

# PETROCHEMISTRY OF OPAQUE MINERALS IN BIOTITE GRANITE GNEISS OF ABEOKUTA AREA SOUTHWESTERN NIGERIA

ANTHONY T. BOLARINWA

(Received 16 January, 2003; Revision Accepted 25 March, 2004)

## ABSTRACT

Oxide minerals, notably ilmenite and titanite occurring in the biotite granite gneiss of Abeokuta area, southwestern Nigeria, were analysed using an electron microprobe with a view to contribute to the existing knowledge on the petrogenesis of the rock.

Ilmenite occurs as idiomorphic euhedral crystals in the biotite granite gneiss. Compositionally, it belongs to the ilmenite-pyrophanite series consisting of about 94mol.% FeTiO<sub>3</sub>, 5mol.% MnTiO<sub>3</sub> and 1mol.% MgTiO<sub>3</sub>. It constitutes about 80% of the opaque minerals in the rock. Grey, wedge-shaped prisms of titanite were observed in close association with pyrite. Other opaque minerals present include pyrrhotite, which is associated with chalcopyrite and covellite.

Petrography and chemical data of the ilmenites and titanites suggest that the protoliths of the biotite granite gneiss are mainly igneous. These chemical data can also serve as petrogenetic discriminator, particularly in a polymetamorphic terrain.

**KEYWORDS:** Ilmenite, titanite, petrochemistry, granite gneiss, Abeokuta

## INTRODUCTION

The biotite granite gneiss of Abeokuta area is part of the Precambrian basement complex of southwestern Nigeria, which is believed to have evolved through at least three major episodes of deformation, metamorphism and remobilization (Rahaman, 1988). Geochemical study of gneisses in the basement complex of southwestern Nigeria has shown that many of the gneisses are of metasedimentary origin (Jones and Hockey, 1964; Burke et al., 1972; Elueze, 1982a and 1982b). Other workers, notably Grant (1970), Rahaman and Ocan (1978) and Onyeagocha (1984) proposed igneous origin for certain gneisses in the basement complex of Nigeria. It is therefore a general consensus that the variations in the chemical compositions of the gneisses underscore the need to use more geochemical data to decipher the origin and evolution of these ubiquitous rock bodies. This is very important since available geochemical data are insufficient to equivocally distinguish between a sedimentary and an igneous origin for the gneisses (Rahaman, 1988).

Oxide minerals of the ilmenite group occur in the biotite granite gneiss of Abeokuta area, southwestern Nigeria (Fig. 1). Many workers have used ilmenite and titanite compositions to unravel the petrogenesis of diverse rock types of igneous and sedimentary origin. Studies by Tompkins and Haggerty (1985) have shown that FeTi oxide minerals are useful monitors that may reflect changes in the bulk composition, volatile contents, temperatures and oxygen fugacities of crystallization. According to Haggerty (1976), ilmenite of high MgO is typical of kimberlite, while Ulrych and Lang (1985) proposed that the presence of Mn-rich ilmenite (pyrophanite) in the metamorphic rocks of Manicaragua zone, Cuba was associated with contamination by Mn-rich granites from the underlying zones.

The aim of the present investigation is therefore to assess the petrogenesis of the rock body, using petrographic and microchemical data of ilmenite and titanite phases in the granite gneiss of Abeokuta area. This novel method can also serve as petrogenetic discriminator in the polymetamorphic terrain of the basement complex of Nigeria.

## PETROGRAPHY

The biotite granite gneiss within the Precambrian basement complex of Abeokuta area, southwestern Nigeria, occurs within a zone characterized by granitic intrusions (Fig. 2). It is medium to coarse grained. The rock is composed of quartz (ca. 20%), plagioclase feldspar (oligoclase to andesine) (ca. 30%), microcline (ca. 30%), biotite, (ca. 15%) and calcic amphibole (ferrokaersutite) (ca. 5%). Petrographic studies show that titanite and ilmenite are common accessory minerals in the rock. Others are inclusions of zircon, apatite, pyrite, pyrrhotite and chalcopyrite.

The gneisses in this area contain index minerals garnet and hornblende. The mineral assemblages occurring in the rocks indicate that the metamorphism was regional medium to high amphibolite grade. Elsewhere, north of the study area, low to medium grade schists containing garnet and staurolite are present. Also, high-grade gneisses characterized by the presence of sillimanite occur towards the eastern part of the area near Ibadan. However, in the biotite granite gneiss studied, minerals of sedimentary origin, such as sillimanite, kyanite, staurolite and cordierite, are not seen in the thin section of the rocks. The occurrence of rocks of varied metamorphism and age within this area is an indication of polyphase metamorphism of the basement complex.

Fine grained, discrete laths of ilmenite (0.5mm) are present as idiomorphic euhedral crystals. In reflected light, prismatic crystals of rutile and apatite (0.03mm) are seen disseminated within the rock. Grey

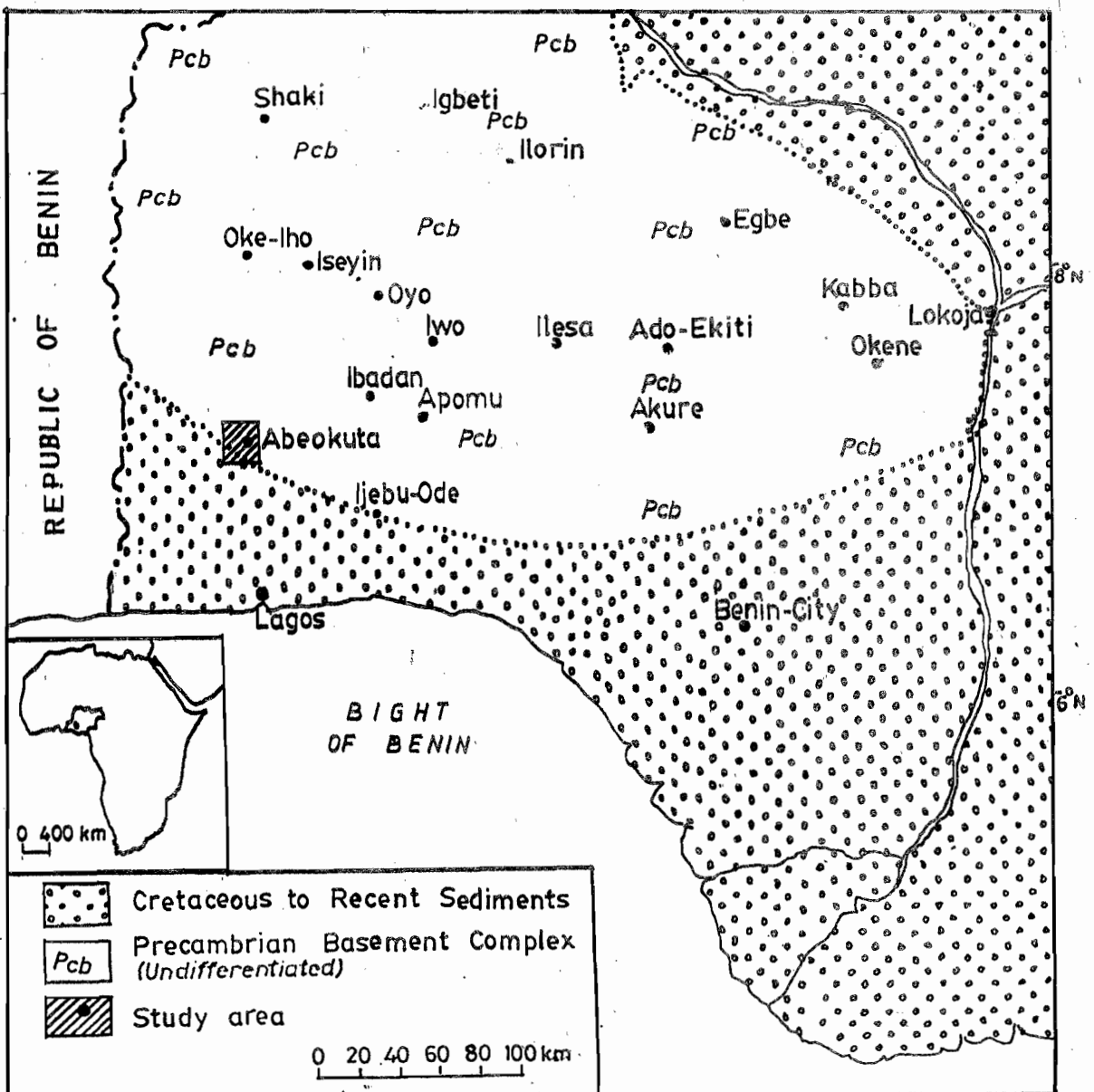


Fig. 1: Location map of Abeokuta area within the basement complex of southwestern Nigeria.

wedge-shaped elongated crystals of titanite with pyrite inclusions were also observed in the polished section (Fig. 3). Both pyrite and pyrrhotite occur as irregularly shaped sulphide grains of about 0.04mm (Fig. 4).

#### ANALYTICAL TECHNIQUES

Polished samples of the biotite granite gneiss of Abeokuta area were prepared for chemical analysis. Ilmenite and titanite phases to be analysed were selected using the ore microscopic method. An electron probe micro-analyzer, CAMECA<sup>®</sup> SX-100, operated at 20kV and 20nA was used, after calibration of the instrument with standard minerals. Major elements concentration of Si, Ti, Al, Fe, Mn, Mg, Ca and V were determined. The analytical data were converted to oxides and recalculated to their respective structural formulae as shown in Tables 1 and 2.

The other opaque accessory minerals in the biotite granite gneiss, notably pyrite, pyrrhotite and chalcopyrite were not analysed because the micro-analyzer was not calibrated for sulphide analyses. Also, it is difficult to obtain with confidence the compositions of minor constituents such as magnetite or haematite alone, since these minerals generally occur as very small crystals and as intergrowths with other minerals including ilmenite.

#### MINERAL CHEMISTRY

##### Ilmenite

Rhombohedral plates of ilmenites in the biotite granite gneiss of Abeokuta area are euhedral to subhedral in shape. These textures are similar to those of ilmenites crystallizing in basaltic environment (Haggerty, 1976). The chemical formula of ilmenite,

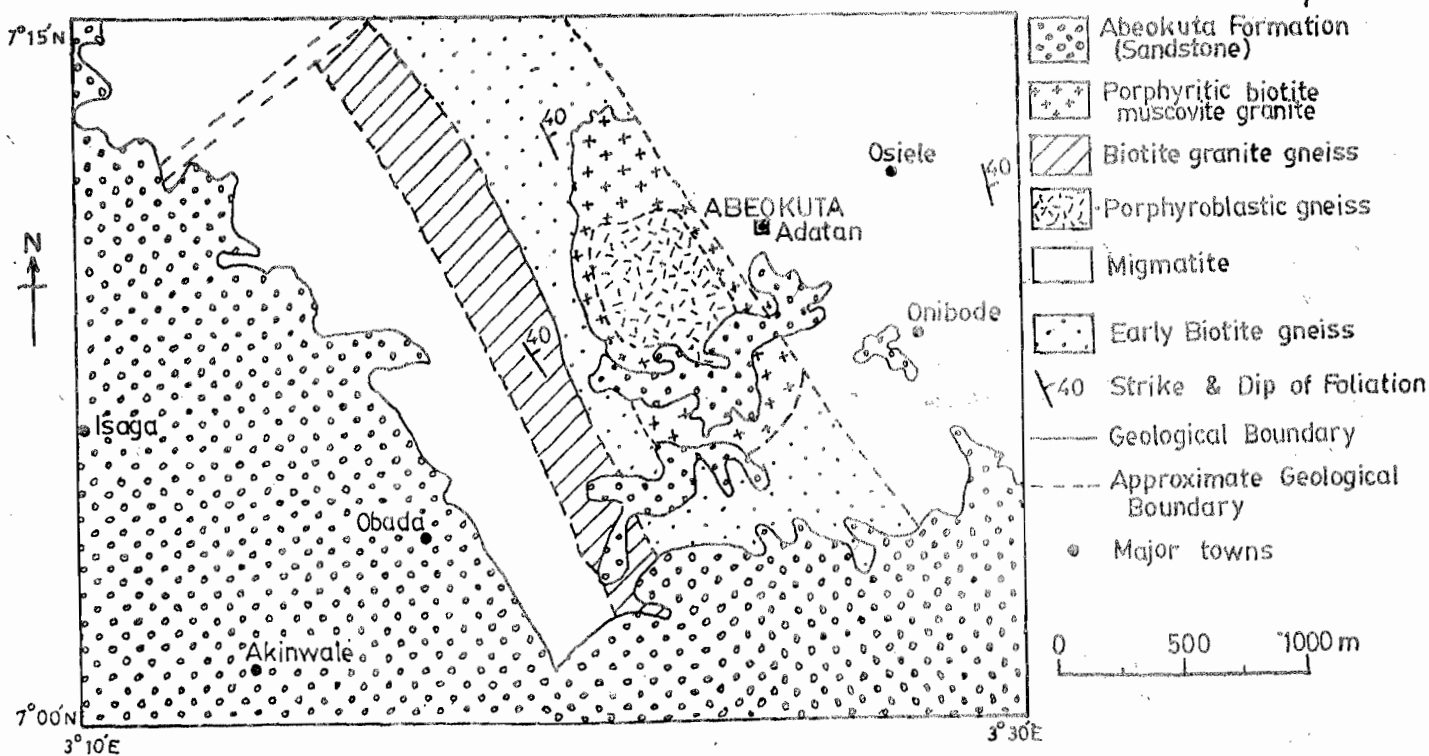


Fig. 2: Geological map of Abeokuta area (modified after Jones and Hockey 1964).

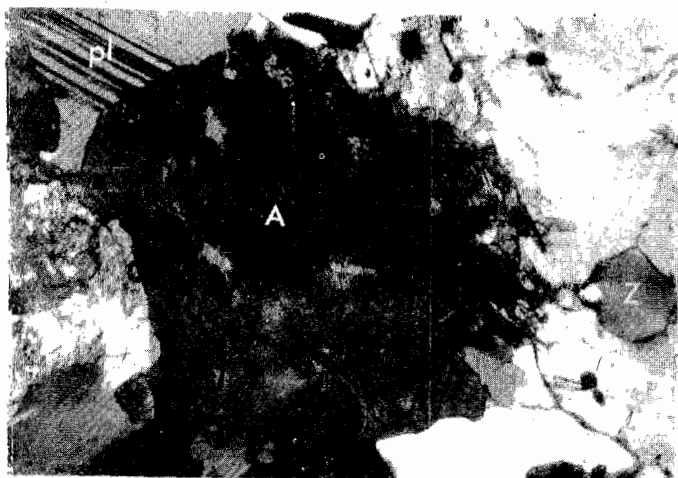


Fig. 3: Photomicrograph of the biotite granite gneiss showing ferrokaersutite amphibole (A), plagioclase (pl) and zircon (Z). Crossed polars. x 2.5mm.

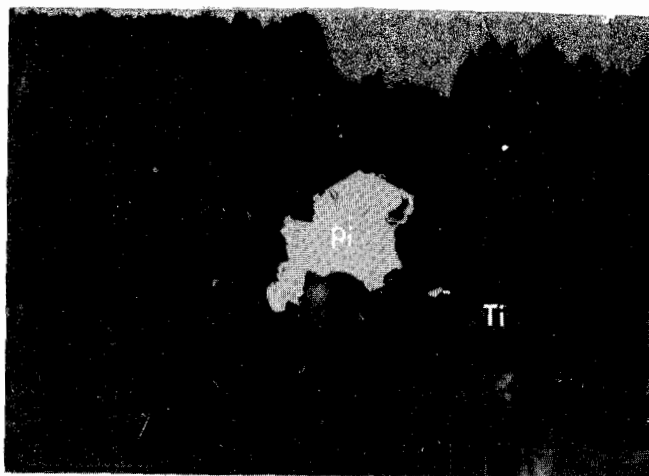


Fig. 4: Photomicrograph of the biotite granite gneiss showing inclusion of pyrite (Pi) in titanite (Ti). Crossed polars, oil immersion, longer edge of photo is 420µm.

calculated on the basis of three oxygens, is presented in Table 1. The chemical data show that the ilmenites are high in FeO (ca. 45%), TiO<sub>2</sub> (ca. 53%) and MnO (ca. 2.0%) contents, with low MgO (0.05%) and total absence of Al<sub>2</sub>O<sub>3</sub> (Table 1). V<sub>2</sub>O<sub>3</sub> content varies from 0.13 to 0.53%. This composition suggests that the protolith of the gneisses has igneous affinity.

The absence of Fe<sup>3+</sup> in the chemical composition of the ilmenite (Table 1) is attributed to an overall lack of oxidation in the parageneses. This reflects total reduction of the protolith during amphibolite facies metamorphism by the sulphides (pyrite, pyrrhotite

and chalcopyrite) present (Pinet and Smyth, 1985). Also, this could explain the absence of free hematite in the mineral assemblage. The Fe<sup>3+</sup> composition and the haematite content would have been higher if the rock is metasedimentary.

A distinguishing feature of the ilmenite in the Abeokuta granite gneiss is their high and variable MnO content (1.23-3.46%), which may be attributed to the mobilization of Mn into the ilmenite during metamorphism. Mole percent pyrrhotite (Mn), ilmenite (Fe<sup>2+</sup>) and geikielite (Mg) content for each of the ilmenites analysed are plotted in Fig. 5. The samples

Table 1: Chemical compositions (wt.%) of ilmenite in biotite granite gneiss of Abeokuta area.

	1	2	3	4	5	6	7	8	9	10
SiO <sub>2</sub>	-	-	-	-	-	-	-	-	-	-
TiO <sub>2</sub>	52.60	53.31	52.67	52.30	51.32	53.40	51.57	51.74	53.25	50.76
Al <sub>2</sub> O <sub>3</sub>	-	-	-	-	-	-	-	-	-	-
FeO	45.25	45.73	44.76	43.24	45.71	44.22	44.83	45.57	44.61	46.92
MnO	2.19	1.86	2.37	3.46	3.30	2.51	3.25	2.35	2.43	1.23
MgO	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05	0.04
V <sub>2</sub> O <sub>3</sub>	0.43	0.44	0.39	0.40	0.13	0.15	0.25	0.33	0.41	0.53
Total	100.5	1012.39	100.24	99.45	100.51	100.32	99.95	100.04	100.75	99.48

Structural formulae on the basis of 3 oxygens, for ilmenite

Si	-	-	-	-	-	-	-	-	-	-
Ti	0.993	0.998	0.997	0.998	0.967	1.011	0.965	0.981	1.003	0.967
Al	-	-	-	-	-	-	-	-	-	-
Fe <sup>2+</sup>	0.950	0.952	0.943	0.918	0.958	0.931	0.960	0.961	0.935	0.994
Mn	0.047	0.039	0.051	0.074	0.070	0.054	0.068	0.050	0.052	0.026
Mg	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
V	0.008	0.009	0.008	0.008	0.003	0.003	0.005	0.007	0.008	0.011
Total	2.000	2.000	2.001	2.000	2.000	2.001	2.000	2.001	2.000	2.000

Table 2: Chemical compositions (wt.%) of titanite in biotite granite gneiss of Abeokuta area.

	1	2	3	4	5	6	7	8	9	10
SiO <sub>2</sub>	30.47	30.70	30.95	31.33	31.84	30.75	29.96	31.20	30.88	31.56
TiO <sub>2</sub>	35.67	36.90	36.08	35.52	34.96	37.11	37.05	35.48	36.22	35.34
Al <sub>2</sub> O <sub>3</sub>	3.52	2.62	2.70	2.87	3.41	3.05	3.58	2.64	3.71	2.55
FeO	0.09	0.64	0.82	0.79	0.55	0.69	0.72	0.68	0.95	0.80
MnO	0.08	0.09	0.08	0.06	0.10	0.05	0.07	0.09	0.07	0.08
CaO	29.23	29.49	29.54	28.91	28.85	27.91	28.05	29.10	28.62	28.95
V <sub>2</sub> O <sub>3</sub>	0.29	0.31	0.33	0.25	0.30	0.28	0.26	0.34	0.25	0.20
Total	100.16	100.75	100.50	99.73	100.01	99.84	99.69	99.53	100.70	99.48

Structural formulae on the basis of 5 oxygens, for titanite

Si	0.974	0.980	0.988	1.007	1.018	0.992	0.967	1.005	0.983	1.017
Ti	0.858	0.886	0.867	0.859	0.840	0.900	0.899	0.860	0.867	0.857
Al	0.133	0.099	0.102	0.109	0.128	0.116	0.136	0.100	0.139	0.097
Fe <sup>2+</sup>	0.024	0.017	0.022	0.021	0.015	0.019	0.019	0.018	0.025	0.022
Mn	0.002	0.002	0.002	0.002	0.003	0.001	0.002	0.003	0.002	0.002
Ca	1.002	1.008	1.011	0.996	0.988	0.965	0.970	1.005	0.977	1.000
V	0.007	0.008	0.008	0.006	0.008	0.007	0.007	0.009	0.006	0.005
Total	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	2.999	3.000

form a cluster around the FeTiO<sub>3</sub> peak of pure ilmenite (90 mol.%). The pyrophanite content is about 5mol.%, while MgTiO<sub>3</sub> is averagely 1mol.%. Such pure ilmenites are characteristic of igneous progenitor.

#### Titanite

Grey, wedge-shaped prismatic crystals of titanite, otherwise known as sphene identified in the polished section of the Abeokuta granite gneiss were

analysed. The chemical formula of titanite is calculated on the basis of 5 oxygens (Table 2). Na and K were excluded from the formulae because of their presence in negligible amounts. Fe in the titanite studied is considered as only Fe<sup>2+</sup>. The Fe<sup>2+</sup> is suggested to occupy the Ca-dominated site. These support the view of Coombs et al., (1976). Ti was also assigned to the Si-populated tetrahedral site in line with the views of Hollibaugh and Rosenberg (1983).

The titanites analysed shows the presence of considerable amount of Al, small amounts of Fe and Mn. Al<sub>2</sub>O<sub>3</sub> ranges from 2.62 to 3.58%, FeO 0.64 to 0.95% and MnO from 0.05 to 0.09% (Table 2). According to

Higgins and Ribbe, (1976), the occurrence of Al and Fe contents in the structure of titanite is mainly attributed to the substitution of Ti by Al and Fe. The titanite is also enriched in V<sub>2</sub>O<sub>3</sub> to the tune of 0.29 to 0.31% (Table 2).

The analysis of titanite (Table 2), were plotted with data from the literature in an Al – Ti – Fe<sup>2+</sup>+Fe<sup>3+</sup> triangle (Fig. 6). Titanites of the Abeokuta granite gneiss concentrate in one region, which shows Al content of between 9 and 14% (Fig. 6, Field A). Titanites from some metamorphic rocks, such as pumpellyite-bearing graywackes (Coombs et al., 1976) and basalts (Nystrom, 1982) lie between 5 and 10% Fe<sup>2+</sup>+Fe<sup>3+</sup> (Fig. 6, Field B). The titanites generally contain higher

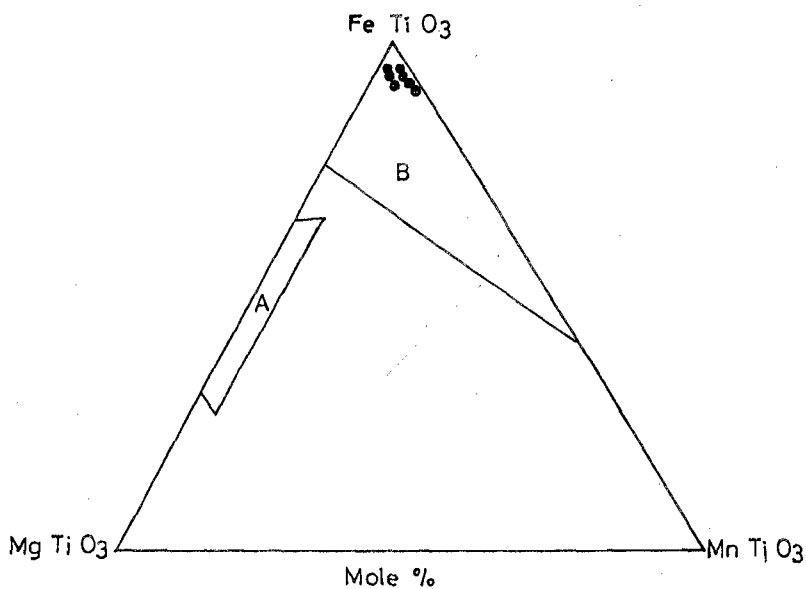


Fig. 5: FeTiO<sub>3</sub> – MgTiO<sub>3</sub> – MnTiO<sub>3</sub> triangular plot comparing the ilmenite composition in granite gneiss of Abeokuta area with those of carbonatites and kimberlites (Mitchell, 1979). (A) – Kimberlites field. (B) – Acid-basic igneous rocks, carbonatites and lamprophyres field.

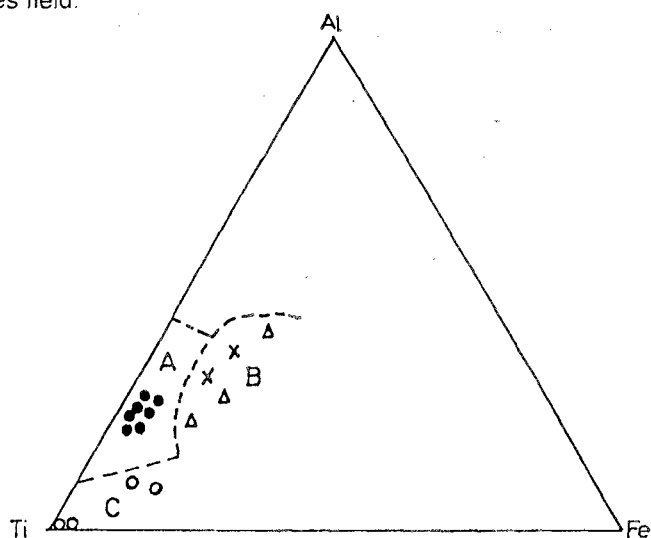


Fig. 6: Plots of titanite in an Al – Ti – Fe triangle.

- – Titanite from granite gneiss of Abeokuta area (Field A, This study).
- x – Titanite from pumpellyite bearing greywackes ( Field B, Combs et al., 1976).
- ▲ – Titanite from basalts ( Field B, Nystrom, 1982).
- – Titanite from felsic igneous rocks and pegmatite ( Field C, Deer et al., 1982).

amounts of Al and/or Fe than those of the granite gneiss of Abeokuta area. Analysis of four titanite crystals in felsic igneous rocks and pegmatite (Deer et al., 1982), show higher Ti and lower Al compared to the other parageneses (Fig. 6, Field C). The intermediate position occupied by the titanite of the biotite granite gneiss of Abeokuta area, on the triangular diagram, indicate that the rock probably evolved through an igneous process, with probable crustal contamination, in line with the views of Bolarinwa, (2001) and Elueze and Bolarinwa, (2004).

## DISCUSSION AND CONCLUSIONS

Mitchel, (1979) and Gaspar and Wyllie, (1984) attempted using ilmenite compositions to refute or support a kimberlite-carbonatite relationship, respectively. Their arguments are based on the compositions of ilmenite assigned to kimberlites in terms of  $\text{FeTiO}_3 - \text{MgTiO}_3 - \text{MnTiO}_3$ . As shown in Fig. 5, the Mn contents in kimberlitic ilmenites (Field A) are very low. Also, the Fe contents are somewhat lower than those of ilmenite derived from acid and basic igneous rocks, carbonates and lamprophyres (Field B).

Ilmenites in the biotite granite gneiss of Abeokuta area (Fig. 5, Field B) show considerable overlap with the fields for ilmenites in acid and basic igneous rocks, carbonates and lamprophyres (Field B, Mitchel, 1979). However, plots of  $\text{TiO}_2$  against MgO for the discrimination of the ilmenites into typical rock compositional fields of Haggerty (1976) show that the ilmenites fall near the field of tholeiitic rocks (Fig. 7, Field B). This is consistent with the dioritic nature

of the rock (Table 3, Fig. 8). Also, most of the ilmenite samples from Abeokuta area possess higher Ti content than what obtains in the compositional fields of Haggerty, (1976) as shown in Fig. 7. This can be attributed to crustal contamination (Elueze and Bolarinwa, 2004).

Tompkins and Haggerty (1985) noted that because the majority of ilmenites are not melt-derived, it is invalid to draw any genetic or petrological inferences between kimberlites and carbonatites based on ilmenite compositions of diverse origin. They observed that the compositional fields overlap and that genetic implications may be tenuous. They stated further that the only valid conclusion is that both kimberlitic and carbonatitic melts are charged with late stage silicate-incompatible elements including Nb, Zr, Mn and to some extent Ti, which can be used as petrogenetic indicators in the rock formed from the melt. It is worthy of note that Nb (ca. 31ppm), Zr (ca. 507ppm) and Ba (ca. 963ppm) are enriched in the biotite granite gneiss of Abeokuta area (Table 3). The wide range of variations in the composition of these trace elements, have been attributed to a mixture of igneous and sedimentary input (Elueze and Bolarinwa, 2004).

Ti, Si and Ca are needed for the formation of titanite. The association of titanite with titanium-bearing minerals, such as Ti-rich biotite and hornblende, and also with Fe-Ti oxide of rutile (Gorbatshev, 1962; Merino, 1975; Morad and Aldahan, 1982, 1985 and 1986) indicates that the major source of Ti is through mobilization from these minerals. The major sources of

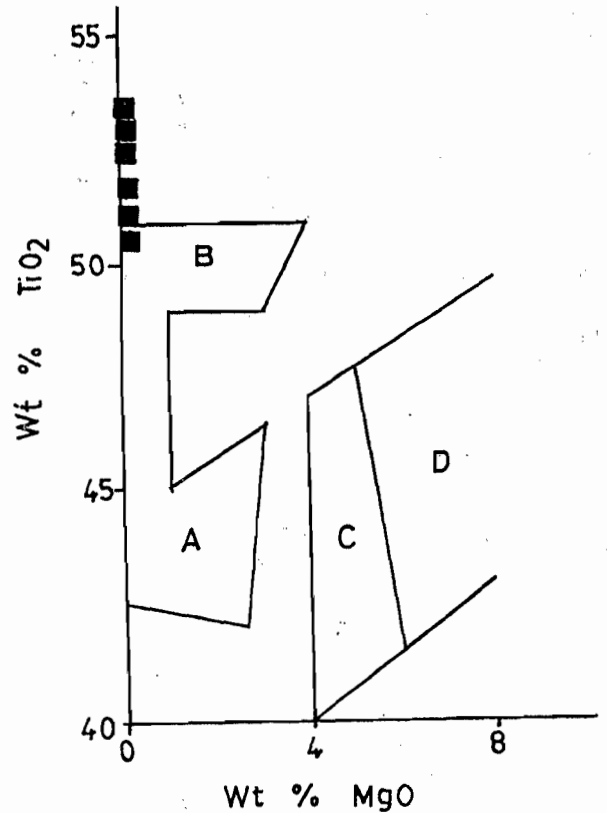


Fig. 7: Plot of the Abeokuta ilmenites on the  $\text{TiO}_2$  versus MgO diagram of Haggerty (1976).

- - Abeokuta ilmenites, Ilmenite from
- (A) - acid rocks, (B) - tholeiitic rocks,
- (C) - basanitic rocks and (D) - kimberlites.

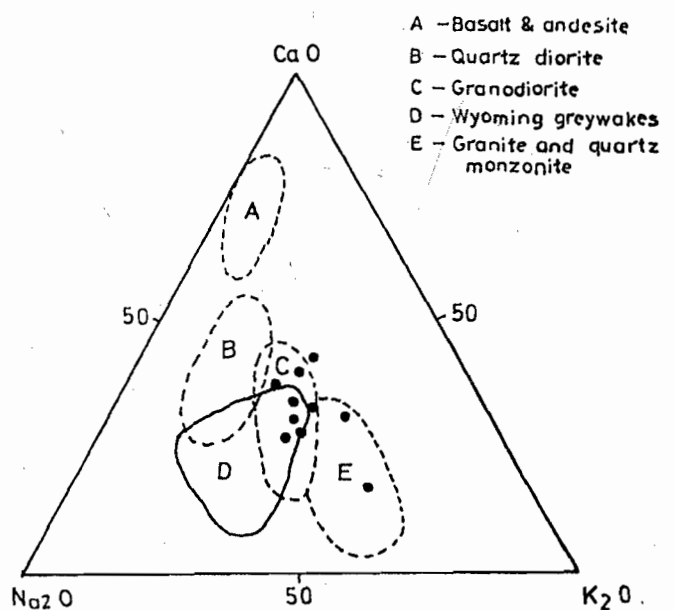


Fig. 8: CaO - NaO -  $\text{K}_2\text{O}$  diagram of granite gneiss from Abeokuta area (after Condie, 1967)

Table 3: Whole rock chemical compositions of the biotite granite gneiss.

	1	2	3	4	5	6	7	8	9	10	Mean	Range
SiO <sub>2</sub>	57.90	58.45	68.80	59.82	68.90	66.50	65.78	68.26	67.74	69.09	65.12	57.90-69.09
TiO <sub>2</sub>	1.93	1.56	0.66	1.79	0.51	0.32	0.41	0.31	0.35	0.28	0.81	0.28-1.93
Al <sub>2</sub> O <sub>3</sub>	14.80	14.06	14.40	14.86	15.30	15.21	16.33	14.85	15.66	15.54	15.10	14.80-16.33
Fe <sub>2</sub> O <sub>3</sub>	10.30	8.79	4.89	9.34	3.24	4.23	3.86	3.18	4.01	3.23	5.51	3.18-10.30
MnO	0.16	0.14	0.08	0.12	0.04	0.08	0.09	0.06	0.07	0.06	0.09	0.06-0.16
MgO	1.92	1.76	1.34	1.56	0.50	0.86	0.72	0.67	0.85	0.61	1.08	0.61-1.92
CaO	5.01	4.45	2.35	5.00	1.78	3.25	3.68	3.96	3.04	3.20	3.57	3.04-5.01
N <sub>2</sub> O	3.00	3.56	3.09	3.02	3.07	3.84	3.75	3.84	3.26	3.09	3.35	3.00-3.84
K <sub>2</sub> O	3.65	5.85	2.85	3.39	5.81	3.78	3.36	3.04	3.19	3.42	3.83	3.04-5.85
P <sub>2</sub> O <sub>5</sub>	0.67	0.56	0.13	0.22	0.24	0.26	0.35	0.26	0.33	0.27	0.33	0.26-0.67
H <sub>2</sub> O	0.11	0.15	0.32	0.14	0.07	0.10	0.15	0.07	0.11	0.05	0.13	0.05-0.15
LOI	0.25	0.58	0.76	0.39	0.46	0.75	0.82	0.65	0.59	0.36	0.56	0.25-0.48
<b>Total</b>	<b>99.70</b>	<b>99.91</b>	<b>99.68</b>	<b>99.65</b>	<b>99.92</b>	<b>99.18</b>	<b>99.30</b>	<b>99.15</b>	<b>99.10</b>	<b>99.15</b>	<b>99.48</b>	

## Trace elements (ppm)

	1	2	3	4	5	6	7	8	9	10	Mean	Range
Nb	29	38	11	40	17	33	36	44	30	35	31	29-44
Zr	770	655	298	507	325	725	688	279	526	296	507	253-770
Y	54	52	20	46	20	32	39	52	48	44	41	20-54
Sr	261	306	468	235	128	136	364	148	432	279	276	121-468
Rb	154	277	95	214	309	208	255	306	274	168	226	154-309
Pb	22	25	21	33	36	25	28	34	32	35	29	22-36
Ga	25	24	20	30	25	28	32	26	30	26	27	25-32
Zn	110	88	68	106	71	32	45	39	36	47	64	32-110
Cu	31	25	<5	17	8	16	21	26	24	20	19	16-31
Ni	92	66	31	82	23	24	20	18	25	16	40	16-92
Co	35	30	25	24	11	28	25	23	25	24	25	23-35
Cr	11	33	51	48	11	30	42	33	38	26	32	11-51
V	78	46	75	35	14	79	75	80	75	83	64	14-83
Ba	784	835	1587	966	839	745	808	963	856	1249	963	784-1587
Sc	19	12	9	10	<5	25	14	21	18	23	15	19-25

Si and Ca come from the calcic plagioclase feldspars and amphiboles. Microprobe analysis of the amphibole present in the biotite granite gneiss shows that it is the calcium-rich ferrokaersutite (Fig. 3) from which Si and Ca may be mobilized to form titanite. The chemistry of the titanite studied compare fairly well with titanite from basalts (Nystrom, 1982, Fig. 6). The Fe content is however lower than those of basalts (Fig. 6). The low Fe, Mg and Mn contents of the titanite suggest felsic igneous origin. This supports the view of Rahaman and Ocan (1978) that most of the granite gneiss in the Nigerian basement complex is intrusive. The relatively higher Al of the Abeokuta titanite compared to that of igneous rocks and pegmatite of Deer et al., (1982; Fig. 6) may be due to crustal contamination.

On the basis of the chemical compositions of the ilmenites and titanites in the biotite granite gneiss of Abeokuta area and its whole-rock geochemistry, a magmatic origin involving partial melting, which was probably augmented by crustal contamination is proposed. The primary ilmenite and titanite compositions may have been altered due to post-crystallization deformation associated with recrystallization of the rock, as evident in the alignment of the ilmenite and titanite crystals (Fig. 4). Thus, ilmenite, titanite and other

opaque minerals composition could serve as petrogenetic discriminator, particularly in a polymetamorphic terrain, such as the Nigerian basement complex.

## ACKNOWLEDGEMENTS

This research work was completed through a DAAD short-term fellowship in the Mineralogy - Petrology Institute, Georg-August University, Goettingen. The author is very grateful to Prof. (Dr.) Arno Mücke and Dr. F. Farshad for hospitality and invaluable assistance with electron microprobe analysis. Thanks to the reviewers for their invaluable suggestions, which improved the manuscript.

## REFERENCES

- Bolarinwa, A. T., 2001. Compositional characteristics and economic potentials of lateritic Profiles over basement and sedimentary rocks in Ibadan - Abeokuta area southwestern Nigeria. Unpubl. Ph.D. Thesis, University of Ibadan, Nigeria, 255p.

- Coombs, D.S., Nakamura, Y. and Vuagnat, M., 1976. Pumpellyite - actinolite facies schist of the Taveyanne Formation near Loeche, Valais, Switzerland. *J. Petro.* 17: 440-471.
- Deer, W. A., Howie, R. A. and Zussman, J., 1982. Rock-forming minerals, IA: Orthosilicates, Longman, London, 919p.
- Elueze, A. A., 1982a. Geochemistry of the Ilesha Granite gneiss in the basement complex of southwestern Nigeria. *Precambrian Research*, 19: 167-177.
- Elueze, A. A., 1982b. Petrochemistry of Precambrian gneisses and migmatites in the western part of Nigeria. *Revista Brasileira de Geociencias* 12 (1-3): 301-306.
- Elueze, A. A and Bolarinwa, A. T., 2004. Petrochemistry and petrogenesis of Granitic gneisses of Abeokuta area, southwestern Nigeria. *Jour. Min. Geol.* 40 (1).
- Gaspar, J. C. and Wyllie, P. J., 1984. The alleged kimberlite carbonatite relationship: Evidence from ilmenite and spinel from Premier and Wesselton mines and the Benfontein Sill, South Africa. *Contrib. Mineral. Petrol.* 85: 113-140.
- Gorbatshev, R., 1962. Secondary sphene in the Malar sandstone. *Geol. Foren. Stockholm Forh*, 84: 32-37.
- Haggerty, S. E., 1976. Opaque mineral oxides in terrestrial igneous rocks. D. Rumble (ed) *Oxide Minerals short course notes*. Mineral Soc. Am. 3: 101-300.
- Higgins, J. B. and Ribbe, P. H., 1976. The crystal chemistry and space groups of natural and synthetic titanites. *Amer. Miner.* 61: 878-888.
- Hollabaugh, C. L. and Rosenberg, D. E., 1983. Substitution of Ti for Si in titanite and new end-member cell dimensions for titanite. *Amer. Miner.* 68: 177-180.
- Jones, H.A. and Hockey, R.D., 1964. The Geology of part of southwestern Nigeria. *Geol. Surv. Nigeria Bull.* 31, 101p.
- Merino, E., 1975. Diagenesis in Tertiary sandstones from Kettleman North Dome California. I Diagenetic Mineralogy. *J. Sediment. Petrol.* 45: 320-336.
- Mitchel, R. H., 1979. The alleged kimberlite carbonatite relationship: Additional contrary mineralogical evidence. *Am. Jour. Sci.* 279: 570-589.
- Morad, S. and Aldahan, A. A., 1982. Authigenesis of titanium minerals in two Proterozoic sedimentary rocks from southern and central Sweden. *Jour. Sed. Petrol.* 52: 1295-1305.
- Morad, S. and Aldahan, A. A., 1985. Leucoxene-calcite-quartz aggregates in sandstones and the relation to decomposition of sphene. *N. Jb. Miner. Mh.* 1985: pp. 458-468.
- Morad, S. and Aldahan, A.A., 1986. Alteration of detrital Fe-Ti oxides in sedimentary rocks. *Geol. Soc. Amer. Bull.* 97: 567-578.
- Nystrom, J. O., 1982. Extent of host rock alteration - A control of pumpellyite composition in burial metamorphosed rocks from central Sweden. Unpubl. Ph.D. Thesis, Univ. Stockholm.
- Pinet, M. and Smith, D.C., 1985. Petrochemistry of opaque minerals in eclogites from the Western Gneiss Region, Norway. 1. Petrology of the oxide microassemblages. In: D.C. Smith, G. Franz and D. Gebauer (Guest-Editor), *Chemistry and Petrology of Eclogites*. *Chem. Geol.*, 50: 225-249.
- Rahaman, M. A., 1988. Recent advances in the study of the basement complex of Nigeria. In: *Precamb. Geol. Nig., Geol. Surv. Nig. Publication*, pp.11-43.
- Rahaman, M. A. and Ocan, O., 1978. On relationships in the Precambrian migmatite gneiss of Nigeria. *Jour. Min. Geol.* 15 (1): 23-32.
- Tompkins, L. A. and Haggerty, S. E., 1985. Groundmass oxide minerals in the Koidu kimberlite dikes, Sierra Leone, West Africa. *Contrib. Mineral. Petrol.* 91: 245-263.
- Ulrych, J. and Lang, M., 1985. Accessory pyrophanite in granite and manganojacobsite in dioritic amphibole from the Manicaragua zone, central Cuba. *Chem. Erde.* 44: 273-280.