International Journal of Geosciences, 2012, 3, 1065-1073
http://dx.doi.org/10.4236/ijg.2012.35107 Published Online November 2012 (http://www.SciRP.org/journal/ijg)

U-Pb Geochronology of the Jebba Granitic Gneiss and Its Implications for the Paleoproterozoic Evolution of Jebba Area, Southwestern Nigeria

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Received July 10, 2012; revised August 22, 2012; accepted September 21, 2012

ABSTRACT

Jebba area southwestern Nigeria forms part of the Nigerian basement complex which lies in the Neoproterozoic Pan-African mobile belt. It is underlain by several lithological units among which is a polydeformed granitic gneiss. This rock has been dated by LA-ICP-MS yielding a concordant U-Pb zircon age of 2207 ± 20 Ma indicating the crystallization age of the granite protolith. This early Rhyacian age and its affinity with within-plate granites indicates emplacement during crustal extension and rifting preceding the main phase of the Eburnean orogeny. The strong, early, shear fabric, S_1, in the rock is interpreted to be also of Paleoproterozoic age i.e. imprinted during the Eburnean orogeny. The Jebba granitic gneiss is thus correlatable with the widely abundant Paleoproterozoic granitic magmatism now represented by many orthogneisses and documented in other parts of southwestern Nigeria, the West African craton, the Borborema Province, the Gurupi Belt, Sao Luis craton and Sao Francisco craton in Brazil.

Keywords: Jebba Area Nigeria; Granitic Gneiss; U-Pb Dating; Paleoproterozoic; Eburnean Orogeny

1. Introduction

The Nigerian basement complex forms the southern part of the Trans-Saharan Pan-African mobile belt [1] of Neoproterozoic (500 - 750 Ma) age situated between the Archean-Paleoproterozoic blocks of the West African craton to the west, the East Saharan block to the east and the Congo craton to the southeast (**Figure 1**). This basement complex comprises gneisses, migmatites and supracrustals which have yielded Archean and Proterozoic ages [2,3] and bears the imprints of Liberian (*ca* 2700 Ma), Eburnean (*ca* 2000 Ma) and Pan-African (*ca* 600 Ma) orogenic events [3-9]. The polyphasal nature of the deformation and metamorphism of the Nigerian basement complex rocks has been recognized and documented by several workers e.g. [7,10-13]. Several orthogneisses of Paleoproterozoic age have been documented from some parts of southwestern Nigeria including Ibadan granitic gneiss-Rb/Sr isochron age of 2206 ± 70 Ma [4], Ile-Ife grey gneiss-U-Pb age of 2.3 Ga [9], Igbeti augen gneiss-Rb/Sr isochron age of 1.9 Ga [14], Kabba granodioritic gneiss-U-Pb age of 2103 ± 8 Ma [2].

However, in Jebba area, lack of geochronological data has not allowed the different rock suites related to the different orogenic cycles to be distinguished. In particular, the age relations of the various rock units in the area were not known and it was not possible to constrain the lithotectonic evolution of the area on a geochronogical basis. Of critical importance are the age relations of the several generations of granitic rocks showing a wide range in terms of tectonic deformation and development of structural fabrics that are exposed in the area. In particular, the ages of the strongly foliated and folded granitic orthogneisses and their stratigraphic position in relation to the other rock units and to the recognised orogenic events affecting the Nigerian basement complex has been unclear.

This paper reports the first data on the geochronology of the leucocratic Jebba granitic gneiss, a very strongly deformed and folded unit in the area and examines its significance in the Paleoproterozoic crustal evolution of the area and also discusses it correlation with other parts of the Nigeria basement complex and western Gondwana, especially Brazil.

2. Geology of Jebba Area

Jebba area lies at the northern margin of the southwestern sector of the Nigerian basement complex (**Figure 2**). The area is underlain by metasedimentary and metaigneous rocks which have undergone polyphase deformation and metamorphism in the range of greenschist to amphibolite

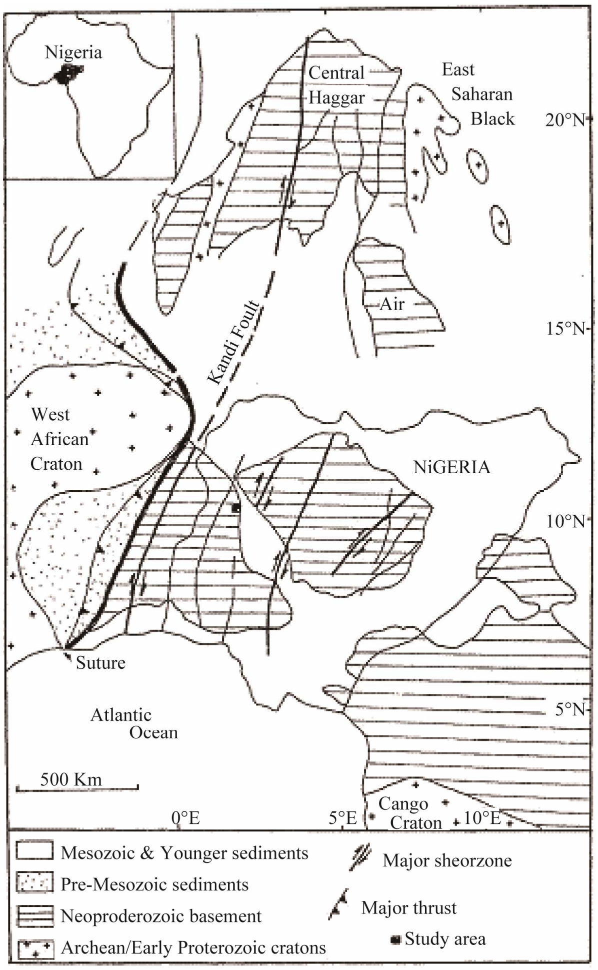


Figure 1. Index map showing the location of Jebba area, Nigeria within the Neoproterozoic trans-saharan mobile belt (after Ferre *et al*., 2002).

facies [13]. These rocks have been intruded by largely undeformed granitic rocks of probable Neo-Proterozoic age emplaced during the Pan-African orogeny. Four lithostratigraphic units have been recognized in Jebba area (**Figure 2**). In the east is an N-S trending belt of quartzofeldspathic gneiss with local quartzofeldspathic veining which contains a thick, intercalated quartzite. This gneiss is bounded on the west by an N-S belt of granitic gneiss. West of this is a metagreywacke unit with intercalated amphibolites bands, to the west of this is a very thick sequence of quartzites which locally contain preserved cross-stratification. The western and eastern bodies of quartzite are locally pebbly. Quartz mica schists occur in the far west. These metamorphic rocks have been intruded by largely undeformed granitic rocks ranging from porphyritic to medium-grained varieties.

Five phases of deformation have recognized in the metamorphic rocks of the area. These involved foliation development, several generations of folding as well as ductile shearing and brittle faulting [13]. The boundary between the granitic gneiss and the metagreywacke is a tectonic one defining a ductile thrust with a top to the southeast transport direction [13].

This paper reports geochronological data on this granitic gneiss and assesses their implications for the tectonic evolution of Jebba area.

3. Petrography of the Jebba Leucocratic Granitic Gneiss

This is a leucocratic, medium-grained strongly foliated and lineated rock containing plagioclase (40%), quartz (25%), microcline (18%), muscovite (15%) and a few biotite grains. Muscovite forms overgrowths on muscovite as well as on the opaque mineral suggesting some replacement of biotite by muscovite accompanied by the release of the ore mineral. Accessory minerals are magnetite, apatite, titanite, zircon, chlorite, sericite and epidote. The very strong planar fabric is defined by the alignment of muscovite and quartz ribbons as well as by opaque mineral (magnetite) strewn along the foliation.

The granitic gneiss is also locally marked by also a very strong linear fabric—a stretching lineation—defined by quartz and feldspar grains plunging gently to the NNW [13]. Locally, the granitic gneiss contains very thin, elongate slivers (xenoliths) of dark, schistose material believed to be derived from the preexisting country rock.

4. Geochemistry of the Granitic Gneiss

The chemical compositions of seven samples of the granitic gneiss obtained by X-Ray Fluorescence spectrometry are presented in **Table 1**. Analytical methods and precision are as described by [15].

4.1. Major Elements

The rock classifies as a granite on the classification diagram of [16] (**Figure 3(a)**). It is a highly siliceous rock with SiO_2 contents higher than 75%. Total iron as Fe_2O_3 contents range from 2.53% to 3.06%. MgO and CaO contents are very low, less than 0.20%, and 1%, respectively. On the K_2O versus SiO_2 plot after [17] it plots as a high-K calc-alkaline granite (**Figure 3(b)**) and in the calc-alkaline field in the AFM triangular diagram (**Figure 4(a)**). The granitic gneiss is slightly peraluminous in the molecular Al_2O_3/CaO + NaO + K_2O versus SiO_2 diagram (**Figure 4(b)**) and ferroan (**Figure 4(c)**) in the Fe_2O_3t/ Fe_2O_3t + MgO) versus SiO_2 diagram of [18].

4.2. Trace Elements and Tectonic Classification

The rock contains appreciably higher concentrations of the high field strength elements e.g. Zr, Nb and Y and the heavy rare-earth elements e.g. La Ce and Nd. On the Nb versus Y tectonic setting discrimination diagram after [19]

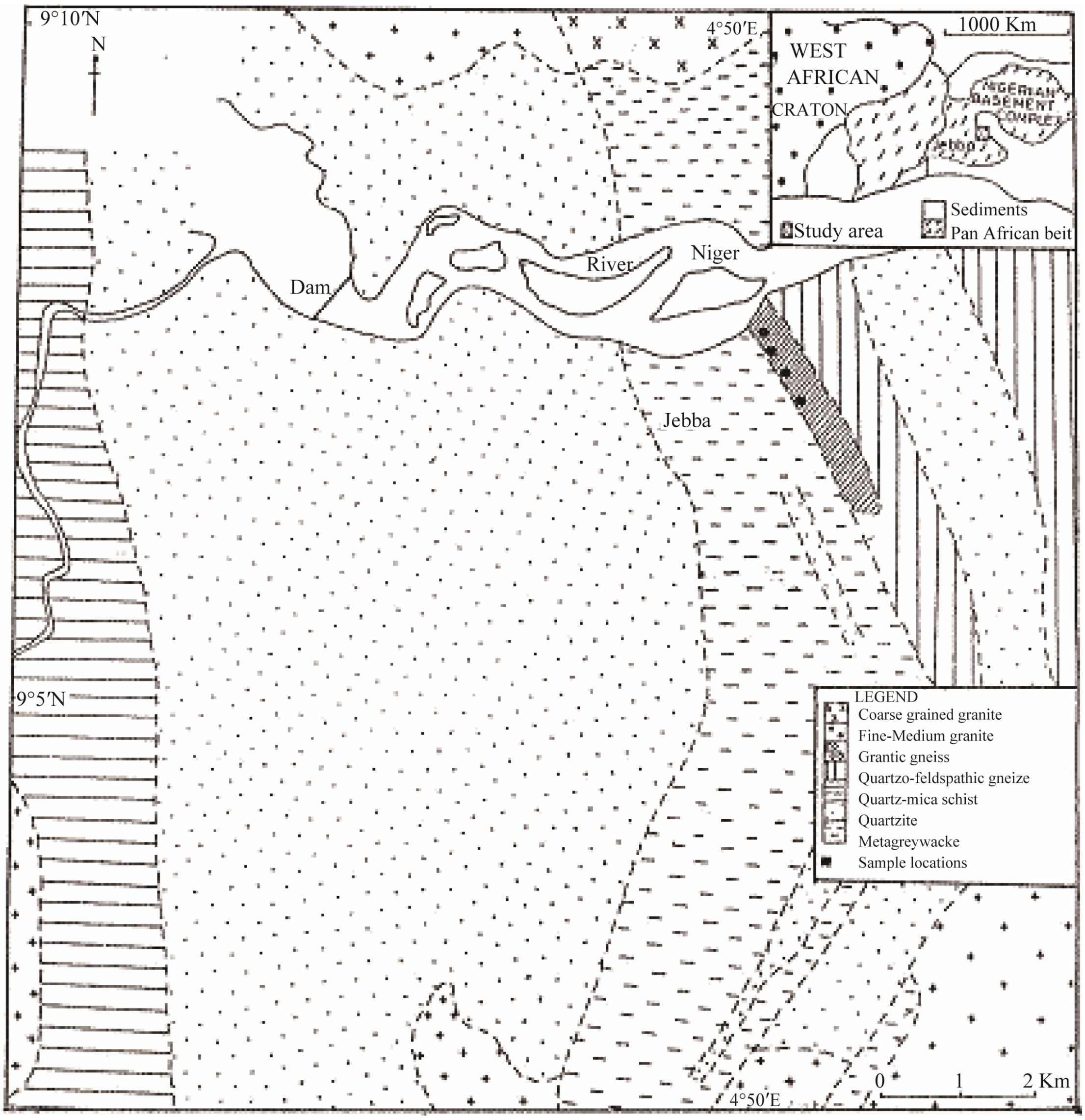


Figure 2. Geological map of Jebba area.

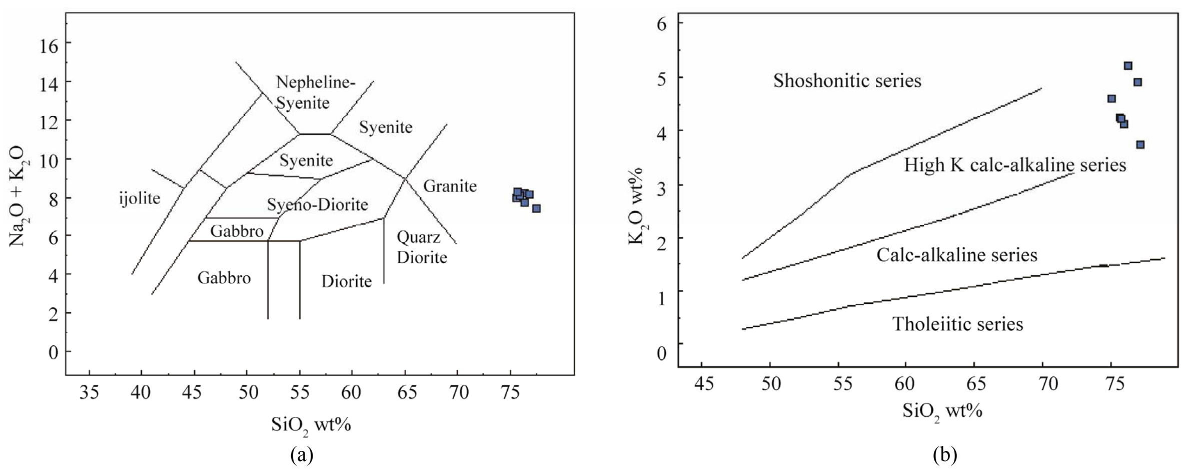


Figure 3. (a) Chemical classification of the rocks after cox *et al*. (1979); (b) Classification of the granitic gneiss after peccerrillo and taylor (1976).

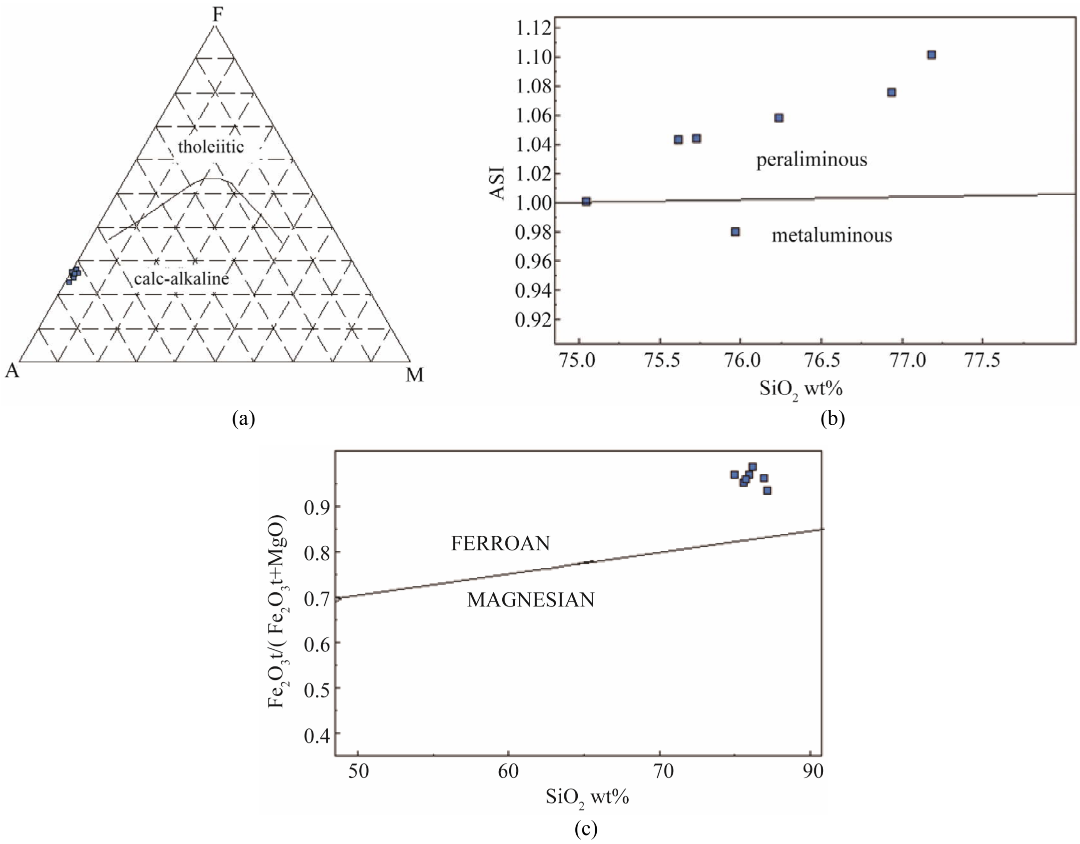


Figure 4. (a) AFM diagram shwoing the calc-alkaline classification of the gneiss; (b) ASI versus SiO_2 plot indicating the peraluminus character of the rock; (c) $Fe_2O_3t/(Fe_2O_3t + MgO)$ versus SiO_2 plot shwwing the ferroan nature of the gneiss after Frost *et al*. (2001).

(**Figure 5(a)**) the granitic gneiss plots in the within-plate field. This is also supported by the plot of the rock in the Rb versus Nb+Y diagram (**Figure 5(b)**).

Thin sheets of amphibolite intercalated with the metagreywacke in the area also have chemical characteristics of within-plate basalts [20] suggesting that they were emplaced in an extensional tectonic environment. The protoliths of the granitic gneiss and the amphibolite were therefore products of bimodal magmatism associated with intracontinental rifting [20].

5. Zircon Morphology and Internal Features

Zircon grains from the granitic gneiss are largely squat-shaped with one end broken and are characterized by fractures (**Figure 6**, BSE image). The grains also exhibit well-developed oscillatory (concentric) growth zoning (**Figure 6**, CL image) indicative of originally igneous zircons [21]. The obtained average Th/U ratio (0.54) is also typical of zircons formed by igneous processes.

Geochronology

Zircons from this rock were analyzed by LA-ICP-MS technique in the Institute of Mineralogy and Crystallography of Bulgarian Academy of Sciences, Sofia, Bulgaria using a PerkinElmer ELAN DRC-e ICP-MS connected to the NWR/ESI UP-193FX ArF excimer laser ablation system. A cathodoluminescence (CL) and back-scattered electron (BSE) imaging of each selected zircon grain previously mounted in epoxy and finely polished were performed prior to the mass spectrometry measurements. The representative zircon selection was made from an initial sample set of more than 100 grains. All electron microscopy investigations were performed on the Zeiss EVO 25LS SEM. The main parameters of the LA-ICP-MS instrument set-up are described in **Table 2**.

The machine was calibrated and optimized to the proper U-Pb ratios at high signal sensitivity level by repeated measurements of GJ-1 natural zircon standard [22]. Another widely used LA-ICP-MS geochronology zircon reference material (Plesovice) was adopted for data verification purposes [23]. Each five sample unknowns were bracketed by two standard measurements both from GJ-1 and Plesovice performed under the same analytical conditions. The off-line data reduction code Iolite [24] was implemented for calculation and correction of the U-Pb ratios before final age calculation procedure was performed by Isoplot toolkit [25]. The ob-

Table 1. Chemical composition of Jebba granitic gneiss (major elements in wt%, trace elements in ppm).

	CT908	CT909	CT921	JBG4	JBG5	909B	8802
SiO_2	76.24	75.05	75.97	75.62	77.19	76.94	75.73
TiO_2	0.28	0.28	0.27	0.35	0.28	0.28	0.27
Al_2O_3	11.65	11.88	11.69	12.14	11.48	11.82	12.19
Fe_2O_3t	2.97	3.06	2.68	2.78	2.72	2.53	2.96
MnO	0.00	0.02	0.04	0.03	0.02	0.02	0.03
MgO	0.04	0.10	0.09	0.14	0.19	0.10	0.13
CaO	0.23	0.78	0.91	0.40	0.18	0.18	0.24
Na_2O	3.02	3.33	3.54	3.85	3.67	3.26	4.06
K_2O	5.20	4.60	4.12	4.23	3.75	4.90	4.22
P_2O_5	0.03	0.03	0.02	0.02	0.06	0.02	0.03
LOI	0.20	0.69	0.53	0.33	0.36	0.18	0.14
S	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	99.87	99.82	99.88	99.88	99.88	100.26	99.99
Ba	1487	1034	1371	1285	1114	1192	1344
Cr	19	19	17	16	14	13	17
Cu	6	2	6	1	1	1	1
Ga	17	17	17	19	20	18	18
Nb	15	14	13	14	16	15	13
Ni	4	5	3	4	4	4	4
Pb	24	25	31	21	15	19	15
Rb	157	140	127	126	124	154	118
Sr	74	110	119	95	78	80	92
Th	12	15	17	11	7	9	20
V	6	10	10	16	10	8	18
Y	61	61	50	48	54	64	56
Zn	50	67	92	51	85	77	50
Zr	284	320	264	329	315	321	147
La	67	62	75	64	30	47	137
Ce	118	160	180	137	95	98	289
Nd	63	59	55	57	33	44	93

Table 2. Instrument operating conditions and settings.

ICP-MS		Laser system	
Type	Quad in first zone	Type	ArF excimer
Mode	Standard	Wavelength	193 nm
Scanning regime	Peak jumping	Pulse duration	<5 ns
RF power	1400 W	Energy density	10.2 J/cm^2
Plasma gas flow rate	15 l/min	Output laser energy	6.2 Mj
Aux. gas flow rate	0.82 l/min	Focus conditions	At sample surface
Neb. gas flow rate	0.84 l/min	Repetition rate	5 Hz
Abl. gas flow rate (He)	0.92 l/min	Spot size	35 µm
Dwell times: ^{202}Hg, ^{204}Pb, ^{208}Pb, ^{232}Th ^{235}U, ^{238}U, ^{206}Pb, ^{207}Pb	 10 ms 20 ms 30 ms	Cell volume	30 cm^3

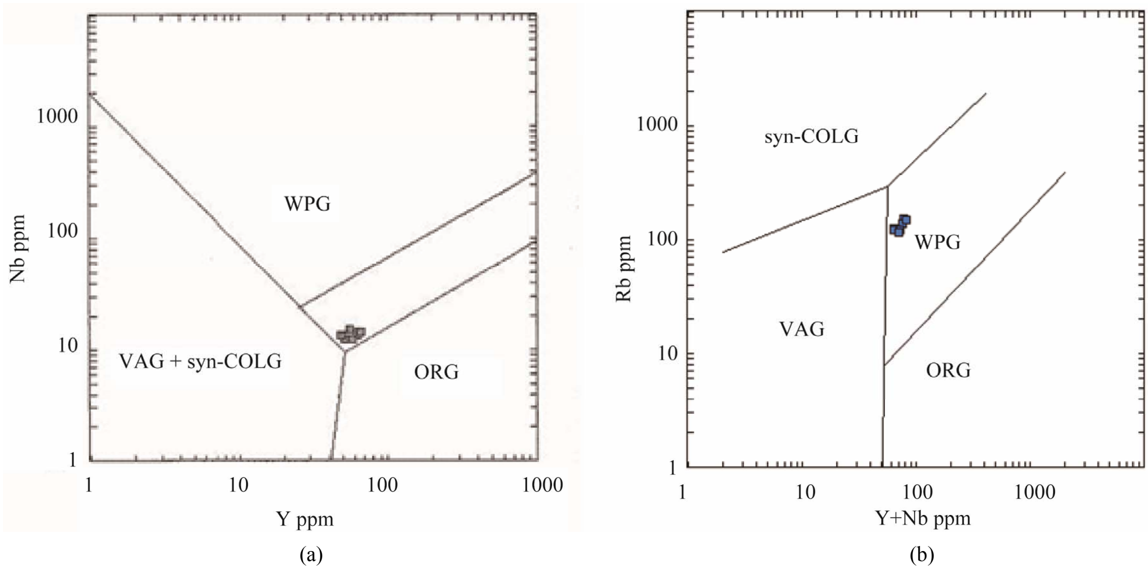


Figure 5. (a) Tectonic classification of the gneiss after Pearce *et al*. (1984); (b) Tectonic classification of the gneiss after Pearce *et al*. (1984).

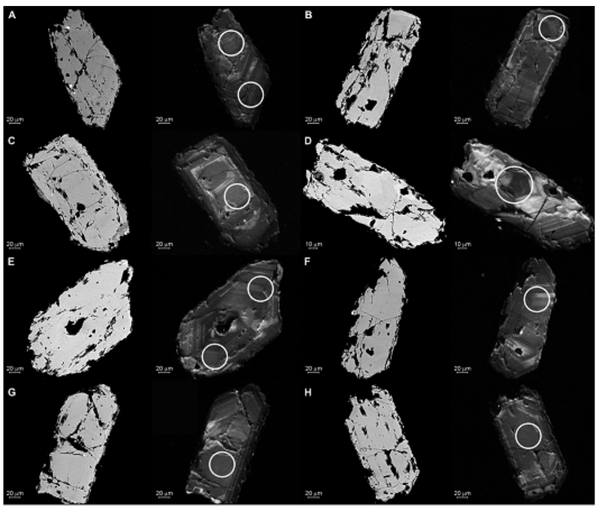


Figure 6. Back-scarrered electron images (left side) and cathodoluminescence images (right side) of the analyzed zircon grains (letter symbols as in Table 3); the ablation points are marked with circles.

tained isotope ratios are presented in **Table 3**. The concordia diagram and the weighted average ratio of the $^{206}Pb/^{238}U$ age are presented in **Figures 7(a)** and **(b)**, respectively.

The fifteen analyzed zircon grains give a concordant data cluster age of 2207 ± 20 Ma (**Figure 7(a)**) which can be interpreted to be the crystallization age of the granite protolith and therefore the time of emplacement of the granite. The above-mentioned concordant age has no record of the Pan-African imprint and so indicates that inspite of its Paleoproterozoic value and the relatively low level of concordance obtained, this particular isotopic system had remained closed since the Eburnean times. It has therefore not been affected by the Pan-African tectonothermal reworking.

6. Discussion

The age obtained, 2207 ± 20 Ma, for the emplacement/crystallization of the Jebba leucocratic granitic gneiss which is early Paleoproterozoic is slightly earlier than the time of the Eburnean orogenic cycle in southern Mali, West Africa, which has been established at between 2100 and 2070 Ma [26]. The gneissic Gondo granite in the Paleoproterozoic Bole-Nangodi belt, Ghana associated with Birimian rifting has been dated at 2187 Ma [27] and was emplaced prior to the Eoeburnean collision at *ca* 2150 Ma.

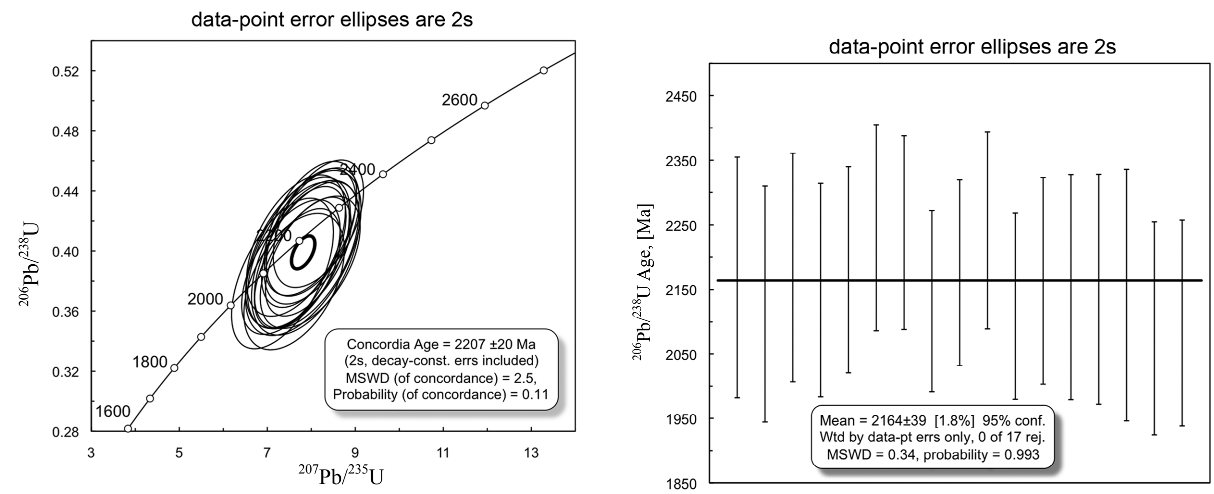
According to [28] ferroan calc-alkali granitoids are more likely to have formed from magmas derived from crustal melting or those that have incorporated large amounts of crustal melt. The geochemical characteristics of the Jebba granitic gneiss as well as its close association with amphibolites similar to icelandites [20] suggest its emplacement in a within-plate, continental, extensional tectonic regime and derivation from a magma that had crustal influence.

The heterogeneous nature of the Pan-African tectonothermal reworking in the Nigerian basement complex whereby Paleoproterozoic rocks have escaped isotopic resetting has been recognized by some workers, especially in southwestern Nigeria [2,3]. Geochronological data particularly U-Pb on zircons have documented the occurrence of several Paleoproterozoic orthogneisses in southwestern Nigeria including the Kabba granodioritic gneiss [2], dated 2103 ± 8 Ma.

The Paleoproterozoic was a very important crust-

Table 3. LA-ICP-MS data of 15 zircon grains (17 ablation points) from the Jebba granitic gneiss.

Ablation points	207/235	r.s.e. [%], (2σ)	206/238	r.s.e. [%], (2σ)	rho	206/238 age, [Ma]	r.s.e. 6/8, [Ma]
Grain-01	7.87024	10.3	0.39554	8.6	0.51	2168.3	186.5
Grain-02	7.34559	10.4	0.38502	8.6	0.55	2127.3	182.9
Grain-03-A (up)	7.70871	9.9	0.39708	8.1	0.53	2183.8	176.9
Grain-03-A (down)	7.65087	9.7	0.4035	7.7	0.5	2148.8	165.5
Grain-04-B	8.01039	8.9	0.40997	7.3	0.54	2180.4	159.2
Grain-05-C	7.98088	8.7	0.41499	7.1	0.51	2245.3	159.4
Grain-06-D	8.16117	8.3	0.4181	6.7	0.51	2237.9	151.1
Grain-07-E (up)	7.93274	8.1	0.39621	6.6	0.56	2131.4	140.7
Grain-07-E (down)	7.83037	8.1	0.40266	6.6	0.51	2175.9	143.6
Grain-08	7.99646	8.4	0.4124	6.8	0.5	2241.2	152.6
Grain-09	7.68639	8.4	0.38821	6.8	0.53	2124	144.4
Grain-10-F	7.97556	9.4	0.39251	7.4	0.53	2163.2	161.1
Grain-11	7.89206	9.9	0.39738	8.1	0.55	2153.4	174.4
Grain-12-G	7.69848	10.2	0.39899	8.3	0.52	2149.7	178.4
Grain-13	7.81764	11.1	0.39867	9.1	0.54	2140.9	194.8
Grain-14	7.61033	9.9	0.37961	7.9	0.47	2089.5	165.1
Grain-15-H	7.53674	9.8	0.3893	7.6	0.56	2097.9	159.4



(a) (b)

Figure 7. (a) U-Pb concordia diagram of the analyzed zircons; (b) Weighted average $^{206}Pb/^{235}U$ age of the zircons.

forming period of time marked by long-lived granitic magmatism in Africa and South America [29,30] as similar ages on orthogneisses and granitoids have been documented from the Nigerian basement complex, parts of the West African craton, the Zenaga inlier, Morrocco [31], the Borborema Province [32], Gurupi Belt, Brazil [33], Sao Luis craton, Brazil [34], and the Sao Francisco craton, Brazil [35], among others.

It has been suggested on the basis of geological and geochronological data that the Amazonian, West African, Sao Francisco, Congo cratons as well as the basements of the Araguaia, Borborema, Nigerian and Cameroon provinces were part of the Atlantica Supercontinent established at the end of the Trans-Amazonian/Eburnean orogenic cycle at *ca* 2000 Ma [35].

7. Conclusions

In Jebba area, Paleoproterozoic, early Rhyacian, granitoid magmatism was related to crustal extension and rifting prior to the main period of the Eburnean orogenic cycle. Early tectonic fabrics in the Jebba granitic gneiss defined by the strong planar preferred orientation of quartz, the feldspars, muscovite and opaque ores are probably the products of Eburnean deformation at mid amphibolite facies of metamorphism. The late tight to open recumbent folds of these early fabrics are probably due to the Neoproterozoic, Pan-African (*ca* 600 Ma) orogeny which also involved the emplacement of largely undeformed granitic rocks which intruded the metamorphic rocks in the area.

The Jebba granitic gneiss therefore forms part of the Paleoproterozoic basement that escaped remobilization during the subsequent Neoproterozoic Pan-African orogeny at *ca* 600 Ma and still retains the imprint of the Paleoproterozoic Eburnean orogeny at *ca* 2000 Ma.

8. Acknowledgements

We acknowledge the assistance of Prof. J. A. Winchester and Mr D. Emley with XRF geochemical analysis, L. Macheva for preparation of the zircon grain mounts and N. Issa for assistance during the fieldwork.

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