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URANIUM-LEAD ZIRCON GEOCHRONOLOGY OF THE ITAMERIN TWO-MICA GRANITE, SOUTHWEST NIGERIA: IMPLICATIONS FOR AGE AND PETROGENESIS

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ABSTRACT

Itamerin two-mica granite is one of the different types of granitoids that are associated with the Ilesha schist belt. It is a medium-grained, weakly foliated unit that could easily be taken for a Pan African granitoid in the absence of age data. Establishment of age and petrogenetic implications is sought with the present study using U-Pb zircon Laser Ablation (Multi Collector) Inductively-Coupled-Plasma Mass Spectrometer [LA-(MC)-ICPMS] data. Zircon grains are generally colorless, transparent to translucent and range in length and width from 30 – 250 µm and 25–100 respectively and with varying degree of defects. They display variable concentrations of U and Th with Th/U ratios that are largely in the range typical of magmatic zircons. The Itamerin two-mica granite represents two episodes of Proterozoic magmatism forming two broad age clusters of Paleoproterozoic and Neoproterozoic. The former is demonstrated by U-Pb concordia plots where the upper intercept represents crystallization age while the lower intercept represents tectonic disturbance consistent with lead loss during the Pan African orogenic event. The latter is equally supported by U-Pb concordia, in addition to weighted average age plots, euhedral zircon crystals as well as the high degree of concordance in their age data. The Paleoproterozoic age of the Itamerin two-mica granite is similar to ages documented for granitoids in some parts of the Nigerian basement complex such as the Jebba granite gneiss and the Bode Saadu orthogneiss. The same is also true when extended further along the West African coastal transect despite the difference in tectonic history across the region, including granitoids from the Dahomeyan orogenic belt as well as the Kibi-Winneba volcanic belt and the Birimian granitoids of the West African Craton. The same can also be said for correlation across the north Atlantic, in the Borborema province, northeast of South America.

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INTRODUCTION

Itamerin, a community located along the Ife-Ilesha highway is a type locality for a medium-grained granitoid, named the Itamerin two-mica granite. It is one of the numerous types of granitoids that are associated with the Ilesha schist belt. The Ilesha general area falls within the Benin-Nigeria Shield (Fig. 1), separated from the West African Craton by the Pan-African Dahomey Belt, which latter consists of the Buem and Atacora structural units (Affaton et al., 1991), and by the adjoining Pre-Mesozoic Volta Basin, a passive margin that developed into a foreland basin (Carney et al., 2010).The Benin-Nigerian shield has been given variable designations depending on the extent of reference,such as the Pan African or Trans-Saharan mobile belt (Caby, 1989; Ajibade and Wright, 1989; Feybesse et al., 2006; Arthaud et al., 2008; Dada, 2008).This area falls within the larger west Gondwana orogen (WGO), which extends from northeast Africa to central Brasil (Ganade de Araujo et al., 2014). It is separated into the northern and southern segments by the North Atlantic Ocean. The northern segment runs from the coast of West Africa up to the Hoggar Massif in the north and to Cameroon and Congo Craton in the southeast, while the southern segment liesnortheast of South America, in the Borborema province of Brazil. The west Gondwana consists predominantly of Proterozoic basement granitoids, schist belts as well as Mesozoic and younger sediments.

Ilesha area, located in the southwest of Nigeria, exemplify the basement complex rocks of southwest Nigeria, consisting of gneissic granitoids, an unconformably overlying metasedimentary cover, with which the former are infolded, and subsequently intruding Pan-African granites. Based on limited geochemical, geochronologicaland structural data, the basement complex rocks of Nigeria have been assigned an Archaean to Neoproterozoic age range (McCurry, 1976; Fitches et al., 1985; Rahaman, 1988; Dada, 2008), the oldest rock being the Kaduna gneiss at 3.6 Ga (Kröner et al., 2001).

The predrift reconstruction of West Africa and northeastern South America has become imperative as it enables regional correlation of tectonic and structural events across east and west Gondwana (Amaral et al, 2023; Rogers, 1996; Neves, 2011; Grenholm, 2019). These two areas jointly span the Borborema province, north of the Sao Francisco Craton, through the Benin-Nigeria shield to the Andrar des Iforas and the Air region up north (Figure 1). Regional mega-tectonic markers of the events linking these areas are the Transbrasiliano (located in the NE Brazil), Ifewara-Zungeru and Kandi lineaments (located in the Pan African belt). Parts of these tectonic markers within the present study area are the Ifewara and Iwaraja faults. These two provinces taken side by side have been considered to present a vital piece towards a proper understanding of the amalgamation of West Gondwana by continental collision during the Brasiliano/Pan African orogenies (Neves, 2003; Amaral *et al.*, 2023; Arthaud *et al.,* 2008).

The present study, the first of its kind in this area, is an attempt at using U-Pb zircon geochronology data in the investigation of the Itamerin two-mica granite and its implications for age and petrogenesis. It is expected that investigation of individual lithological components with respect to geology, geochemistry and geochronology will enhance the understanding of their relationship to the other components within and outside the belt; this would help towards establishing a coherent lithostratigraphy and geotectonic evolution of the area as a whole.

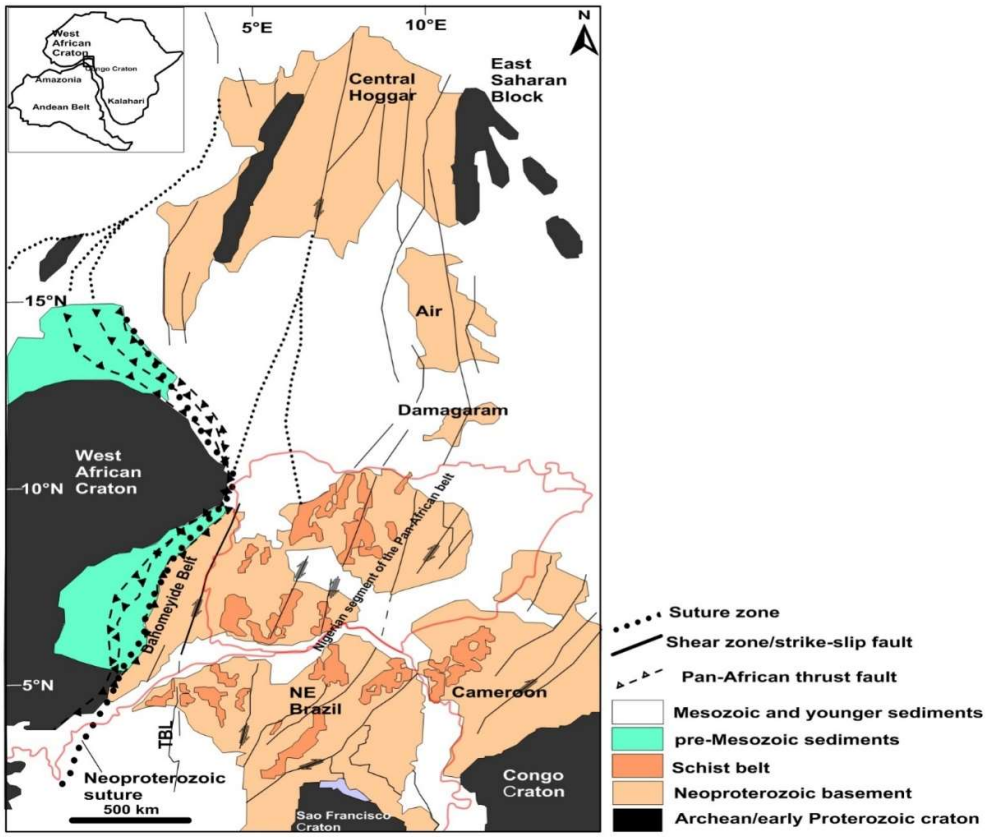


Figure 1: Pre-Mesozoic drift reconstruction of NE Brazil and NW Africa showing Borborema province and the Pan-African/Trans Saharan mobile belt (after Caby, 1989).

GEOLOGICAL SETTING

The most common lithological makeup of the Nigerian basement terrain comprises of older and unconformably underlying migmatite-gneiss complex, the metasedimentary units and the subsequently intruding Pan African granitoids. These apparently conform to three different suites in time, space and process. The older suite comprising gneissic granitoids such as hornblende and/or biotite gneiss, metamorphosed mafic/ultramafic as well as felsic bodies, with documented ages ranging from Archean to Paleoproterozoic (Kröner et al., 2001; Okonkwo and Ganev, 2012 and 2015). The intermediate suite comprises green schist to amphibolite facies phyllites, greenstone and schist while the latter suite comprises syn-to-late tectonic plutonic intrusions of granite-granodiorite with small masses of diorite, gabbro, syenite and related rocks. Rocks in this region are typical of the basement complex and include gneissic and migmatitic granitoids, metasedimentary schists and Pan-African granitoids. The basement complex carries the imprint of the Neoproterozoic Pan-African Orogeny, whose effects are largely a reworking of older, polycyclic crust that has been given dates corresponding to the Liberian (2.9 – 2.5 Ga), Eburnian (2.2 – 1.8 Ga) and Kibaran (1.3 – 0.9 Ga) orogenic events (Odeyemi, 1981; Turner, 1983; Rahaman, 1989; Peters, 1991; Imeokparia, 1991). Evidence of older events is, however, limited as subsequent events tend to obliterate imprints of preceding events. The metamorphic grade within the basement complex of Nigeria has been reported to be generally within the upper amphibolite to greenschist facies (Elueze, 1988). The dominant structural elements like lineations, foliations, and

faults are generally oriented N – S, NW – SE and NE – SW and this is exemplified by the Ifewara – Zungeru lineament as well as the Iwaraja fault line (Ajibade, 1982; Bafor, 1982).

TheIlesha schist belt has been divided into two major segments, separated into the eastern and western section, by the Ifewara fault system, (Ajayi, 1981; Rahaman et al, 1988). The lithology of the eastern section comprises of metasediments dominated by quartz muscovite schist, quartz schist, quartzite, quartzo-feldspathic gneisses and biotite garnet schist. The western lithology consists of volcano sedimentary sequence of pelitic schist, quartzites and metamorphosed basic as well as crushed rocks (Figure 2). Also documented are migmatites, gneisses, amphibolites and metamorphosed clastic materials (Elueze, 1988; Odeyemi 1993).

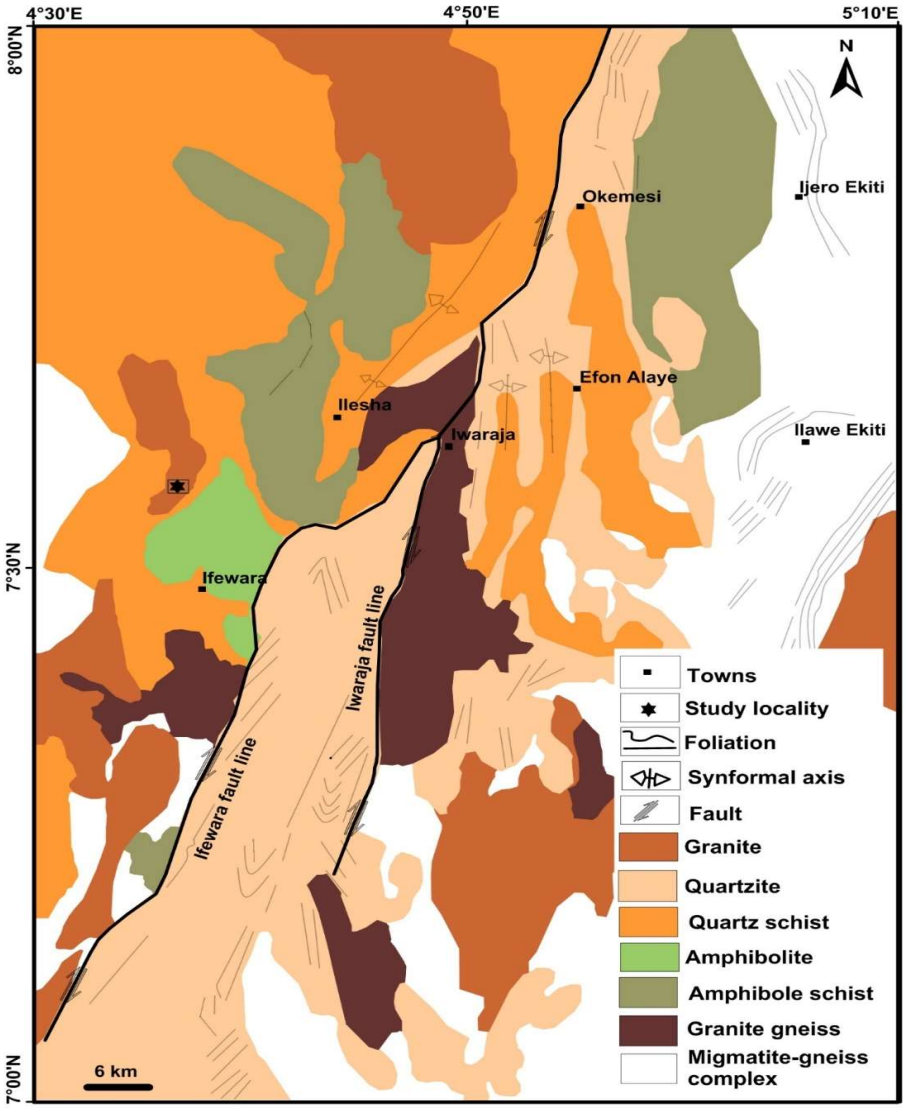


Figure 2: Geological map of the Ilesha area showing the dominant NE – SW and NW – SE trend of foliation and fault planes (modified after Ferre et al., 2002).

Three tectonic models have been proposed for the schist belts (Oyinloye 1998), including evolution by ensialic continental processes (Ajibade, 1980; Ajibade, 1982; Ajibade and Wright, 1989; Ajibade and Fitches, 1988; Odeyemi, 1981; Ogezi, 1988; Bafor, 1982), evolution in oceanic island-arc and marginal basin settings (Ajayi, 1981; Rahaman et al., 1988) and evolution in a back-arc basin (Wright et al., 1985; Olaniyi, 1992). Difference in composition of rocks and their response to tectonism resulted in the variable tectonic imprint retained in them, which emphasizes the need to establish their absolute ages in addition to other geological information.

MATERIALS AND METHOD

Field mapping of the study area, using base maps, satellite images was carried out resulting in the collection of fresh rock samples. This area has been the subject of research activities because of the famous Ifewara fault and the gold mineralization associated with the Ilesha belt. Another peculiarity associated with the area is the wide variety of granitoids crowded together within a relatively small area and constituting the basement complex in the area. However, in certain locality, accessibility is hampered by thick overburden, rugged topography and thick vegetation of the rain forest. Fresh outcrops are therefore rare as most exposures are found along the river channels and are highly weathered in most cases.

Zircon for U-Pb geochronology were separated from selected bulk samples using standard techniques including crushing, milling, panning and magnetic separation. Approximately 1kg of selected representative sample of the Itamerin two-mica granite was used for the analysis; from this, a total of 65 zircon grains were extracted for laser ablation. Zircon grains thus liberated, were hand-picked under binocular microscope, stacked on a double-sided tape and cast in a 1 inch, round epoxy resin mounts. The mounts were then polished and coated with 25 µm carbon to enhance conductivity for cathodo-luminiscence (CL) imaging of zircon grains using scanning electron microscope (SEM). The carbon coating is however removed after CL-imaging before laser ablation. Geochronological data were obtained using 193nm ArFRESOlution SE excimer laser (Australian Scientific Instruments, Fyshwick), Nu Plasma II MC-ICPMS (Nu Instruments, Wrexham) with 16 Faraday detectors and 5 ion counting detectors under RF Power of 1300 W. The laser was operated at a 30 µm spot size, 6mj energy beam and 50% attenuation; repetition rate was 2.5Hz while fluency was 2j/cm^3 with ablation and blank signals of 40 and 15 seconds respectively. Primary standards used to correct for instrumental mass bias and elemental fractionation were zircon OGC1 (Stern et al., 2009), A382 (Huhma et al., 2012), 91500 (Wiedenbeck et al., 1995) and GJ1 (Jackson et al., 2004); secondary standards used to evaluate accuracy was zircon CDQGNG (Schoene et al., 2006).Inbuilt data reduction code *NuAge2*was implemented for calculation and correction of the U-Pb ratios before final age calculation procedure was performed by Isoplot toolkit (Ludwig, 2009).All geochronological procedures were carried out at the analytical laboratory facility (Spectrum) of the Department of Geology, University of Johannesburg, South Africa.

RESULTS AND DISCUSSION

The Itamerin two-mica granite was mapped as an isolated pluton of about 2 km^2 in Itamerin community where it is being quarried as aggregate and hence it is well exposed at the quarry face (Figure 3a). It shows evidence of having undergone some deformation as manifested by weak foliation (Figure 3b); this is further corroborated by sutured grain boundaries of quartz and the mortar texture of the microcline. Mineralogically, it is composed of quartz, plagioclase, biotite, muscovite and microcline with accessory opaque minerals.

Cathodo-luminiscence (CL) images of zircon from the Itamerin two-mica granite are shown in Figure 3. The cathodo-luminiscence (CL) techniques allows for examination of magmatic zoning, inherited cores and overgrowth and other such things in zircon grains, thus enabling selection of the best grains for ablation. Selection of zircon for laser ablation was therefore based on size, morphology, presence or absence of cracks and inclusions, etc. Zircons in the investigated rock consist of subhedral to euhedral, equant to prismatic grains with typical oscillatory zoning, characteristic of igneous rocks, (Pupin, 1980). Zircon grains are generally colorless, transparent to translucent and range in length and width from 30 – 250 µm and 25 – 100 respectively and with varying degree of defects. The equant grains display regular concentric zoning with bright luminescence while the short prismatic grains have oscillatory to patchy zonation with low luminescence. Few grains have unzoned and oscillatory zoned rims, while inclusions, where present in zircon grains, vary across the different grains in terms of relative intensity of inclusions.

The results of the U-Pb analyses of the Itamerin two-mica granite are presented in Table 1. U-Pb analytical spots for constituent zircon were carried out on 17 zircon grains. Zircon grains of the analyzed sample of the Itamerin two-mica granite have very large variations in U and Th content and hence Th/U values. The highest U value is recorded in the zirconB7b-04 of the Itamerin two-mica granite (1594 ppm), while the lowest value is shown by B7b-26 at 30 ppm with average U content at 504 ppm. Th content stands at 8.3 ppm (B7b-42) and 430 ppm (B7b-17) as lowest and highest values respectively with average content at 107 ppm. ForTh/U ratio, it is highest in zircon grain B7b-32 at 1.8 and lowest in zircon grain B7b-42 at 0.013 with an average of 0.4. The Itamerin two-mica granite have Th/U ratios that are largely in the range typical of magmatic zircons.

Similarly, $^{207}Pb/^{206}Pb$, $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ages stand at minimum and maximum of 552 Ma each (zircon grain B7b-43 with 1σ error of 32, 12 and 13) and 2005 Ma, 1720 Maand 1496 Ma (zircon grain B7b-06 with 1σ error of 13, 11 and 15) respectively.

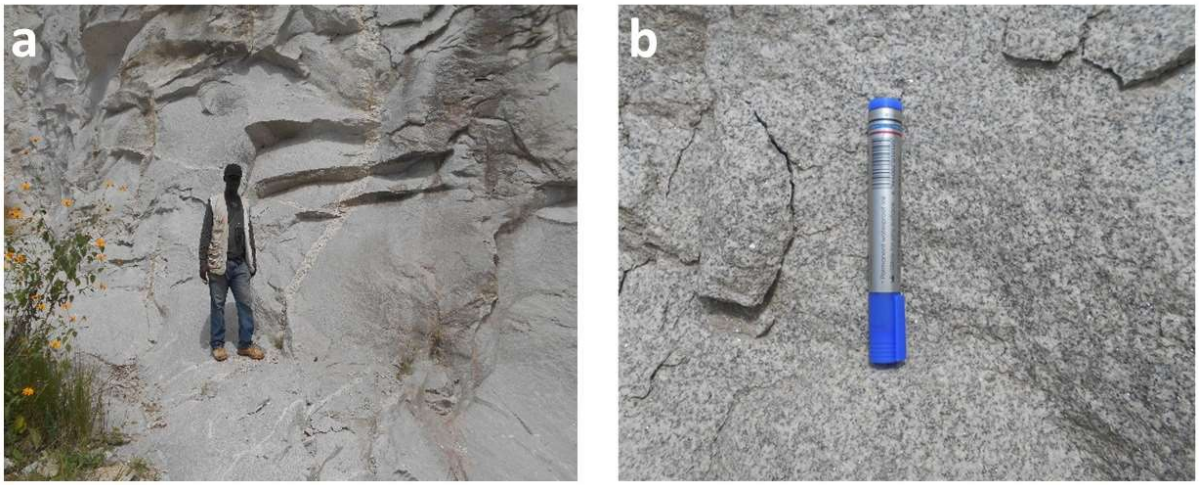


Figure 3: Field photographs of the Itamerin two-mica granite: (a) Quarry face (b) Sample-size view

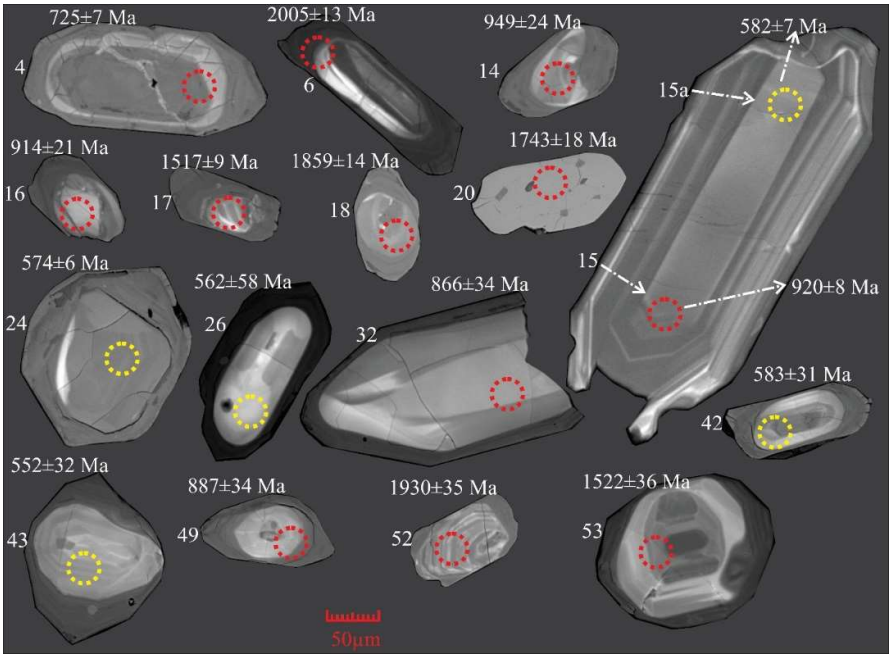


Figure 4: CL images of selected zircon grains for the Itamerin two-mica granite

The Itamerin two-mica granite is one of the few granitoids within the Precambrian basement rocks of Nigeria that could be taken for either one of Pan African or older gneissic granitoid due to its weak foliation. It contains moderate to highly subhedral zircon crystals. Inclusions and grain fractures are also moderate in the zircon grains extracted from the sample. Total zircon content in the rock is relativelylow as only a total of 65 grains of zircon was recovered from a 1kg sample processed from which a total of 17 ablation points were obtained from the sample. These form two broad age clusters of 207/206: the lower cluster of 552 – 949 Ma and an upper cluster of 1196 – 2005 Ma.

A plot of selected grains from both age clusters on the bases of percentage discordance yielded a U-Pb concordia age with lower and upper intercepts of 570.7 ± 8.0 and 2167 ± 28 Ma respectively and an MSWD of 0.55 (Figure 5a). Given that all the selected samples grains fall on the discordia regression line; it can be implied that the upper intercept at ca 2167 Ma represents crystallization age while the lower intercept at ca 571 Ma represents tectonic disturbance consistent with lead loss during the Pan African orogenic event. The plots of upper age clusters on separate U-Pb concordia diagrams yielded age with lower and upper intercepts of 546 ± 700 and 2121 ± 82 Ma respectively and an MSWD of 5.7 (Figure 5b). Here again, all the selected samples grains fall on the discordia regression line and thus can be interpreted that the upper intercept represents crystallization age while the lower intercept represents tectonic disturbance consistent with lead loss during the Pan African orogenic event.The U-Pb concordia diagrams for the lower age clustersyielded upper Proterozoic age of 580 ± 12 Ma and an MSWD of 0.23 (Figure 5c). This age cluster also produced a weighted average age of 593 ± 2.3 and an MSWD of 0.23 with 95% confident limit (Figure 5d). This is further supported by the relatively high euhedral nature of these crystals as well as the high degree of concordance in their age data.From the foregoing, it could be argued that the upper Proterozoic age represent a dual effect of the Pan African orogenic event. On the one hand, it could represent effect of lead loss on the paleoproterozoic grains and on the other, a contemporaneous fresh crystal growth.

Table 1: U-Pb isotope data for theItamerin two-mica granite

	Concentration [ppm]			Ratios							Ages (Ma)						
Grain number	**U**	**Th**	**^{206}Pb**	**206/204**	**^{207}Pb/^{235}U***	**1σ**	**^{206}Pb/^{238}U***	**1σ**	**Rho**	**^{207}Pb/^{206}Pb***	**1σ**	**207/206**	**1σ**	**207/235**	**1σ**	**206/238**	**1σ**	**%Discordance**
B7b-06	354	46.3	76.1	3331	4.442	0.058	0.261	0.003	0.836	0.123	0.001	2005	13	1720	11	1496	15	-28.4
B7b-04	1594	21.4	128.1	4373	0.854	0.008	0.098	0.001	0.925	0.063	0.000	725	7	627	5	600	5	-18.0
B7b-14	732	94	59.8	1218	0.963	0.016	0.099	0.001	0.659	0.071	0.001	949	24	685	8	607	6	-37.8
B7b-15-CPb	429	128.8	33.5	19932	0.775	0.009	0.095	0.001	0.960	0.059	0.000	582	7	583	5	583	6	0.1
B7b-15a	378	117.7	30	1152	0.927	0.012	0.096	0.001	0.948	0.070	0.000	920	8	666	6	593	7	-37.2
B7b-16	407	32.2	34.4	1978	0.987	0.018	0.103	0.002	0.810	0.070	0.001	914	21	697	9	632	9	-32.4
B7b-18	512	14.6	86.2	1705	3.220	0.058	0.205	0.003	0.894	0.114	0.001	1859	14	1462	14	1204	18	-38.6
B7b-24-CPb	683	23.2	52.7	16544	0.761	0.010	0.093	0.001	0.811	0.059	0.000	577	17	574	6	574	6	-0.7
B7b-26	30	26.1	2.8	1006	0.739	0.022	0.091	0.001	0.278	0.059	0.002	562	58	562	13	562	4	-0.1
B7b-32	128	227.9	11.2	1396	0.815	0.026	0.087	0.002	0.847	0.068	0.001	866	34	605	14	538	14	-39.5
B7b-42	658	8.3	61.3	7377	0.749	0.022	0.091	0.002	0.875	0.059	0.001	583	31	567	13	563	14	-3.6
B7b-43	171	70.4	15.5	4437	0.722	0.021	0.089	0.002	0.853	0.059	0.001	552	32	552	12	552	13	0.0
B6b-49	260	205.3	24.9	1257	0.882	0.030	0.093	0.003	0.864	0.069	0.001	887	34	642	16	575	16	-36.8
B6b-52	553	315.7	136	6544	3.941	0.114	0.242	0.005	0.739	0.118	0.002	1930	35	1622	23	1395	27	-30.8
B6b-53	250	37.6	23.1	363	1.188	0.045	0.091	0.003	0.862	0.095	0.002	1522	36	795	21	561	18	-65.9
B7b-20	511	14.3	86.4	1940	2.999	0.085	0.204	0.005	0.936	0.107	0.001	1743	18	1407	22	1196	29	-34.3
B7b-17	918	430	77.5	410	1.326	0.016	0.102	0.001	0.904	0.094	0.000	1517	9	857	7	625	6	-61.62

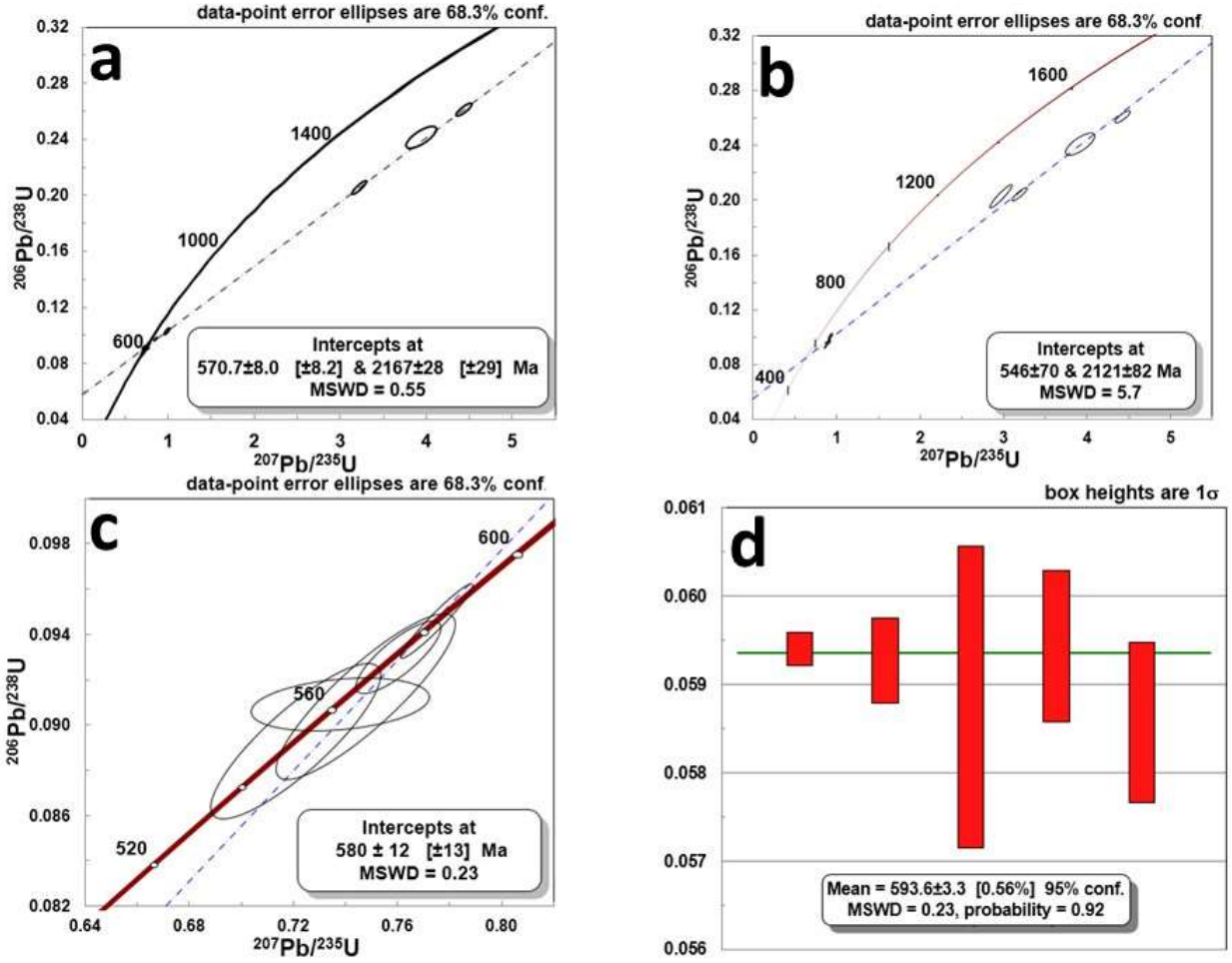


Figure 5: Zircon U-Pb concordia plots for the Itamerin two-mica granite: (a) Combined upper and lower age cluster plot; (b) Plot of the upper age cluster; (c) Plot of the lower age cluster; (d)Weighted average plot.

A peculiarity of the Itamerin two-mica granite is the two broad age clusters. Out of the total of seventeen grains of zircon ablated, eleven are under 1.0 Ga while the remaining grains are above 1.0 Ga. These represent 65 and 35 percent respectively. It is however noteworthy that in the lower age cluster, those 207Pb/206Pb, 207Pb/235U and 206Pb/238U ages below 0.6 Ga display a relatively high degree of concordance while those on the upper limit of the age cluster generally display relatively higher degree of discordance with respect to 207Pb/206Pb, 207Pb/235U and 206Pb/238U ages.

The concordia age diagrams (Figure 5) represent variable and selected combinations of U-Pb zircon data of the ablated zircon grains from which acceptable ages were selected based on range of error and MSWD. Figure 5a being a selected combination of age data of zircon grains from both lower and upper age cluster is an indication of magmatic zircon input from the paleoproterozoic era. The same could be true for Figure 5b which consists solely of zircon data from the upper age cluster. The relatively higher error margin associated with the upper cluster is attributable to tectonic disturbances resulting from metamorphism. Figure 5c and d represents the plot

for the lower age cluster and the weighted average plots respectively. These are indicative of Neoproterozoic magmatic zircon contributions and as expected, they display relatively lower error margin as their emplacement is contemporaneous with the Pan African orogenic event.

The West African Craton, the Dahomeybelt and the Benin-Nigeria shield jointly constitute a large segment of West African geology with the Dahomey belt separating the former from the later. The lower Proterozoic ageof the Itamerin two-mica granite mirrors its counterpart's ages documented for granitoids in parts of the Nigerian basement complex including2.2 Ga for Jebba granite gneiss and Bode Saadu orthogneiss (Okonkwo and Ganev, 2012 and 2015). The same is also true when extended further along the West African transect despite the difference in tectonic history across the region, including 2.10 Ga, 2.12 Ga and 2.14 Ga, for granitoids from the Dahomeyan orogenic belt (Kalsbeek et al 2020; 2.19 Attoh et al., 2013), 2.19 Ga and 2.13 Ga for the Kibi-Winneba volcanic belt (Anum et al., 2015) as well as 2.34 Ga and 2.38 Ga for the Birimian granitoids of the West African Craton (Sakyi et al., 2020).

The results of this investigation is in conformity with attempts at reconstructing NE Brazil with West Africa which suggests a pre-Atlantic continuum of granitoids north and south of the Atlantic; a structural manifestation of this is the Transbrasiliano Lineament in South America which corresponds to the Kandi Lineament in Africa, providing a present-day fit between NW Africa and NE Brazil (Arthaud et al., 2008, Ganadede Araujo et al., 2014).Similarly, the lower Proterozoic age of the Itamerin two-mica granite is correlatable with the widely abundant Paleoproterozoic granitic magmatism, now represented by granitoids documented further south, across the Atlantic, in the Borborema province of northeast Brazil, which represents the pre-Atlantic reconstruction of the Benin-Nigeria shield. Similar age records documented include 2.13 Ga for Cipo orthogneiss (Martins et al., 2009), 2.20 Ga for Caico complex granitoids (Holanda et al., 2011) as well as2.19 Ga and 2.12 Ga for Caninde do Ceara complex (Amaral et al., 2023). Paleoproterozoic age as indicated by the Itamerin two-mica granite therefore testify to a pre-Pan-African/Braziliano continuum between Borborema and Benin-Nigeria shield and thereby corroborating the fact that the Paleoproterozoic was a very important crust-forming period of time marked by prolonged granitic magmatism in Africa and South America.

A general observation with regards to the Benin-Nigeria shield is the fact that given the regime of regional metamorphism, most of the Paleoproterozoic granitoids were only affected by Pb loss as a result of the Pan-African thermo-tectonic reworking, rather than new zircon growth (Annor, 1995; Dada, 2008). This has consistently been demonstrated by U-Pb zircon documented ages such as the Kabba, Jebba and Bode Saadu granitoids (Annor, 1995; Okonkwo and Ganev, 2012; Okonkwo and Ganev, 2015). The Itamerin two-mica granite has now become the exception in this regard where both age effect of lead loss as well as new zircon growth are observed in a rock.

CONCLUSION

The attempt here represents the first time the Itamerin two-mica granite was investigated comprehensively with a view to establishing geochronology and tectonic evolution. This rock which could easily pass for a Pan African granitoid due to its minimal deformation has proven to be much older with dual U-Pb zircon age. The Itamerin two-mica granite represents two episodes of Proterozoic magmatism forming two broad age clusters of Paleoproterozoic and Neoproterozoic. The former is demonstrated by U-Pb concordia plots where the upper intercept represents

crystallization age while the lower intercept represents tectonic disturbance consistent with lead loss during the Pan African orogenic event. The latter is equally supported by U-Pb concordia and a weighted average age plots. This is further supported by the highly euhedral nature of these crystals as well as the high degree of concordance in their age data. The lower Proterozoic age of the Itamerin two-mica granite is similar to ages documented for granitoids in some parts of the Nigerian basement complex such as Jebba granite gneiss and Bode Saadu orthogneiss. The same is also true when extended further along the West African transect despite the difference in tectonic history across the region, including granitoids from the Dahomeyan orogenic belt as well as the Kibi-Winneba volcanic belt and the Birimian granitoids of the West African Craton. The same can also be said for correlation across the north Atlantic, in the Borborema province of Brazil.

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