1986, 1987), Ofoegbu and Amajor (1987), Orjakaka and Umenwaliri (1989), Ekwueme (1992), Ezepepe (1992), Obiora (1994), Obiora and Umeji (1995) and Maluski et al., (1995). The igneous rocks occur in a belt of Pb-Zn mineralization and saline groundwater occurrence. The igneous rock bodies, which are over one hundred and twenty in number have been emplaced within pre-Santonian sedimentary rocks as mainly small minor intrusives (sills), major intrusives (phlotons) and pyroclastics, with rare lava flows (Obiora, 2002). The sedimentary rocks are predominantly calcareous shales with subordinate siltstones, sandstones and occasional interbeds of limestones and mudstones. The igneous rocks are generally basaltic/doleritic to dioritic in composition, with a few syenitic and phonolitic types. Both the dolerites and dikes commonly contain low-temperature alteration mineral assemblages (Gunthert and Richards, 1960, Obiora, 1994, Obiora and Umeji, 1995, Maluski et al., 1995).

In the work of Gunthert and Richards (1960) which was on the geology and petrography of the pyroxene microdiorite of Eziator Hill, eastern Nigeria, the low-temperature minerals were described to have occurred in the microdiorites as amygdaloids which are over 16 mm in diameter. Apart from this description of Gunthert and Richards (1950), later reported by Wright (1976), there has not been other published petrographic descriptions of amygdaloidal intrusive rocks from the Lower Benue rift.

In this study, the petrographic descriptions of eight (8) intrusive rocks from the Lower Benue rift, and a diorite from the Eziator Hill are presented.

Field occurrence and characteristics

The igneous rocks in this study intruded calcareous shales and silty shales of the Assu River and Eze-Aku Groups (Fig. 1). The sedimentary rocks have been folded into series of anticlines and synclines with a general NE-SW trend and dip values of 11 to 55°. The amygdaloidal intrusive rocks crop out at locations 1 to 8 (Fig. 1). A common feature of these rocks is the occurrence of cavity-fillings or amygdaloids of well-formed crystals of calcite, with or without pyrite and analcime, all of which are clearly discernible in hand specimens. The rocks exposed at locations 1, 2, 5, 6 and 7 are altered dolerites whereas those at locations 3, 4, and 8 are altered dikes. The exposure at location 1, about 100 m, 190° SSW of Ikot-Ibenta culvert along the road leading to Oyoba village, NE of Wanikande, is medium-grained with cavity fillings of calcite and pyrite. This altered dolerite constitutes a hill which is about 3 m higher than the surrounding, 40 m long and 10 m wide, in an essentially 280° NWN trend. The rock at location 2 is exposed exactly at the boundary between Okpodom No. 3 ad Wanakom,
along the Izekwe-Wanakom road. It is coarse-grained and porphyritic, constituting a small hilly terrain. The rock exposed at location 5, Ipuole Ebo farmland is pyritiferous. The outcrop is 70 m wide and about 1.2 km long, in an essentially 35° NNE trend. A possible chilled margin about 6 m wide, constituted by a dark-grey basalt is exposed midway along the intrusion at the western margin. The host sedimentary rock which is a deeply weathered silty shale is exposed around the contacts of the intrusion. At location 6, Okpodumu, Izzi Local Government of Ebonyi State, the dolerite exposure is 50 m wide and 250 m long in an essentially NE-SW trend. The rock exposed at location 7, an old quarry site along the Enugu - Port Harcourt express road, is about 10 m wide and 40 m long in an orientation of 40° NNE.

Unlike the dolerites, the diorites are generally medium-to coarse-grained and mesocratic to leucocratic. The outcrop at location 3, Amagu-Anyim junction in Izekwe, is a medium-grained, leucocratic diorite. It is 210 m wide and 600 m long, in 60° ENE trend. The rock is finer-grained towards the margins. Spheroidal weathering is conspicuous at the exposure. The host rock is silty shale which is deeply weathered. The exposure at location 4, Woleche Ebo, is a large and elongate intrusive body, which trends 330° NNW towards its eastern end and 65° ENE at the western end. It is about 228 m wide, about 1 km long and rises more than 18 m above the surrounding. The exposure is finer-grained towards the peripheries and coarse-grained towards the centre; three different grain sizes were distinguished. A chilled margin which is up to 20 cm wide was exposed. This marginal rock is dark-grey, fine-grained and glassy. The host sedimentary rock exposed at the contacts is also a deeply weathered silty shale. At location 8, Eziator quarry, situated very close to Ishiagu, along the road leading from the Enugu-Port Harcourt express way to Ishiagu, the diorite is texturally heterogeneous. The exposure consists of rocks of various grain-sizes, ranging from fine-to coarse-grains without any definite pattern. Vein/fracture mineralization of calcite is characteristic of the exposure. The coarse-grained varieties of the rock contain cavity-fillings of pyrite and galena in addition to calcite. The fine-grained varieties are 'bleached' to a greyish white colour.

Petrographic studies

Methods

Thin sections were prepared from representative samples of the rocks. Four (4) of the rocks were also analysed by X-ray Diffraction (XRD) powder method for a comprehensive identification of their mineral constituents. The instrument used for the XRD analyses was the Philips PW 1800 X-ray Diffractometer.

Pulverised bulk rock samples(< 1mm) weighing 0.5 g were analysed. The diffraction peaks were measured and plotted by the aid of computer as the samples were analysed. The time for the analysis of each sample was roughly 20 minutes. X-ray diffractograms were run on all the rock samples from 0 to 65° 2q using CuKα radiation. Identification of the peaks of the minerals in the
diffractograms was done manually because the standard peaks for the expected minerals were not installed in the computer software used in the analysis. The minerals were, therefore recognised by the use of their d-values (values of interplanar spacing).

A list of minerals expected in the rocks as deduced from megascopic and microscopic petrographic studies was compiled. The d-values for each of the minerals in each rock sample were therefore picked from X-ray powder diffraction data cards published by Berry et al. (1974). The d-values so picked were located on the XRD data for each rock sample. The corresponding 2θ values for the d-values were traced on the diffractograms and the peaks marching them were marked. Since the powder pattern, hence the d-values are to each mineral in much the same way as the finger print is to a human being (Zussman, 1977), once four or more peaks including the peak of 100% intensity of a mineral were located on the diffractogram, that mineral is invariably present. The peaks for all the important minerals in each of the rock samples were all located on the diffractograms within the range of 0 to 45° 2θ.

Results

In thin section, both the dolerites and diorites consist of randomly oriented crystals of plagioclase feldspars with intersertal clinopyroxene. The diorite from Ezator (Loc. 8) however shows a clear ophitic texture consisting of randomly orientated crystals of plagioclase, completely enclosed by clinopyroxen (diopside) with maximum extinction angles for 010 sections, 35° to 53°. The highly seritized nature of the plagioclase which obliterated their twin lamina could not allow the determination of their composition by optical means. In addition to the amygdales of well crystallized calcite, common in the rocks in this study (Fig. 2a), the dolerite from Ipuole Ebo (Loc. 5) consists of circular amygdales (2.4 mm diameter) of a light

Fig. 2a. Large crystal of calcite (C) in the dioritic rock from Ikot-Ibena stream, Oyoha road, Wanikande area. Nicols crossed (X63); 2b-c. Octagonal to rounded forms of analcime (colourless) and opaques in the dioritic rock from Lokpanta. Plane polarised light (x63). 2d-e. Serpentine pseudomorphs (Sp) after olivine showing characteristic features in the dioritic rock from Ipuole Ebo farm. Nicols crossed (x63)
greenish to brown mineral which has formed feldspar-rich spherulites.

Another characteristic feature of the rocks in this study is the high degree of alteration of their essential mineral constituents. Whereas the plagioclase is relatively less altered than the clinopyroxene in most of the rocks (Loc. 1 and 5), the reverse is the case in the one from Loc. 2. Generally, the secondary minerals resulting from the alteration of the plagioclase and clinopyroxene are similar to those in the amygdales; they include calcite, opaques (magnetite and pyrite) and chlorite. Other alteration products include analcime which is associated with the alteration of the clinopyroxene in the dolerite from Lokpanta (Loc. 7) and serpentine pseudomorphs after olivine which occur in the dolerite from Ipuole Ebo from (Fig. 2b-c). The octagonal to round forms and complete isotropic nature of analcime are its diagnostic properties. Table 1 shows the modal compositions of the rocks.

From the XRD studies, the same minerals identified in thin section were obtained, in addition to apatite and the low-temperature/low-pressure alteration minerals, namely: epidote and tremolite. The plagioclase feldspar was identified as oligoclase in the dolerite and andesine in diorite. Table 2 shows the mineralogical compositions of the rocks, determined from XRD. The peaks representing the minerals are labelled in the diffractograms in Figs. 3 to 6.

### Table 1. Modal compositions of the igneous rocks

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<td>Loc. 4 (1)</td>
<td>Loc. 4 (2)</td>
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<tr>
<td>Plagioclase</td>
<td>66.5</td>
<td>58.0</td>
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<tr>
<td>Pyroxene (clino)</td>
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<td>30.0</td>
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<tr>
<td>Calcite (secondary)</td>
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<td>0.2</td>
</tr>
<tr>
<td>Chlorite (secondary)</td>
<td>3.0</td>
<td>5.6</td>
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<tr>
<td>Opaques</td>
<td>9.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Analcime</td>
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### Table 2. Mineralogical compositions of some of the rocks determined from XRD

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<td>Dolerite (altered)</td>
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<tr>
<td>6</td>
<td>32.DI</td>
<td>Oligoclase, diopside, calcite, tremolite, thuringite, analcime</td>
<td>Dolerite (altered)</td>
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<tr>
<td>7</td>
<td>35. DI</td>
<td>Oligoclase, diopside, calcite, epidote, tremolite, thuringite, analcime, apatite, pyrite</td>
<td>Dolerite (altered)</td>
</tr>
<tr>
<td>8</td>
<td>34.DI</td>
<td>Andesine, diopside, calcite, epidote, tremolite, thuringite, pyrite</td>
<td>Diorite (altered)</td>
</tr>
</tbody>
</table>

Key to abbreviations for the minerals as used on the diffractograms:

Olg: oligoclase, diopside, tr- tremolite, anal - analcime, ep - epidote, pr - pyrite, ap - apatite, and - andesine, Cc-Mn - manganese calcite, thg (chl) - thuringite (chlorite)
Fig. 3. Diffractogram of sample No. 32.DI (Loc. 6) from Okpodumu

Fig. 4. Diffractogram of sample No. 33.DI (Loc. 1) from Ikot Ibenta stream, Oyoba road
Fig. 5. Diffractogram of sample No. 34.DI (Loc. 8) from Eziator

Fig. 6. Diffractogram of sample No. 35.DI (Loc. 7) from Lokpanta
Discussion

The occurrence of intersertal and ophitic textures which are characteristic features of basic intrusives, as well as the presence of clinopyroxene, instead of amphibole as the main mafic mineral in the rocks described as altered diorites suggests that they belong to basic diorites in the diorite-monzonite-syenite group (Moorhouse, 1964). These are common features of the diorites in the Lower Benue Trough (Obiora, 1994; Obiora and Umeji, 1995). The cavities which are filled by secondary minerals such as calcite could have resulted from the emplacement of the rocks at shallower depths where it is possible for gases contained in the magma to bubble out due to rapid cooling, giving rise to cavities which were later filled by secondary minerals. The intense alteration of the primary mineral constituents of the rocks is a possible result of fluid/rock interaction. The generally small sizes of the intrusive rocks made them vulnerable to the effects of the fluid. The low-temperature alteration assemblages of calcite, tremolite, chlorite (thuringite), epidote, analcime, serpentine and pyrite are comparable to those of metabasites of low grade (Metcalfe and Robinson, 1989). The occurrence of chlorite and analcime (a zoelite the formation of which is a possible marker of the boundary between diagenesis and very-low-grade metamorphism) in the assemblage is a strong indication that the metamorphic alteration is still at the lower part of the greenschist facies.

The predominance of calcite in the alteration assemblages in this study is evidence that the fluid phase with which the rock had interacted had high concentration of CO₂.

The processes by which the alteration assemblages in these basic rocks were formed could be illustrated as follows:

\[
\begin{align*}
\text{Clinopyroxene} & \Rightarrow 2(\text{Ca,Na})\text{AlSi}_3\text{O}_6 + \text{H}_2\text{O} + \text{CO}_2 + \text{O}_2 \\
\text{dolomitic calcite} & \Rightarrow 2(\text{Ca,Mg})\text{CO}_3 + 2\text{FeO}.\text{Fe}_2\text{O}_3 + 3\text{SiO}_2 + (\text{Na,Ca})\text{AlSi}_3\text{O}_6 + 10\text{H}^+ \\
\text{Oligoclase} & \Rightarrow (\text{Na, Ca})\text{AlSi}_3\text{O}_6 + 2\text{H}_2\text{O} + \text{CO}_2 \rightleftharpoons \text{NaAlSi}_3\text{O}_6.\text{H}_2\text{O} + \text{CaCO}_3 + \text{SiO}_2 + \text{H}^+ \\
\text{Diopside} & \Rightarrow 5\text{CaMgSi}_2\text{O}_6 + 3\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{Ca}_2\text{Mg}_{3}\text{Si}_8\text{O}_{22}\text{(OH)}_2 + 3\text{CaCO}_3 + 2\text{SiO}_2 \\
\text{Labradorite} & \Rightarrow 3\text{CaAlSi}_3\text{O}_8 + \text{CaCO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{Ca}_2\text{AlSi}_3\text{O}_{16}\text{(OH)}_2 + \text{CO}_2 + 3\text{O}_2
\end{align*}
\]

Such a fluid with high concentration of CO₂ could have come from either late magmatic (deuteric/hydrothermal) fluids or connate water released from the host sediments which are predominantly calcareous shales at the various times of intrusion and during compaction and diagenesis accompanying their burial. At the end of crystallization, the residual (late magmatic) fluid gradually cools to a condition of low-temperature active aqueous solutions which are capable of altering the primary minerals as well as depositing low temperature minerals as they permeate fractures and interstices between the earlier formed crystals. The chemical trend in the saline groundwater in the study area (Tijani et al., 1996) which correlates with the trends of "metamorphic" brines (Obiora, 2002) is an evidence that connate water could have been released from the predominantly calcareous shales. The similarity of the minerals in the cavity-fillings with the alteration assemblages indicates an origin from similar fluids. The close association of large crystals of calcite-filling, with altered primary minerals suggests that the minerals which appear as cavity-filling might have resulted from the alteration of the primary minerals.

Wright (1976) had suggested that the diorite at Eziator studied by Guthert and Richards (1960) was heavily altered by soda and carbonate-rich deuteric/hydrothermal fluids, consequent upon emplacement into partly consolidated, but still wet sediments some of the fluids responsible for both igneous rocks alteration and Pb-Zn mineralization also were brines already within the sedimentary rocks. The fracture controlled mineralization in some of the outcrops suggests that the hydrothermal system in which the fluids possibly occurred was related to a fracture network. From the observed contact relations – chilling effects on the magma and baking of the sedimentary rocks it is very unlikely that the sediments were still wet at the time of emplacement of the rocks. This unlikely wet state of the sediments is supported by radiometric ages of some of the intrusive rocks which gave predominantly Santonian to Campanian ages (Umeji, 2000) as opposed to the older Albian age of the sediments. These ages show a time lapse.
of about 26.4 to 28.7 Ma from the time of deposition of the sediments to the time of emplacement of the intrusive rocks. The sediments therefore could have been lithified over this period of time.

Conclusions
The rocks described in this study are altered dolerites and basic diorites. They contain cavity-fillings or amygdales whose compositions are much similar to those of low-temperature alteration assemblages which are also present in them.

The cavity-fillings, the alteration assemblages, and the general petrographic characteristics of the rocks suggest that the rocks are shallow intrusives. There was also interaction of the rocks with a fluid phase which resulted in the low-temperature alteration assemblages, with the fluid phase very likely enveloped in CO₂. It is also possible that such a fluid was either late magmatic (deuteritic/hydrothermal) fluid or connate water pressed out from the sediments during burial.

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