

Tin Mineralisation in Nigeria: A Review

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ABSTRACT

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Nigeria is endowed with vast but largely untapped solid mineral resources including tin ores (cassiterite and stannite). Tin, which is one of the oldest metals known to man, is invaluable in a wide variety of uses due to its intrinsic properties such as great malleability and ductility, low melting point, softness, corrosion resistance, non-toxicity, anti-friction qualities, and silvery-white appearance. In the present century, the main uses of tin have been in the coating of steel to produce tins, production of alloys (solder, bronze and brass), and chemicals. Tin deposits occur in two distinct provinces in Nigeria. The older suite is related to Pan-African pegmatite belt. This Sn-Ta-Nb mineralized pegmatite belt stretches for over 400 km from southwestern (Ijebu area) to northern Nigeria (through Wamba-Jema'a to Zuru-Gusau areas). The later stage mineralization is hosted by granites of ring complexes of Jurassic age known as Younger Granites. In the Younger Granites, Sn-Nb-Ta mineralisation is associated with late-stage peraluminous granites both as disseminations and in veins and greisens. This work synthesizes and discusses the available data on tin mineralisation in Nigeria and possible metallogenesis and controls. Recommendations on how to encourage and improve the mining of tin and its associated minerals in Nigeria are also made in this work.

1. INTRODUCTION

Tin is one of the metals known to mankind since the earliest times [1-2]. It was possibly one of the first metals used by man as an ingredient of bronze (alloy of copper and tin). Bronze objects such as weapons, tools, jewelry etc with 10-14% tin have been found in excavations of different ancient civilization. A bronze rod found in Egypt has been dated back to 3700 B.C. Tin has also been found in the tombs of ancient Egyptians and was exported to Europe in large quantities from Cornwall, England during the Roman period [1].

Tin has been mined and used in Nigeria as early as the 9th century with exquisite bronze artifacts from three sites in the Igbo-Ukwu area of Anambra State dating back to this period. These artifacts are older than the earliest Benin bronzes, which are dated to the 13th century [2].

Tin is a relatively soft, pliable and ductile metal with a silvery white colour. The Latin word for tin is "stannum". It is a metallic element (Sn) which occurs in group 14 (or IVA) and period 5 of the periodic table. The atomic number and atomic weight of tin are 50 and 118 respectively.

Physical properties of tin include: silvery-white colour, brilliant luster, high ductility and malleability at 100°C (212°F), low tenacity, specific gravity of 7.3, low melting point of 232°C (449°F), high boiling point of 2,625°C (4,757°F) and allotropy. Some of the chemical properties of tin are non-toxicity, resistance to oxidation and corrosion, and existence in two oxidation states (+4 and +2).

The Earth's crust contains averagely 2-3 ppm Sn. Primary deposits of tin are considered workable if they have a cut-off

grade of 0.35% (or 3500 ppm) Sn [3]. However, deposits with lesser grade have been mined. This is because economic and market forces as well as availability of necessary technology play important roles in determining the workability of a deposit [4].

Tin finds industrial applications in the production of corrosion-resistant alloys (bronze, brass, solder), tins, chemicals, tin foil, pottery, and glass. Although tin is usually a minor constituent in alloys, it is an essential one on account of the way in which its special properties confer improvements to the matrix metal.

Cassiterite (SnO₂), stannite (Cu₂SnFeS₄) and cylinderite (Pb₃Sn₄FeSb₂S₁₄) are the major ore minerals of tin. Tin ores occur mainly in veins, stockworks, disseminations, pegmatites, replacements and placers. Primary tin deposits are formed by magmatic, hydrothermal and/or replacement processes. Secondary deposits are the products of weathering of primary deposits, and the subsequent transportation and deposition of the resulting sediments in a new environment.

Tin deposits are abundant in China, Malaysia, Indonesia, Peru, Thailand, Brazil, Bolivia, D.R. Congo, Australia, Nigeria, Myanmar (Burma), Russia, Zimbabwe, Rwanda, South Africa, United Kingdom, Mongolia, Colombia, Germany, Canada, Mexico and Morocco [5-8].

The estimated total world reserve of tin metal as at 2017 is over 4.80 million tonnes and global production amounted to 290,000 tonnes with China being the largest producer (100,000 tonnes) and Nigeria contributing about 2,400 tonnes [9]. About 80% of tin mined in Nigeria is from secondary deposits found downstream (tin placer deposits) derived from primary tin lodes and granitic rocks [10].

2. OVERVIEW OF THE GEOLOGY AND MINERAL RESOURCES OF NIGERIA

The geology and mineral resources of Nigeria have been studied in details by several geoscientists [6, 11-17].

Obaje [17] divided the geology of Nigeria into 3 major petrological components – Basement Complex, Younger Granites, and Sedimentary Basins of Precambrian ($\geq \pm 600$ Ma), Jurassic (ca. 150 Ma) and Cretaceous – Recent (≤ 145 Ma) ages respectively (Figure 1).

Mineral resources associated with the Basement Complex rocks of Nigeria include gold, lead-zinc-copper, iron formation, silver, gemstones, marble, talc, sillimanite-kyanite-andalusite, etc. The Younger Granites are notable for their Sn-Nb-Ta mineralisation and associated minerals such as sphalerite, pyrite, uraninite, thorite, fluorite and pyrochlore [18].

Hydrocarbon deposits (crude oil, natural gas, coal and bitumen) have been found in most sedimentary basins of Nigeria [17, 19-20]. Lead, zinc, copper, silver, uranium, brine, ironstone, baryte, gypsum, limestone, clays, sands and gravels, diatomite are other mineral resources concentrated in the sedimentary basins of Nigeria [21-24].

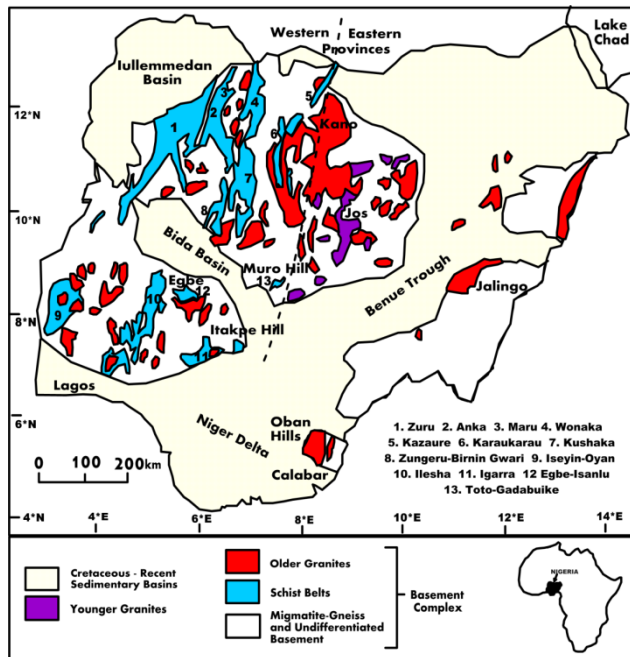


Figure 1. Outline geological map of Nigeria (modified after [15])

3. TIN MINERALISATION IN NIGERIA

Tin minerals, particularly cassiterite are one of the mineral endowments of Nigeria [25-26]. There are two tin provinces in Nigeria. These provinces form parts of the four major metallogenic provinces of the country [27].

The four metallogenic provinces of Nigeria (Figure 2) are:

1. Sn-Ta-Nb Pegmatite Belt of Late Pan-African age
2. Sn-Nb-Ta Younger Granite Province of Jurassic age
3. Pb-Zn Province of the Benue Trough of Cretaceous age
4. Au Province of Western Nigeria

This paper discusses only the tin metallogenic provinces of Nigeria. [21, 30-31] and other related literatures have

extensively researched on the Pb-Zn and Au Provinces of the Benue Trough and western Nigeria respectively.

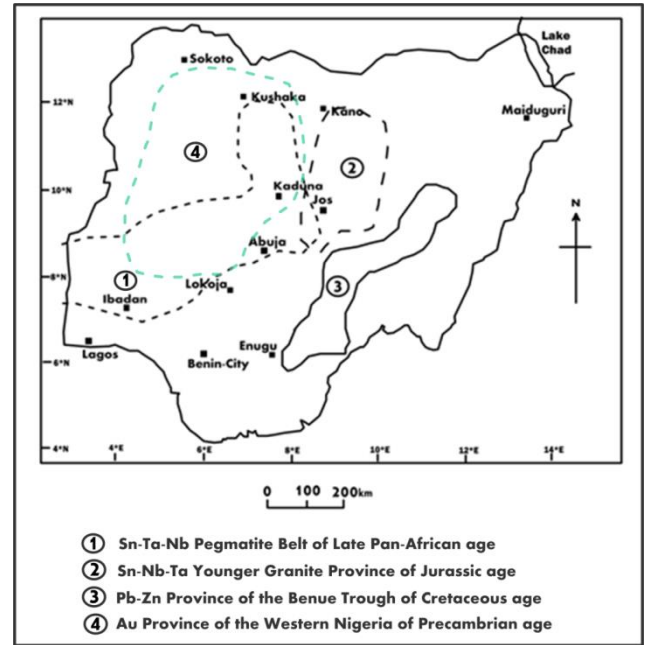


Figure 2. Metallogenic Map of Nigeria (modified after [27-29])

3.1 Sn-Ta-Nb Pegmatite Belt of Late Pan-African age

The Sn-Ta-Nb Pegmatite Belt of Nigeria consists of over 3,000 tin-bearing pegmatites of diverse mineralogy, structural orientations and chemical compositions ranging between 10 m – 1,500 m in length and sometimes up to 50 m in width occurring in granites, schists, gneisses, amphibolites and quartzites [25, 29]. The mineralized pegmatite belt extends from southwestern (Ijebu area) to northern Nigeria (through Wamba-Jema'a to Zuru-Gusau area) covering a broad, over 400km long zone trending NE–SW and parallel to the linear pattern of the other two metallogenic provinces (Younger Granite and Cretaceous Benue Trough provinces) [25, 29, 32, 33]. The pegmatite belt of Nigeria is presumed to extend into northeast Brazil [28, 34, 35].

The mineralized or rare metal-bearing pegmatites consist mainly of quartz, potash feldspar, albite, muscovite and less commonly, biotite and a range of accessory minerals including tourmaline, beryl, aquamarine, lepidolite and economically important cassiterite, columbite and tantalite.

The mineralized pegmatite belt, also known as the Older Tin field of Nigeria, is the only basement metallogenic feature that cross-cuts the schist belt structures although most pegmatites are oriented N-S [32, 36]. The belt is divided into 3 zones: (i) the main central Nigerian pegmatite belt (ii) area of richest stanniferous pegmatites (iii) and area of subordinate mineralization (Figure 3).

Okunlola [29] grouped the rare-metal bearing pegmatites of Nigeria into seven broad fields, which are: Kabba–Isanlu, Ijero–Aramoko, Ibadan–Oshogbo, Oke–Ogun, Nassarawa–Keffi, Kushaka–Birnin-Gwari and Lema–Share fields (Figure 4). The tin concentrations of some of the rare metal-bearing pegmatites in these fields are shown in Table 1.

Notable mineralized pegmatites are found in Ijero, Sepeteri, Aramoko, Ife-Ilesha, Ikoro, Osu, Igbeti, Oro, Oke-Ogun, Komu, Egbe, Akata, Wamba-Jema'a, Keffi, Akwanga,

Gwon Gwon, and Jos Plateau, all occurring within the Nigerian mineralized pegmatite belt. A few occurrences of poor – low grade tin-bearing pegmatites have also been found outside the pegmatite belt in the Obudu and Oban massifs in southeastern Nigeria [29, 33, 37-40]. The mineralized pegmatites have yielded about 5% of the total cassiterite produced in Nigeria [25, 41].

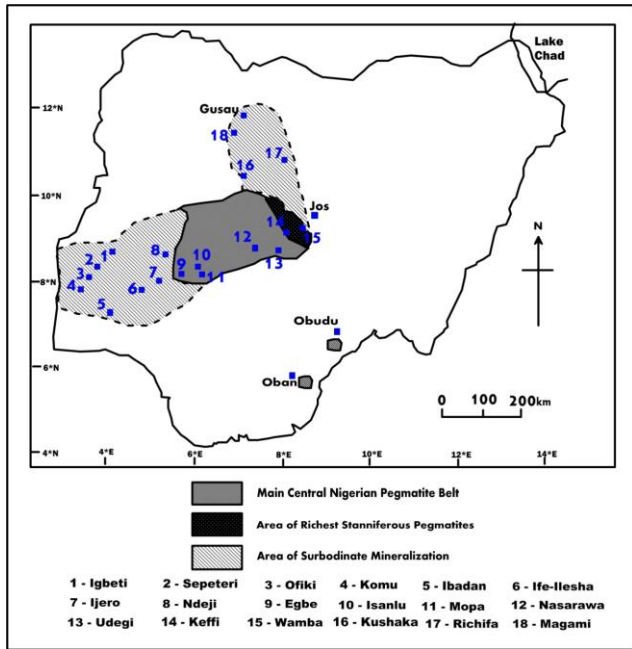


Figure 3. Map showing the locations of notable tin-bearing pegmatites in Nigeria (modified after [28, 29, 36])

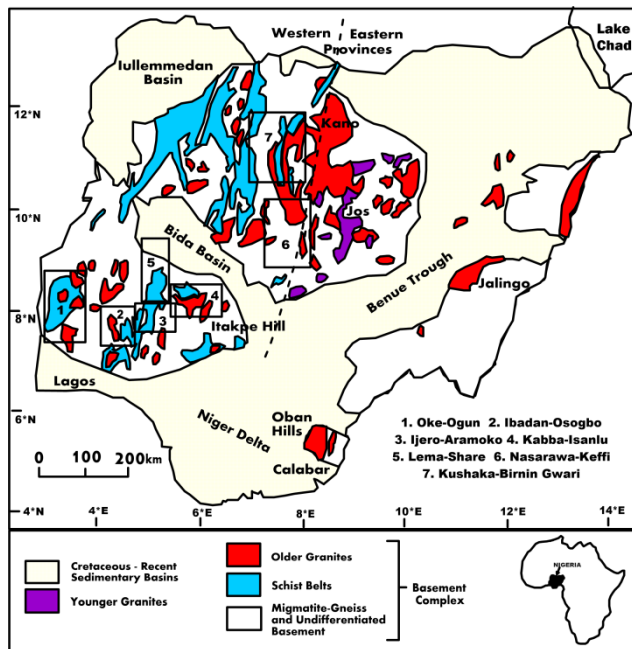


Figure 4. Geological Map showing the Pegmatite Fields of Nigeria (modified after [29])

Notable mineralized pegmatites are found in Ijero, Sepeteri, Aramoko, Ife-Ilesha, Ikoru, Osu, Igbeta, Oro, Oke-Ogun, Komu, Egbe, Akata, Wamba-Jema'a, Keffi, Akwanga, Gwon Gwon, and Jos Plateau, all occurring within the Nigerian mineralized pegmatite belt. A few occurrences of poor – low grade tin-bearing pegmatites have also been found

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The Nigerian tin-bearing pegmatites are probably related to the Pan-African Older Granite suite which often occurs in close proximity. The mineralized pegmatites were formed due to magmatic differentiation processes during late Pan-African orogenic event, in the range 580 – 500 Ma [48, 54]. They are younger than the Older Granites and barren pegmatites but older than the Younger Granites. Tin-bearing pegmatites associated with metasedimentary rocks (schists, paragneisses and quartzites) in schist belts (as in Ijero, Egbe, Ilesha) suggest metamorphic or metasomatic replacement processes (particularly late-stage albitization) are important in their formation [17, 36, 55].

3.2 Sn-Nb-Ta Younger Granite Province of Jurassic Age

The Younger Granite Province in north central Nigeria, trending NE-SW, covers a total area of about 7,500 km². The province consists of over 50 massifs of anorogenic complexes (Figure 5) made up of both volcanic (rhyolites, trachytes and basalts) and plutonic rocks (aegirine-, arfvedsonite-, riebeckite-, biotite- and hornblende-bearing granites, syenites, quartz porphyry, granite porphyry and gabbro) formed during the Mesozoic, probably related to the early break-up of Gondwanaland and splitting of Africa from South America. This event was also responsible for the opening up of the Benue Trough [56]. The Younger Granite Province terminates the Sn-Ta-Nb Pegmatite belt in the east. Wright [36] referred to the Younger Granite Tin Province as Younger Tin field of Nigeria.

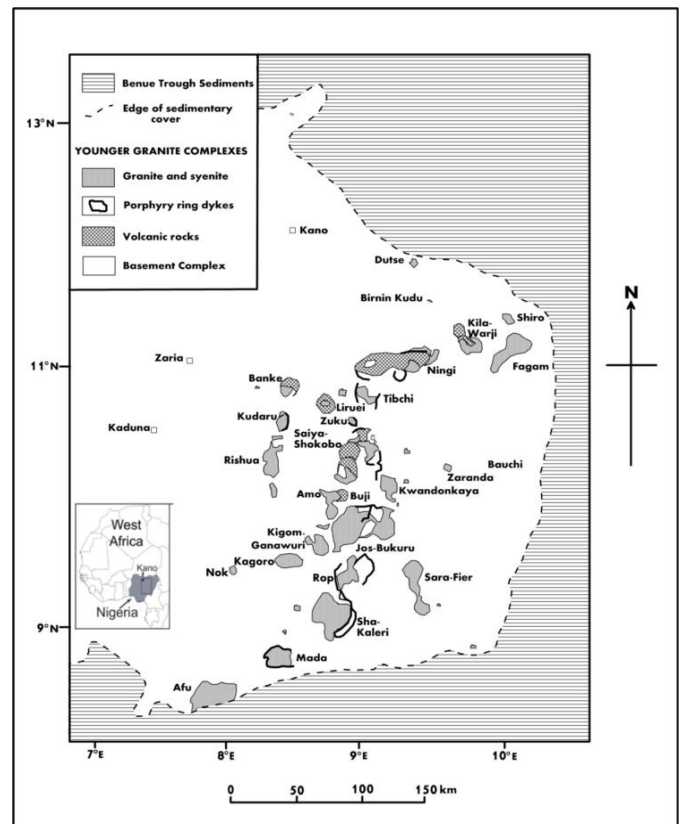


Figure 5. Geological Map of the Sn-Nb-Ta Younger Granite Province of Nigeria [2, 58-59]

Table 1. Tin (Sn) concentrations of some rare metal-bearing pegmatites of Nigeria

Pegmatite Field	Location	Host Rock(s)	Average and Range of Sn content (ppm)	References
Ijero-Aramoko	Ijero	Biotite Schist and Amphibole Schist	18; 4–37	[42]
	Oke-Asa	Biotite Schist and Biotite Gneiss	8.3; 5–14	[43]
Nassarawa-Keffi	Wamba (Angwan Rimi)	Biotite Gneiss and Schist	105; 12–137	[44]
	Nassarawa	Granite and Schist	136; 9–659 (WR) 352; 61–902 (ME)	[28]; [45]
	Keffi Angwan Mallam Angwan Doka	Schist Granodiorite	760; 5–6000 638; 5–3373	[46]
	Gwon-Gwon	Granite & Gneiss	72.4; 66–79	[47]
Oke-Ogun	Komu	Gneiss, Schist and Amphibolite	242.5; 0.05–777	[48]
	Igbeti	Schist and Gneiss	18.5; 10 – 25	[49]
	Sepeteri	Amphibole Schist	50.41; 11.2–279	[50]
Kabba-Isanlu	Egbe	Amphibolite, Gneiss and Schist	92.3	[51]
	Oro	Schist & Gneiss	6.06; 1.06–14.89	[52]
Ibadan-Oshogbo	Awo	Banded Gneiss	109; 2–244 (WR) 1089.8; 1050–1104 (ME)	[53]
Kushaka-Birnin-Gwari	Kushaka	Schist, Gneiss and Migmatite	148	[28]
	Magami	Gneiss and Migmatite	7 (WR), 234 (LME)	[28]
	Richifa	Granite	6	[28]
Lema-Share	Lema-Ndeji-Share	Gneisses and Granitoids	85; 15–125	[25]

WR – Whole Rock Pegmatite, ME – Muscovite Extract, LME – Lithium Muscovite Extract

Tin ores (cassiterite and stannite) occurs in the Younger Granite complexes in two primary forms: (i) disseminations and (ii) veins and greisens. Disseminations of accessory cassiterite occur in association with columbite, tantalite and other ores (monazite, zircon, cryolite, rutile, ilmenite, genthelvite, beryl, molybdenite, sphalerite and chalcopyrite) in the roof zones and margins of peraluminous biotite granites in most of the Younger Granite Complexes, but known enrichment is focused in parts of the Jos-Bukuru, Tongolo, Tibchi, Dutsen-Wai and Afu complexes. The values in a particular granite may vary from zero to over 400 ppm SnO₂ (Table 2) [6, 10, 57].

The peralkaline granites, inspite of their high Sn content as revealed by chemical analyses, contain no cassiterite ore. This suggests that Sn did not occur as cassiterite but probably remains dispersed in the sodic-bearing minerals [6, 10]. However, the peralkaline albite-riebeckite granites contain significantly high concentrations of niobium, zinc, uranium and zirconium [68].

Few highly mineralized quartz-sulphide-cassiterite veins and greisens enriched in cassiterite, stannite, sphalerite, galena, columbite, chalcopyrite, siderite, arsenopyrite, wolframite and bismuth minerals occur within fractures and along the margins of Younger Granite rocks. These are the most economically viable primary tin deposits in the province. Notable cassiterite-bearing veins or lodes and/or greisens occur in the Ririwai, Tibchi, Tongolo and Afu complexes (in decreasing order of mineralisation).

Over 95% of the tin (cassiterite) produced in Nigeria was mined in the Younger Granite Province and were won from alluvial deposits derived from the tin-bearing granites and lodes [2, 69].

The origin of the Sn-Nb-Ta mineralization in the Younger Granite Province is related to the petrogenesis of the Younger Granites. Wright [36] suggested that cassiterite and its associated ore minerals in the Younger Granite ring complexes of Nigeria were not basement-derived, but originated at deeper levels as part of the primary melts. This suggestion was based on the premise that the Younger Granite magmas probably originated in the upper mantle, as salic melts, generated by pressure relief, partial melting, and a concentration of low melting constituents beneath a broad crustal dome, and modified by interaction with basement rocks.

Wright [36] further argued that the ore mineral constituents of the Younger Granites were not extracted and concentrated from the crustal rocks through which the salic magma rose because:

- There is greater volume of mineralisation in the Younger Granites as compared to the basement, and
- Contrasting mineral assemblages associated with the basement tin mineralization and the Younger Granites. Boron, beryllium and tantalum are rare in the Younger Granites but common in the basement pegmatites. Conversely, fluorine, tungsten and hafnium are common in the Younger Granites but rare in the basement.

Table 2. Tin (Sn) concentrations in some lithologies of the Younger Granite Complexes

Younger Granite Complex	Rock Type	Sn content (ppm)	References
Ririwai	Biotite granite	28; 64	[60]; [61]
	Aegirine – arfvedsonite granite	24	[61]
	Albite – arfvedsonite granite	67	[61]
	Albite – riebeckite granite	165	[60]
	Potassic granite	55	[60]
	Quartz-porphyry	15	[61]
	Kaolinised granite	6	[60]
	Partial greisen	1500	[62]
	Greisen assemblage	2016; 1670	[62]; [60]
	Ririwai Zn-Sn lode	6100–7000	[38]
	Ginshi Hill Sn lode	100–21,800*	[63]
Jos-Bukuru	Biotite albite granite	20–1433*	[63]
	Biotite granite	63	[61]
Banke	Biotite granite	9	[60]
	Greisen	1150	[60]
Tibchi	Biotite granite	90	[57]
	Biotite granite	47	[64]
Tongolo	Biotite granite	55	[64]
	Greisenized granite	213	[64]
	Greisen	494	[64]
	Pakaru Sn-Zn-W lode	7500	[64]
	Biotite granite	190	[57]
Dutsen-Wai	Afu biotite granite	12	[65]
Afu	Igo biotite granite	50	[65]
	Jenta biotite granite	74	[65]
	Odegi albite biotite granite	56	[65]
	Kaolinized granite	180	[65]
	Greisenized granite	685	[65]
	Greisen	2160	[65]
	Arfvedsonite-aegirine granite	32	[65]
Shere	Arfvedsonite-biotite granite	22	[66]
	Biotite granite	14	[66]
	Albite-arfvedsonite granite	47	[66]
	Biotite granite	58	[67]
Kwandonkaya	Biotite granite	21	[67]
	Pashanu microgranite	31	[67]

* – SnO₂ content

4. CONTROLS OF TIN MINERALIZATION IN NIGERIA

The distribution of stanniferous pegmatites in the Nigerian Basement and the Younger Granite ring complexes can be more plausibly related to a proposed ancient lineament system than to regional structural trends (Figure 6) [25, 36, 70]. These lineaments possibly acted as passage ways for the mineralizing fluids to be transported and also to deposit their mineral contents. Areas close to the intersection of the lineaments, particularly around the Jos Plateau, contain the richest pegmatites and tin-bearing granites and lodes. This may suggest intermediate activeness of these lineaments especially in the Late Precambrian times [25, 71].

Noticeably, tin-bearing pegmatites in the Late Pan-African Terrain of Nigeria are concentrated close to major faults of transcurrent nature, for example, the Kalangai fault system, Ifewara fault system and Anka fault system which has a southern extension up to the Oke–Ogun areas in southwestern Nigeria [25, 28]. These structures are also of

importance in the localization and structural controls of tin mineralization in Nigeria particularly in the pegmatite belt.

The proximity of most of the rare-metal bearing pegmatite fields to major transcrustal suture zones and subsidiary faults also suggests their timing of emplacement are related to that of gold mineralization [29, 72].

5. TIN RESERVE OF NIGERIA

As at 2010, the estimated tin (cassiterite) reserve of Nigeria is at least 300,000 tonnes [73]. In addition to the estimated reserve, a substantial unestimated amount of cassiterite is known to be buried under basalts and volcanics in the Jos Plateau area [69, 74-75]. Tin resource of Nigeria is estimated to be at least double the amount of reserve. The low level of exploration and estimation of most mineral deposits in Nigeria including tin makes unavailable the accurate amount of mineral resources in the country.

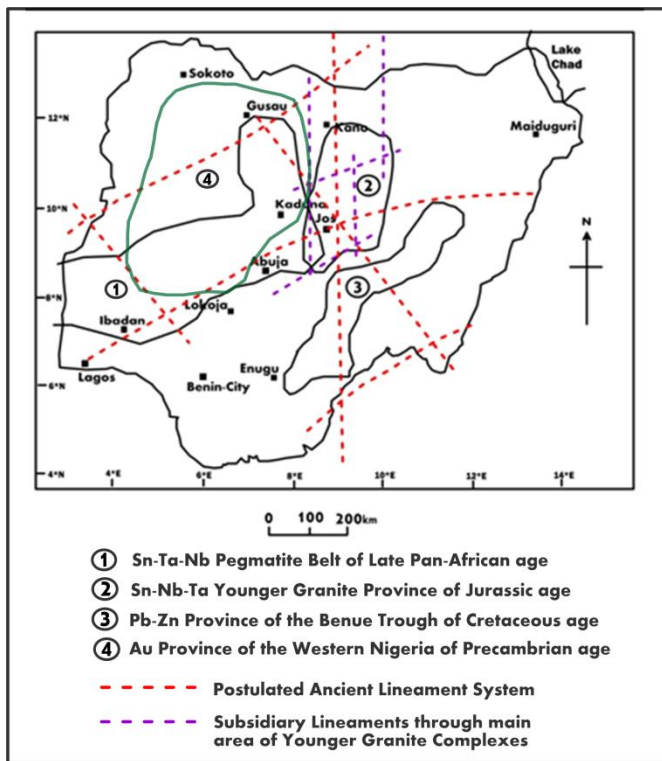


Figure 6. Lineament Map of Nigeria (modified after [36])

6. DISCUSSION AND RECOMMENDATIONS

A substantial percentage of the tin deposits in Nigeria, particularly lodes and greisens in the Younger Granite province and the tin-bearing pegmatites are of economic grade and tonnage. However, most of these deposits have not been properly explored, quantified and mined [3].

Overdependence on revenue from oil and gas exports is the major reason for the neglect of this mineral and other solid minerals which have been a major source of income for Nigeria in the past. In fact, Nigeria was the 5th largest producer of tin and the world's leading producer of columbite in 1965 [76]. After that time, production began to decline drastically even up till date. Other factors that have contributed to the neglect of the solid minerals are fall in price, illegal mining and sales, lack of sophisticated modern mining equipment and funds as well as inability to locate fresh deposits in the past.

What is the way forward? How can tin production be revived in Nigeria? Recommendations on how to revive the production of tin as well as other solid minerals include:

1. Acquisition and provision of advanced and sophisticated mining equipment by the government and interested individuals so as to be able to mine the tin-bearing lodes and pegmatite fields. The equipment can be rented out to interested miners at affordable prices. This will no doubt encourage mining, provide employment and generate income for the government and private investors.
2. Development of equipment by Nigerians (students, teachers, researchers, engineers, etc) which can be used to mine marginal (low grade) ores so that previously non-minable deposits can be profitably mined [10].
3. Training of young people to become professionals in mineral exploration and exploitation, thereby adding to the technical manpower base of the nation.

4. More detailed exploration to find new (hidden) lodes and pegmatites, buried alluvial and other deposits of economic potential.
5. Prevention of illegal mining by indigenes and mining companies. This can be done by the enactment and enforcement of strict mining laws and fines to prohibit such activities.
6. Easy access to mineral rights and mining licenses as well as guaranteed security of tenure.
7. Provision of mining incentives, loans and tax relief to mining companies.
8. Establishment of local manufacturing companies that use tin in the production of different materials.
9. Good governance, political stability, good resource management and shunning of corrupt practices.
10. Provision of basic social amenities such as security, good transportation system, stable power supply, etc. This will encourage investors, both local and foreign, to invest in mining in Nigeria and assure them of making profits.

7. CONCLUSION

Tin deposits abound in two major metallogenic provinces in Nigeria – the rare metal-bearing pegmatite and Younger Granite provinces. Minor occurrences of tin are found in mineralized pegmatites in the Obudu and Oban massifs of southeastern Nigeria. The total estimated tin (cassiterite and stannite) reserve of Nigeria is at least 300,000 tonnes. A substantial amount of the tin-bearing deposits, as revealed by geological (geochemical, mineralogical and geophysical) and economic studies, are minable at profit.

Tin ores occur in association with tantalite, niobite (columbite), sphalerite, gemstones and other economic minerals in the tin metallogenic provinces of Nigeria. This association makes mining of cassiterite profitable because other economic minerals can also be recovered in the process. New measures must be put in place to encourage tin mining in Nigeria as it is a viable source of revenue to the nation if properly exploited.

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