



LITHIUM GEO-RESOURCES IN PAN-AFRICAN PEGMATITES OF NIGERIA - AN EVALUATION OF THEIR GEOLOGICAL AND GEOCHEMICAL CHARACTERISTICS AND IMPLICATIONS FOR MINERAL EXPLORATION

MOSES A. OLADE

Email: mosesolade48@gmail.com

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ABSTRACT

Nigeria has recently witnessed the discovery of several high grade lithium deposits in pegmatites of Late Proterozoic (Pan-African) age. The lithium-bearing rare-metal pegmatites occur as dykes and sill-like bodies of relatively small dimensions (averaging 500m x 20m x 100m) intersecting mostly low to medium-grade metasediments and metavolcanics of Nigeria's Proterozoic 'Schist Belts'. These pegmatites are structurally controlled and belong in chemical composition to the Lithium-Cesium-Tantalum (LCT) family of pegmatites and most commonly enriched in the lithophile elements and mineralized in places with Li, Nb-Ta, Sn and Be. Their distribution is confined mainly to a broad WSW-ENE trending zone within the Precambrian basement complex which is now designated as a metallogenic "pegmatite province" regarded as a northeastern extension of the well-known Eastern Brazilian Pegmatite Province (EBPP). Commercial deposits of lithium, first reported in Nigeria in 2018, have been observed in at least six states, namely; Oyo, Kwara, Kogi, Ekiti, Nasarawa, Kaduna and the Federal Capital Territory. Other states with lithium prospects of unknown economic value are Cross River, Bauchi, Niger, Edo and Taraba. Lithium mineralization occurs as disseminated crystals, mineral veins and felted masses or clusters of the main ore minerals, spodumene and lepidolite, with scattered crystals of the minor minerals; polyolithionite, amblygonite and petalite. Apparently, there is some sort of regional zoning in the distribution of the lithium minerals in which spodumene is dominant over lepidolite in the southwest region of Oyo and Kwara states (spodumene >> lepidolite); lepidolite is almost exclusive in the west-central region of Kogi and Ekiti States, while lepidolite and polyolithionite (both Li micas) exceed or equal spodumene abundance (lepidolite > spodumene) in most parts of the north-central region of Nasarawa and south Kaduna State. The deposits are relatively high grade, ranging from <0.5% Li₂O to up to 13% Li₂O, with the high-end values being attributed mostly to surficial enrichment. The globally accepted cut-off grade for lithium is 0.4% Li₂O. This paper evaluates the geological and geochemical characteristics of the LCT rare-metal pegmatites, and the mode of occurrence of the lithium mineralization and their economic potential. There is an apparent relationship between lithium mineralization and the presence of low to medium-grade metasedimentary host rocks of the Proterozoic schist belts. Most of the lithium pegmatites do not show any spatial, temporal or genetic relationship with the well-known Pan-African granites (aka Older Granites). It is surmised that the lithium pegmatites are mostly of anatectic origin, derived from partial melting and anatexis of Al-rich and Li-rich metapelites during low to medium-grade regional metamorphism, followed by fractionation of the pegmatite melts in the waning and post-tectonic phase of the Pan-African collisional orogeny. The implications of these preliminary findings on mineral exploration strategies and systematics are briefly discussed.

KEYWORDS: Lithium deposits Nigeria; pegmatites; Nigeria's pegmatite province; lithium mineralization; lithium belt; spodumene pegmatite, anatectic pegmatites; spodumene; lepidolite minerals

INTRODUCTION

Global demand for lithium has increased substantially in recent years due to its use as a critical component in various industrial applications, particularly in the production of rechargeable batteries that are used in electric vehicles and a variety of electronic devices such as smartphones, laptops, drones and energy storage systems from solar and wind power.

In addition, lithium finds widespread applications in other industries, including aerospace, automotive, ceramics, glass, and pharmaceuticals. In addition, due to the conscious attempts to mitigate global warming by reducing or eliminating the use of fossil fuels, there has been a growing interest in clean energy which has dramatically increased the global demand for lithium by switching to zero emission electric vehicles.

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For every ton of lithium used in EV batteries will displace about 200,000 tons of CO₂ emission per annum. The global demand for lithium in 2022 was 330,000 metric tons, and is projected by the World Economic Council that, by 2030, the demand will exceed 3 million metric tons. Sustained lithium demand is expected to continue worldwide, and the lithium market deficit is projected to grow out to 2040, driven by significant demand and tight supply. Lithium (Li) ore is derived from mineralized rocks and sediments that contain minerals with substantial amounts of lithium (Evans, 2014). Spodumene, a Li-pyroxene and aluminosilicate (LiAlSi₂O₆) is the principal ore mineral and currently the most explored and processed lithium ore due to its relatively high content of lithium (6-8% Li₂O) and extensive occurrence in hardrock lithium deposits (Bradley et al., 2017). Other important lithium ore minerals are lepidolite, a Li- mica, and petalite (Table 1). In mineralized rocks, these minerals are usually interspersed with gangue minerals mostly quartz, feldspar and mica.

Lithium belongs to the group of elements known as the “alkali metals” (Li, Na, K, Rb, Cs) and is well known for some unique properties, such as being the lightest metal, or having the highest electrochemical potential, and being highly reactive with water. Lithium ores are typically found as mineral deposits in several geological environments within the Earth’s sialic crust, and can be extracted through various mining methods, depending on the location and composition of the ore deposit. There are three major types of lithium deposits: (1) salt brines; (2) sedimentary deposits and (3) hard rock pegmatites; Currently, the world’s lithium supply is mainly derived from four countries: Australia, China, Chile and Argentina which together account for 95% of global production of 184,000 tons in 2023. Australia produced 86,000 metric tons in 2023 that were obtained solely from hard-rock lithium pegmatites. In Africa, the major players in lithium geo-resources are Zimbabwe, Namibia, Democratic Republic of Congo, Ethiopia, Mali and Ghana. They currently have a combined annual production of about 4,000 tons (4% of world production). Global demand for lithium in 2024 was estimated as 1 million tons and is expected to reach about 3 million tons by 2030. The projected demand-supply gap has propagated a “rush” by exploration and mining companies to find more lithium geo-resources, particularly in Africa with unexplored potential for hard rock deposits.

Nigeria is among several countries worldwide that have recently experienced boosted exploration activities and announced discoveries of “huge” deposits that have created a scramble to locate and mine these deposits, and also maximize the value chain by building processing plants and battery manufacturing facilities for the emerging electric vehicle industry and energy storage systems.

The purpose of this paper is to provide an overview of the geological and geochemical characteristics of the Nigerian lithium-bearing pegmatites, evaluate the mode of occurrence and origin of associated deposits, and highlight the implications for mineral exploration strategy and systematics in the search for lithium ore bodies in Nigeria.

LITHIUM GEOCHEMISTRY OF ROCKS

Lithium (Li) is a lightweight, silvery-white element with an atomic number of 3 in the Periodic Table, and an atomic weight of 6.941 (Bradley et al., 2017). Lithium is also a very soft metal with hardness less than talc, the softest mineral on the Mohs scale of hardness. Lithium accumulates predominantly in rocks of granitic composition, and belongs to the alkali group of elements which includes sodium (Na), potassium (K), rubidium (Rb) and cesium (Cs). They all have a valence (charge) of +1, but lithium has the smallest ionic size of 0.68 Å (angstrom units). In nature, Li does not occur in the metallic state but tends to bond preferentially with silicate minerals rather than sulfides or metals. Lithium is relatively soluble as an ion, and therefore, commonly dissolved in saline brines and present in oceanic water (McLennan et al., 2017).

During magmatic crystallization, Li⁺ can replace Mg²⁺ or Fe²⁺ but due to more similarity in ionic size, it tends to replace magnesium (0.66 Å) in silicates rather than the much larger Fe²⁺ (0.92 Å) and alkali ions - Na (0.97 Å), K (1.33 Å), Rb (1.47 Å) or Cs (1.67 Å) to which it has closer geochemical affinity (Garrett, 2004). Consequently, Li normally substitutes for Mg in magmas during crystallization, but because granitic magmas contain little Mg for substitution, Li ends up accumulating in the magma along with the so-called “incompatible” elements. Lithium-bearing minerals usually form during the late- to post-magmatic phases of crystallization and are usually associated with the silicate and aluminosilicate minerals of felsic igneous rocks and pegmatites where Li is widely present in discrete minerals or as an accessory element in K-feldspar, biotite-mica, amphibole and clay minerals. Lithium is found in more than 100 minerals but those with economic value are few, including spodumene, petalite and lepidolite (Table 1), of which the prevalent mineral often depends on the temperature and pressure conditions of crystallization (Bradley, 2017). With respect to abundance in rocks, Li is considered to be a “rare” element in the Earth’s crust, with a crustal abundance in the range of 17 to 70 ppm, and an average of 20 ppm (McLennan, 2001). In igneous rocks, Li ranges from 0.5 ppm in ultramafites, through 16 ppm in basalts to 47 ppm in granites, (Evans 2014; Bradley et al., 2017). The close association of lithium ores with pegmatites is widely known and consistent with the concept of “ore-rock association” (Stanton, 1972).

This relationship is believed to be genetic, and attributable to the behavior of a particular element, such as lithium during crystallization of igneous melts. The concentration of Li in sedimentary rocks is relatively high, with an estimated average of 53 ppm, and values of 17 ppm in sandstones, 66 ppm in shales, 1.5 ppm in carbonate rocks and 57 ppm in deep-sea clays (Bradley et al., 2017). During chemical weathering, Li has a close affinity with clay minerals and is trapped and concentrated in clay deposits. Hence, only little amounts get to sea water which contains less than 1 ppm Li (Bradley et al., 2017). Consequently, Li is largely retained in the products of weathering because of its concentration in clay minerals. This relationship accounts for the high values obtained for shales and other fine-grained sediments (Horstman, 1957). However, under conditions of typical lateritic weathering in tropical terrains, Li becomes more mobile due to mildly acidic conditions associated with ferruginization, and the elevated Li concentrations in clays may be lost. This behavior has some implications for the concentration of Li in surficial geochemical prospecting using stream sediments and soils in tropical terrain. The top soils usually contain far less Li than the underlying substratum.

In igneous environments where Li accumulations occur in pegmatites, granites, and leucogranites, studies have shown that both magmatic and hydrothermal processes contribute to the accumulation and remobilization of Li to form economic mineral deposits (Bradley et al., 2017). During crystallization of felsic magmas or pegmatitic melts, Li along with other cations with relatively large ionic size or high valency, (e.g. Be, Li, Rb, Cs, REE, Nb, Ta and Sn), are concentrated in the residual fluids as fractional crystallization proceeds, and may lead to the formation of Li deposits in pegmatites and associated quartz or mineral veins. Fluorine (F) and sometimes boron (B) minerals may be associated with lithium deposits which may indicate that volatiles were involved in the transportation of lithium during ore formation. Mineralogical zoning in mineralized complex pegmatites is one of the unique features of lithium mineralization suggesting that additional fractionation of pegmatitic fluids could occur, leading to further enrichment of Li in the innermost zones of the pegmatites (Bradley et al., 2017). Studies have also shown that late-stage metasomatism often associated with albitization occurs along the contacts of pegmatites with host rocks and within the pegmatite intrusions, leading to Li enrichment and recrystallization of new Li minerals.

In metamorphic rocks, Li values vary considerably depending on the source rocks. Pelitic metasediments such as mica schists derived from shales, and some felsic metavolcanics usually contain high concentrations of Li due to its affinity for clay minerals compared to the gneisses and amphibolites. During medium to high grade regional metamorphism,

particularly at low P/high T (sillimanite phase) or high P/high T (granulite facies), metasediments containing high Li and Al may crystallize a bunch of Li minerals as aluminosilicates (Knoll et al., 2023). During high grade metamorphism involving partial melting, Li is a fluid-mobile element that can be easily partitioned into partial melts of pegmatitic composition generated during regional metamorphism (Sbaw. et al., 2016).

NATURE OF RARE METAL PEGMATITES AND LITHIUM ENRICHMENT PROCESS

Mineral deposits of lithium in igneous rocks are often referred to as “hardrock lithium”, and they constitute about 25% of world production. The host rocks of these deposits are predominantly pegmatites, with minor occurrences in granites, leucogranites, aplites, and rare quartz veins. Pegmatite deposits are one of the world’s most significant sources of lithium of which the association is primarily genetic. The lithium minerals are commonly spodumene, lepidolite and petalite (Table 1). Spodumene, an aluminosilicate of lithium ($\text{LiAlSi}_2\text{O}_6$) is the most common, and currently the most explored and processed lithium ore due to its relatively high content of lithium (6-8% Li_2O) and ubiquitous presence in hardrock deposits (Kunasz, 2006). Lithium-bearing pegmatites are usually coarse-grained, intrusive rocks characterized by huge crystals, variable texture, and presence of internal zoning. They are composed mainly of interlocking coarse crystals of quartz, albite, microcline and mica, with some accessory minerals such as spodumene, and beryl. Besides lithium, these pegmatites are very significant sources of other rare metals used today, particularly tantalum (Ta), niobium (Nb), cesium (Cs), tin (Sn), beryllium (Be) and the rare earth elements (REE) (London, 2008).

Pegmatites have been classified in many ways, including a simple division into “simple” and “complex” pegmatites, based on their mineral complexity and/or presence of zoning. The “simple pegmatites” that are usually barren of mineralization have a simple composition of minerals found commonly in granitic rocks such as quartz, feldspars and mica, whereas the “complex” pegmatites may contain numerous unusual minerals, and may be distinguished by internal zoning in which the core zones can concentrate a variety of economic minerals (Bradley et al., 2017). Complex pegmatites that are mineralized with lithium and/or Nb, Ta and Sn are often referred to as the “rare metal” pegmatites. London (2018) narrowly defined a “rare-metal pegmatite” as “a pegmatite that hosts appreciable amounts of beryl, lithium ores, tantalite, apatite and tourmaline”. These pegmatites are found in both igneous and metamorphic environments where some are related spatially to granitic intrusions, while others have no such relationship.

There are three salient characteristics of lithium-bearing pegmatites that are of economic significance: (1) extremely large crystal size, (2) mineralogical zoning, and (3) enrichment in a suite of lithophile rare elements, such as Li, Cs, Rb, Be, Ta, Nb, Sn, REE, B, and F (London, 2008). The larger size of Li pegmatite minerals such as spodumene increases the economic value of lithium in pegmatite deposits. For example, spodumene crystals containing up to 8% Li_2O have been found in dimensions exceeding 14 meters in the pegmatite deposits of the Black Hills of South Dakota, USA. Large crystals and coarse texture were previously believed to be a result of slow cooling at great depths in the presence of volatiles. However, London (2018) has demonstrated that slow cooling of melts generally results in larger crystals only within plutonic bodies (granites), but not in pegmatites. This was attributed to the extremely low viscosity and highly supersaturated state of the igneous melt in pegmatite-forming bodies due to the concentration of volatiles. The pegmatite fluid's very low viscosity enhances ionic diffusion which allows components to move about freely and migrate rapidly to join an existing crystal to form large crystals rather, than coming together to form new crystals [London, 2018; Pearce 2018]. Mineralogical zoning is also a unique feature of complex rare metal pegmatites which is characterized by the development of zones comprising unique minerals that are often products of progressive fractionation and crystallization of pockets of volatile-rich, super cooled residual pegmatite fluids at low temperatures. This phenomenon produces mineral segregation and concentration of useful ore minerals including lithium in the core zones. The outermost zones are usually composed of albite, muscovite and microcline (Evans et al., 2017). Further enrichment of lithium usually continues in the innermost zones of the pegmatites which enhances the economic value of lithium deposits (Bradley et al., 2017). In terms of chemical composition, the lithium-bearing pegmatites are mildly to substantially peraluminous and belong to the LCT (Li-Cs-Ta) family (London, 2018); and characterized by enrichment in Li, Cs, Rb, Be and Ta. Most of the world's known lithium deposits are found in LCT pegmatites along with other rare metals, such as cassiterite, tantalite, and beryl, as well as a number of gemstones (Bradley et al., 2017). While these LCT pegmatites are related to fractionated granites and syenites (London, 2008), it is also known that pegmatites formed by anatexis of metasedimentary rocks generally show close affinity in composition with LCT pegmatites (Goodenough et al., 2019).

Both igneous and metamorphic processes accompanied by post-crystallization metasomatism may contribute to the formation of lithium pegmatites.

Those that form by magmatic processes may originate from an S-type or I-type peraluminous parental magma by extreme fractionation and occupy the roof zone of a granite pluton whereas those pegmatitic melts that emanate from partial melting of metasedimentary and metavolcanic rocks can also undergo progressive differentiation (London, 2018). Each genetic process will produce either granitic or pegmatitic melts that evolve into highly fractionated, residual fluids that get progressively enriched in Li, Rb, Cs, Be, Ta and Nb.

Lithium enrichment is a cumulative end product of enhanced or extreme fractionation that can lead to the formation of lithium ore deposits in the very late phase residual pegmatitic fluids. This may be accompanied by metasomatic and/or hydrothermal processes involving addition of aqueous alkali (Na) and in some cases, F- or B-rich fluids, which leave their distinct mineralogical overprint on the already formed lithium minerals; such as the crystallization of fine-grained albite, fibrous or spherulitic aegirine, and tourmalines (Kaeter et al., 2020). Metasomatism may also lead to the alteration and enrichment of existing lithium bearing minerals, such as converting lepidolite to spodumene. In some cases, the primary mineral assemblage and texture are completely obliterated by this late-stage hydrothermal reworking. The addition of albite and removal of plagioclase in the process of albitization of feldspars is one of the prominent manifestations of metasomatism that may be accompanied by lithium enrichment and formation of new spodumene in lithium pegmatites (Shaw et al., 2016). The albite-spodumene subtype of lithium pegmatites reflects products of intense metasomatism. In anatectic pegmatites, lithium-rich melts can be produced by direct partial melting and anatexis of lithium-rich pelitic metasediments during low to medium-grade (sillimanite phase) metamorphism (Shaw et al., 2016; Webber et al., 2018). Lithium is fluid mobile, and can be transferred from an Al-rich metasediment into an anatectic melt through the conversion of staurolite to sillimanite (Shaw et al., 2023). Initially, these pegmatitic melts may be small but become further enriched in lithium during fractional crystallization of quartz and feldspar as the fluid migrates to higher levels in the crust. Recent experimental studies (Schuster et al., 2019) have confirmed that staurolite melting reactions can generate Li-rich melts from metapelite rocks (Knoll et al., 2023). It is believed that these anatectic pegmatites are similar to those formed from melts of peraluminous granites that crystallize at 650 to 750 °C at <4 kbar pressure (Keyser, 2023). They show characteristics of the LCT family of pegmatites although may be not as highly fractionated as the melts from granitic sources.

NIGERIA'S LITHIUM-BEARING PEGMATITES

Rare metal mineralization involving tin (Sn), niobium (Nb) and tantalum (Ta) in Nigeria is associated with two distinct geological environments: (1) Jurassic Younger Granite complexes, and (2) Proterozoic (Pan-African) pegmatites. In the Jurassic Younger Granites, mineralization of mostly cassiterite (Sn) and

columbite ($\text{Nb} \gg \text{Ta}$) occur as hydrothermal veins and disseminations in albitized biotite granites while in the Proterozoic rocks, a similar mineralization pattern is found as tantalite ($\text{Ta} \gg \text{Nb}$), minor cassiterite and lithium minerals exclusively within pegmatites as scattered crystals, felted masses and mineral veins (Olade, 2024)

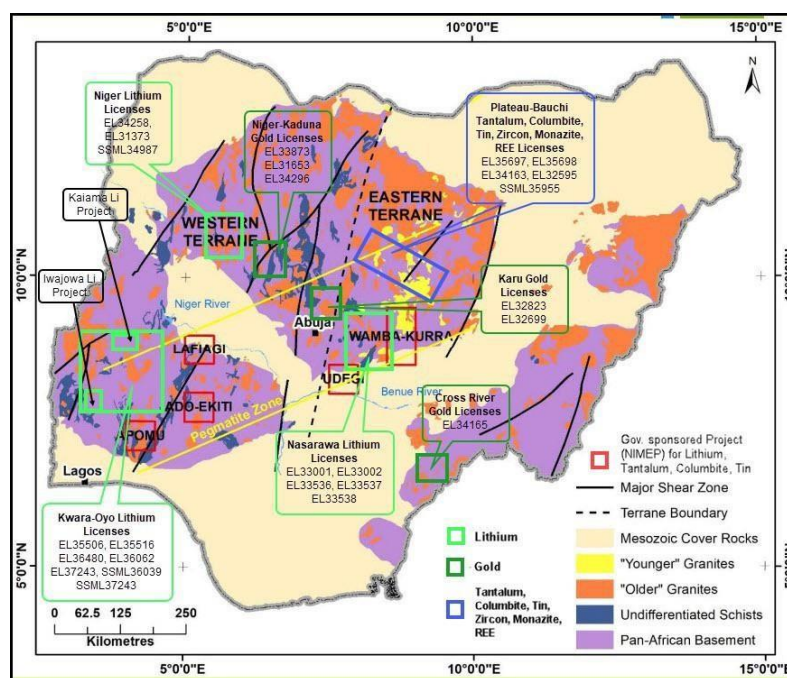


Figure 1: Geological Map of Nigeria Showing Major Rock Groups

The Pan-African pegmatites and the Older Granite intrusives have been considered as related because both were emplaced with overlapping ages during the widespread Pan-African orogeny. However, the Older Granites are neither mineralized nor have direct genetic link with the pegmatites (Matheis, 1987, Okunlola, 2008). Isotopic age determinations show that the pegmatites were late tectonic to post-tectonic (520-450 Ma) whereas the peraluminous granites were syntectonic to late-tectonic (650-500 Ma) (Matheis and Caen-Vachette, 1983). The Pan-African pegmatites occur predominantly as vertical to sub-vertical dykes, tabular and subhorizontal bodies that trend NW-SE or NE-SW, with occasional N-S or E-W orientation. They are found in varying sizes, from a few meters to 1.5 km long, and from <1 m to 150 m wide. The flat-lying tabular pegmatite bodies may show stretched "pinch and swell" structures. More than 3000 pegmatite bodies are known including barren and mineralized varieties, and many more are being discovered in remote areas as a result of the ongoing active exploration for lithium. The pegmatites generally occur as isolated units, sub-parallel groups or in swarms that transect a wide variety of Precambrian basement rocks including schists and gneisses (Fig. 1) (Okunlola, 2006; Adekeye and Akintola, 2007).

Based on mineralogical composition, Jacobson and Webb (1946) recognized three types of Nigerian

pegmatites: (a) quartz-microcline, (b) quartz-mica, and (c) quartz-K-feldspar-plagioclase-mica assemblages, that may be albitized and mineralized. The pegmatites appear as simple and complex varieties, in which the simple pegmatites are usually medium grained and composed of common granite minerals such as K-feldspar, quartz and mica (usually biotite). On the other hand, the complex or rare-metal pegmatites may or may not show internal zoning, with a medium to coarse-grained texture and diverse mineralogy and varied bulk chemical composition. They belong to the quartz-feldspar-muscovite type (London, 2008), in which the principal minerals are quartz, K-feldspar (microcline/orthoclase), Na-plagioclase (mostly albite), and minor muscovite/biotite with a suite of accessory minerals including beryl, lepidolite, spodumene, zircon, apatite, amblygonite, lithiophyllite, cassiterite, tantalite, and monazite (Okunlola, 2005, Kinnard et al., 2016). Metasomatism may introduce a substantial amount of albite in K-feldspar. Tourmaline (mostly schorl) is widespread in many of the mineralized pegmatites reflecting the presence of boron in the pegmatite.

The metallic and gemstone minerals commonly found in the pegmatites are cassiterite and tantalite or columbite-tantalite (coltan) which appear as scattered crystals or pockets of minerals, along with kunzite, beryl, garnets, aquamarine, emerald, amethyst, zircon and tourmaline. Geochemical studies have shown that

Nigeria's rare-metal pegmatites are granitic and peraluminous in composition (Matheis, 1987; Okunola and Akinola, 2010), and fractionated to a certain degree, as indicated by their trace element characteristics and element ratios including K/Rb and Rb/Sr (Oyebamiji et. al., 2018). The pegmatites belong to the Lithium-Cesium-Tantalite (LCT) family, and are enriched in the lithophile elements (Rb, Li, Cs), rare metals (Nb, Ta, Sn) and volatiles (F and B) sometimes in association with albite metasomatism (Kinnard, 1984; Akintola and Adekeye, 2009). Over the years, extensive research has been undertaken to determine the ore-bearing potential of many Nigerian pegmatites using element ratios and trace element contents, and the results have arguably identified as useful geochemical parameters and pathfinder elements that could be helpful in mineral exploration. (Olade and Emofurieta 1988; Garba, 2003; Okunola, 2005, 2008; Akinola and Adekeye, 2008).

The origin of Nigeria's rare metal pegmatites has been widely discussed. Some researchers believe that the pegmatites are fractionated products of the Older Granite magmatism, while others support the idea that they were likely produced by partial melting and anatexis of low to medium-grade metasedimentary host rocks. Most of the pegmatites do not have intrusive granites within a 30km radius. Isotopic age determinations show that the pegmatites were late-tectonic to post-tectonic (550-420 Ma) whereas the granites were largely syntectonic to late tectonic (650-520 Ma). Matheis (1987) and Matheis and Cean-Vachette (1983) studied the relationships between the Pan-African granites and nearby pegmatites but noted that there was no defined "geochemical link" between them, and were separated in age by approximately 100 million years. The preferred model for the origin of the Nigerian lithium-bearing pegmatites is by partial melting and anatexis of Al-rich pelitic schists at upper greenschist to lower amphibolite facies grade metamorphism during the waning and post-tectonic phases of the Pan African orogeny. This was followed

by further fractionation of the LCT pegmatite melts to generate lithium deposits. Emplacement of these pegmatites was controlled by structural features (faults, shear zones, etc.) associated with the Pan-African orogeny. Pelitic rocks are known to contain high concentrations of lithium due to the tendency of lithium to concentrate in clay minerals. LCT pegmatites are known to crystallize at remarkably low temperatures (350 to 500 deg. C). The anatectic origin of rare metal pegmatites has been accepted by numerous research workers both in Nigeria and worldwide (Okunola and Akinola, 2009; London, 2018; Weber et. al., 2019; Shaw et al., 2022). Geological mapping and exploration for lithium have identified more pegmatite bodies in Nigeria's Schist Belt. The highest density of rare-metal pegmatites is found along a WSW-NNE zone that is named the "*Nigeria's Pegmatite Province*" (NPP), as different from the previous "Nigeria's Pegmatite Belt" which covered a much narrower landmass characterized by mostly tin-tantalum-niobium mineralization. Nigeria's Pegmatite Province (NPP) covers a broad swath of land about 200 km wide and over 600 km long, extending WSW-ENE from Oyo State in the southwest to Plateau State in the north-central region (Fig. 3).

The northern boundary stretches from western Oyo State through Kwara, Niger, Kaduna to Bauchi State. The southern boundary extends from Ogun State, through Osun, Ekiti, Kogi, Nasarawa to Plateau State (Fig. 2). More than 3,000 pegmatites, both barren and mineralized, of diverse mineralogy and structural orientation have been identified. within the metallogenic province (Matheis and Emofurieta, 1990; Okunola, 2006). However not all rare-metal pegmatites are confined to this belt. A prominent pegmatite field outside the NPP exists in the Oban-Obudu massif in the southeastern state of Cross River. A few scattered pegmatites that are fault controlled and mostly barren are located in the northwest from Kuseriki/Birnin Gwari towards Gusau (Fig. 2).

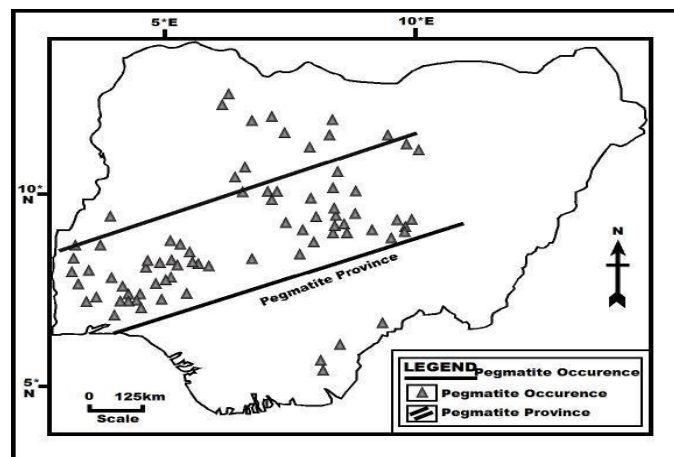


Figure 2: Major pegmatite occurrences in the Pegmatite Province

The NPP has been considered as the northeastern extension of the well-known “Eastern Brazilian Pegmatite Province” (EBPP) that extends from Bahia State in the north through Minas Gerais to Rio de Janeiro State in the south (Pedrosa-Soares et al., 2009; Kinnard et al., 2016). Rare-metal mineralization in the Brazilian EBPP is found in Late Proterozoic (Neoproterozoic) pegmatites associated with granites of the same types and age range as those in the NPB. They were emplaced during the Aracua orogeny which was synchronous with the Pan-African orogeny (Petrossa-Soares et al., 2009). The EBPP is home to high quality lithium ores, mostly spodumene, and regarded as one of the most significant granitic pegmatite provinces in the world (Morteani et al., 2000; Lithium Ionic, April, 2023). Primary mineralization in the pegmatites is characterized of tantalum (Ta), niobium (Nb), tin (Sn) and lithium (Li) which occur in varying quantities and characterized by columbite-tantalite, cassiterite and spodumene ore minerals as disseminations or clusters within pockets or pods in sometimes zoned pegmatites. Commonly associated accessory minerals are beryl, tourmaline and a variety of gemstones (emerald, kunzite, topaz, amethyst, aquamarine, paraiba tourmaline) and industrial minerals (quartz, feldspar, clay). Alluvial and eluvial deposits are the most valuable concentrations of cassiterite and tantalite while lithium ores are extracted predominantly from hard rock mining of

pegmatites. A gradual decrease in tantalite and increase in columbite has been noted from the southwest to the northeastern part of the metallogenic province.

LITHIUM GEO-RESOURCES

The discovery of commercial lithium deposits in Nigeria was first reported from Kaduna State in 2018 by a Nigerian mining company - Kian Smith Trade & Co. Ltd. Since then, several occurrences have been found through surface geological sampling and mined. They are all localized within the Pan-African pegmatites in several states; particularly in the southwest and north-central regions. The Nigerian Geological Survey Agency (NGSA) which has conducted some of the exploration activities under the auspice of the Nigerian Integrated Mineral Exploration Program (NIMEP) officially announced in October 2023 the discovery in Kwara state of several “huge deposits of lithium of high quality with lithium oxide (Li_2O) contents ranging from 1% to 13% in spodumene and lepidolite ore minerals contained in pegmatite”. The high grade lithium discoveries are concentrated in the newly defined “Nigerian Lithium Belt” which lies slightly north of the niobium-tantalum-tin enriched zone (Fig. 3). Currently, commercial deposits of lithium are found in six states; Oyo, Kwara, Kogi, Ekiti, Nasarawa, Kaduna, and the FCT (Fig. 4), while a few occurrences or mineral showings of unknown economic value have been reported in other states in the northeast and southeast regions.

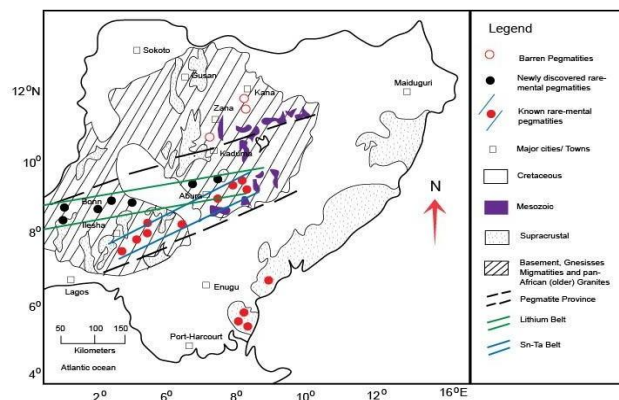


Figure 3: The Lithium and Tantalum Belts in Nigeria's Pegmatite Province

Southwestern Region: Oyo, Kwara, Ekiti States and (Edo?)

North-Central Region: Nasarawa, Kaduna and Kogi States, and the FCT

Northeastern Region: Bauchi and Taraba States (?)

Southeastern Region: Cross River State (?)

Based on surface appearance and subsurface drillhole intersections, the lithium deposits occur as disseminated or crystals and lenticular to irregular masses or clusters of lithium minerals particularly spodumene and lepidolite in host-rock pegmatites that appear in various forms, mostly as dikes, sills, and

irregular bodies emplaced within surrounding country rocks mostly mica schists and amphibolites with rare intrusion into granites and surrounding gneisses. Several important lithium pegmatite districts have been identified namely: (1) Oke-Ogun, (2) Kaiama-Bina, (3) Ijero-Ekiti, (4) Share-Pategi, (5) Egbe-Isanlu, (6) Nasarawa-Karu (7) Keffi-Kokono and (8) Jemaa-Sanga (modified after Okunola, 2008). Table 2 summarizes the characteristics of the lithium pegmatite districts.

A schematic distribution map of the major Li occurrences has resulted in the delineation of a distinct WSW-ENE trending mineral belt for Li that is separate and slightly to the north of the well-known SW-NE trending Sn-Ta-Nb belt, both of which tend to merge in the north central region (Fig. 3). The main lithium ore minerals are spodumene (dominant), and lepidolite, with rare occurrences of amblygonite, polyolithionite and petalite. Kunzite, a distinct form of spodumene, is found as gemstone in several localities of Oyo and Nasarawa States. In the southwestern region, spodumene is dominant with lesser amounts of lepidolite in Oyo and Kwara States (spodumene >> lepidolite). In the west-central region of Ekiti and Kogi States, lepidolite is the only or dominant lithium mineral, while in the north-central region of Nasarawa and south Kaduna states, lepidolite (and polyolithionite) are as abundant as spodumene. This distribution may represent a pattern of regional mineral zoning.

Lithium concentrations in Nigerian mineralized pegmatites are relatively high, ranging from <2% to as high as 13% Li₂O (recommended cut-off grade is 0.4% Li₂O). The very high values exceeding 9%Li₂O may be attributable to surface enrichment, as most deposits that are currently mined are exposed at the surface. The richest deposits are found in Oyo, Nasarawa, Kwara, Kaduna, Ekiti and Kogi States in that order of importance. Other states that may have showings and potential for lithium mineralization are Baauchi, Edo, Niger and Cross River states. A possible correlation seems to exist between lithium mineralization in pegmatites and the presence of micaceous (pelitic) schists and amphibolite host rocks. This relationship may be due to the likely origin of the Li pegmatites by partial melting of metasedimentary host rocks. Lithium mineralization is attributed to partial melting of Al-rich pelitic schists and amphibolites followed by fractionation of the LCT pegmatite melts generated by low pressure-high temperature (sillimanite grade) metamorphism during the waning and post-tectonic phases of the Pan African collisional orogeny. Pelitic rocks are known to contain high concentrations of lithium due to the affinity of lithium to concentrate in clay minerals. Oke-Ogun Lithium Deposits

Oke-Ogun (former Ibarapa) is a subregion in the northwestern part of Oyo State (Fig. 5) known for significant lithium deposits, and arguably the largest deposits so far identified, based on subsurface drilling information (Thor Exploration, 2023). The area shares a western border with the Republic of Benin and is bounded to the north by Kwara State, and in the south by Ogun State. The geology is typical of the Precambrian basement complex of southwestern Nigeria where extensive Archean gneisses, migmatites and quartzites are overlain by low-grade Proterozoic metasediments and metavolcanics that are intersected by intrusive bodies of granites, syenite and pegmatites. As shown in the geological map of Oyo State (Fig. 6), the areas with extensive mica schists and amphibolite schists (in blue) are confined to the west and southern parts of Oke-Ogun region. Rare metal pegmatites sometimes containing tantalite, columbite, beryl, and gemstones including kunzite variety of spodumene have been mined in the area since the 1980s but serious exploration did not begin until 2015 by Symbol Mining, an Australian company. Segilola Resources Operating Ltd commenced lithium exploration and mining in 2017 in the Komu area of Itesiwaju LGA (Fig. 5). Other LGAs containing lithium occurrences are Iwajowa, Atisb, and Irepo.

The lithium mineralization is associated with pegmatites that are emplaced mostly within Proterozoic metasedimentary and metavolcanic rocks and adjacent gneiss-migmatites. The pegmatites have been studied extensively and results indicate they belong to the LCT-family that are enriched in the lithophile elements, Be and Ta (Adeagbo et al., 2008). There are several of these pegmatite bodies in the area that occur as extensive, coarse-grained dykes, tabular sills and subhorizontal irregularly shaped bodies trending generally NE-SW or rarely E-W. The larger bodies are up to 250m wide and 1.5km long. while the smaller bodies are usually about 10m wide and 200 m long (Adepoju and Ocan, 2010). The mineralized pegmatites belonging to the groups of quartz-albite-muscovite-tourmaline pegmatite, and albite-spodumene type with occasional fine-grained saccharoidal albite-muscovite-tourmaline-garnet rock (Adepoju and Ocan, 2010; Olatunji and Jimoh, 2017).

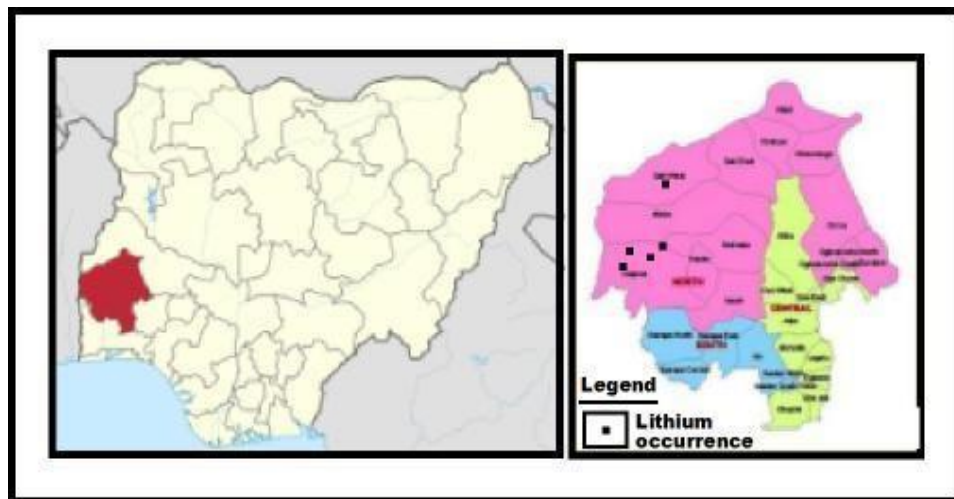


Figure 5: Map of Nigeria Showing Oyo State and Local Government Areas

Significant lithium deposits are concentrated in the Komu and Iwajiwa LGAs with minor occurrences at Kishi and Igbeji areas to the north near the border with Kwara State. The lithium deposits near Komu are located northwest of the village in an area sparsely populated and about 20 km from the border with the Benin Republic (Fig. 5). Detailed geological mapping has shown the Komu area is underlain by Proterozoic

mafic schists, amphibolites, and mica schists surrounded by migmatites and banded gneiss (paragneiss) and granite gneiss (orthogneiss) intruded by granitic pegmatites (Fig. 6) (Adetunji and Ocan, 2010). There are no large bodies of granites nearby but the pegmatite bodies are believed to be of anatectic origin (Adepoju and Ocan, 2010).

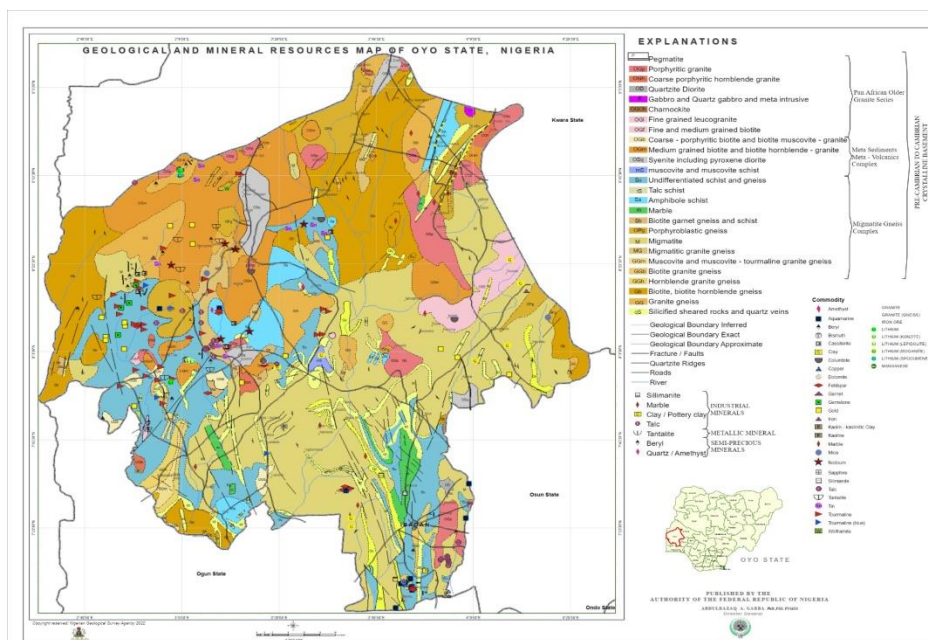


Figure 6: Geological Map and Mineral Resources of Oyo State (After, Musbau, 2014)

In 2022, Thor Exploration, a Canadian mining company established its “West Oyo Lithium project” that carried out a limited sampling of pegmatite bodies in the area to assess the potential for high grade spodumene and lepidolite mineralization.

The sampling data, together with field observations, provided sufficient encouragement to proceed, initially acquiring tenure in areas that returned the highest grade lithium results and potential mineralization (Thor Exploration, 2022).

Table 1: Main Lithium Minerals and Properties

Mineral	Mineral Formula	Lithium %	Specific Gravity	Hardness	Remarks
Spodumene	LiAlSi ₂ O ₆	3.73	3.0 - 3.2	6.5 - 7	A member of the pyroxene group Pegmatite source
Lepidolite	K(Li,Al) ₃ (Si,Al) ₄ O ₁₀ (F,OH) ₂	3.58	2.8 - 2.9	2.5 - 4.0	A member of the mica group (phyllosilicate). Pegmatite source
Petalite	LiAlSi ₄ O ₁₀	2.09	2,4	6.5 - 7	Phyllosilicate (sheet silicate). Pegmatite source
Amblygonite	(Li,Na)Al(PO ₄ (F,OH)	3.44	2.9 - 3.1	5.5 - 6.0	Phosphate. Pegmatite source
Elbaite	Na(Li,Al) ₃ Al ₆ (BO ₃) ₃ Si ₆ O ₁₈ (OH) ₄	1.89	2.9 - 3.2	7.5	Tourmaline group. Pegmatite source
Polyolithionite	KLi ₂ AlSi ₄ O ₁₀ (F,OH) ₂ KLi ₂ AlSi ₄ O ₁₀ (F,OH)	3.0	2.7	2,5 - 4.0	A member of the mica group. Pegmatite source
Holmquistite	Li ₂ (Mg,Fe) ₃ Al ₂ Si ₈ O ₂₂ (OH)	1,85	3.0 - 3.1	5.0 - 6.0	A member of the amphibole group
Hectorite	Na _{0.3} (Mg,Li) ₃ Si ₄ O ₁₀ (OH) ₂	0.54	2.0 - 3.0	1.0 - 2.0	A clay mineral, related to montmorillonite.
Triphylite-Lithiophyllite - Jadarite	LiMn(PO ₄) LiFe(PO ₄) NaSiB ₃ O ₇ OH	4.4 3.38	3.4 - 3.5 2.4	4.0 - 5.0 4.0 - 5.0	Phosphate. Pegmatite source Newly discovered mineral. Hydrothermal alteration product

Table 2: Characteristics of Lithium Mineralization in Selected Pegmatite Districts

	State	Pegmatite District	Pegmatite Field	Host Rocks	Mineralogy	%Li ₂ O
1	OYO	OKE-OGUN	Komu	Schists Metavolcanics	Spodumene >> Lepidolite	Avg. 7% Range 1.3 -9.3%
			Iwajowa	Metasediments	Spodumene >> Lepidolite	Avg. 6%
2	KWARA	KAIAMA/BINA	Kaiama/Bina	Schist/Gneiss Granite	Spodumene	1.3-6.2%
		GBU GBU- LEMA	Gbu-Gbu	Schist & Gneiss	Spodumene >> Lepidolite	Avg. 7% Range: 1 - 13%
		PATEGI-SHARE	Pategi	Schist & Gneiss	Spodumene	Range 0.5 - 4%
3	EKITI	IJERO-EKITI	Ijero	Schist Amphibolite	& Lepidolite	Range 0.2-4.5%
4	KOGI	EGBE-ISANLU	Odo Eri	Schist Amphibolite	& Lepidolite	2.7%
5	NASARAWA	NASARAWA	Nasarawa	Schist /Granite Gneiss	Lepidolite Spodumene	Range: 2.0 -8.4%
		KEFFI/KARU	Keffi/ Kokona	Schist & Granite Gneiss	Lepidolite Polyolithionite	0.7%
			Karu	Schist	Lepidolite Spodumene	—
6	KADUNA	JEMA'A	Dangoma	Serpentinites Gneiss	& Lepidolite Spodumene	Avg. 3.4% Range 2-7%

In August 2023, the company published preliminary results of its investigation and reported discovery of supposedly the “largest” lithium deposit in Nigeria near Komu in Itesiwaju LGA of Oyo State.

During the initial detailed exploration activities in 2022, Thor Exploration found that the ore minerals are spodumene and lepidolite and that the minerals occur as disseminated crystals and masses or clusters of coarse-grained spodumene and lepidolite. Both

minerals occur together, although lepidolite is less abundant. Preliminary ore grade results obtained ranged from 1.34% and 9.31% Li₂O. (The grade of 9.31% Li₂O in one sample may represent surficial enrichment), Mineralization in the pegmatite body is exposed at the surface and is shallow dipping. A follow-up hard rock drilling program in 2023 indicated the pegmatite body was a zoned complex pegmatite, several hundred meters long and about 50 m wide.

The mineralized pegmatite appeared as a tabular body striking NE-SW and dipping slightly at 5 degrees towards the NW, with an average thickness of 20m (Fig. 8). Results of the drilling also indicated that the pegmatite ore body formed a continuous sheet of coarse spodumene mineralization of up to 11m thick towards the upper contact of the pegmatite with mafic country rocks (Fig. 9). There were significant mineralized intersections of about 11m of mineralized rock containing 1.53 to 2.61% Li_2O . Thor Exploration claimed in its report that this pegmatite body is, so far, the largest known zoned spodumene-lepidolite pegmatite in Nigeria. The full extent of this ore body is

still yet to be determined.

A small-scale mining operation is currently extracting a purple colored variety of spodumene known as kunzite which is a gemstone while most of the typical spodumene was once being accumulated. Figure 10 shows the entrance to the mining adit with spodumene crystal swarm (left and center) grading into lepidolite (right wall) (Thor Exploration, 2023). There are still a large number of pegmatites both to the north and south of Komu that need to be systematically explored and evaluated. Thor Exploration has acquired access to approximately 38 km^2 of exploration terrain the Komu area, and has identified several other pegmatite bodies to the northeast and south for systematic lithogeochemical sampling and drilling of up to 5000m of pegmatite rock.

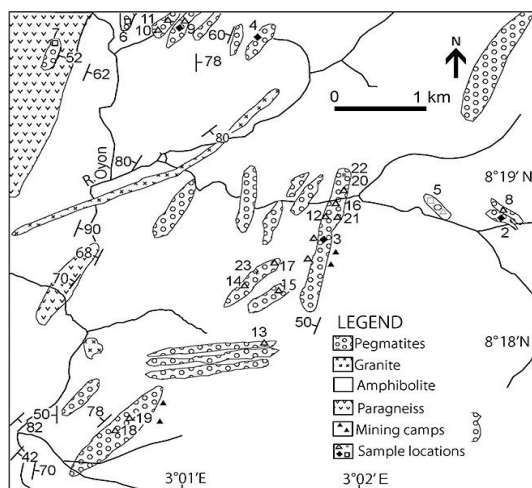


Figure 7; Geological map of Komu area (After Adetunji and Ocan, 2010)

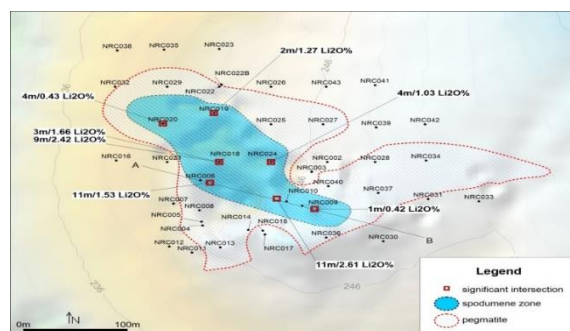


Figure 8: Layout of Drill Holes at Location 6 (Thor Exploration)

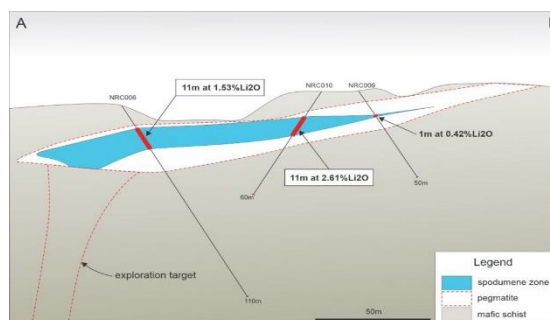


Figure 9: Cross section of Pegmatite and Drillhole Intersections (Thor Exploration)

Another occurrence of a lithium-bearing granitic pegmatite is located north of Komu. It is a coarse-grained, weathered leucocratic albite-spodumene dyke, steeply-dipping and a few meters wide trending NE-SW. The pegmatite which intrudes mafic schists was investigated by Dasen Mining Company of China for lithium in 2022. The lithium mineralization occurs as scattered crystals and small veins of spodumene with minor lepidolite. The grade of the orebody is estimated as 6% Li_2O with an extremely uneven distribution (Dasen Mining Report, 2022). At Iwajowa, approximately 40 km south of Komu, the Emirate Lithium Company has been exploring and working with artisanal miners to sample and extract lithium from the

N-S trending granitic pegmatites that represent the southern extension of those in Komu. The host rocks are mica schist with intercalated mafic schist. Minor occurrences of tantalite, beryl and tourmaline in the pegmatites have been known for several decades. The lithium minerals of interest are spodumene and lepidolite with minor amblygonite. The host rocks for the pegmatites are amphibolites and mica schists. Ore grade ranges between 2 - 6% Li_2O (Babatunde, 2019). Other areas of interest in Oke-Ogun include around Igbeti (Irepo LGA) and Kishi (Olorunsogo LGA) in northern Oyo State along the southern border of the Li-pegmatite bearing areas of Kwara State (Kaiama LGA) where scattered occurrences of lithium pegmatites that are being exploited by artisanal miners.



Figure 10 (a) Exposed lithium ores

(b) Weathered mineralized pegmatite



Figure 11 (a) Spodumene and Lepidolite b) Large crystals of Spodumene (c) Kunzite

Kwara Lithium Deposits

Kwara State is located just north of Oyo State, and is host to significant lithium deposits in the central and northeastern parts of the state (Fig.12). In October 2023, the Nigeria Geological Survey Agency (NGSA) announced the discovery of several “high grade” lithium deposits in Kwara State, with ore grades ranging between 1 and 13% Li_2O . The geological setting of Kwara State is similar to that of other states in the southwestern region that are underlain predominantly by rocks of the Archean gneiss-

migmatite complex with isolated relics of supracrustal schist and amphibolite belts that are intruded in places by Pan-African granites and pegmatites.(Fig.13). The lithium deposits occur in dykes and mineral veins localized within rare metal pegmatites that intersect a variety of rocks including migmatite-gneiss, mica schist, amphibolite and granite, but predominantly mica schist. Mineralization is confined mainly to three pegmatite districts: (1) Kaiama-Bani; (2) Gbugbu-Lema; and (3) Pategi-Share, in Kaiama, Edu and Pategi LGAs respectively. Minor occurrences have also been reported in Oyun and Ifelodun LGAs.

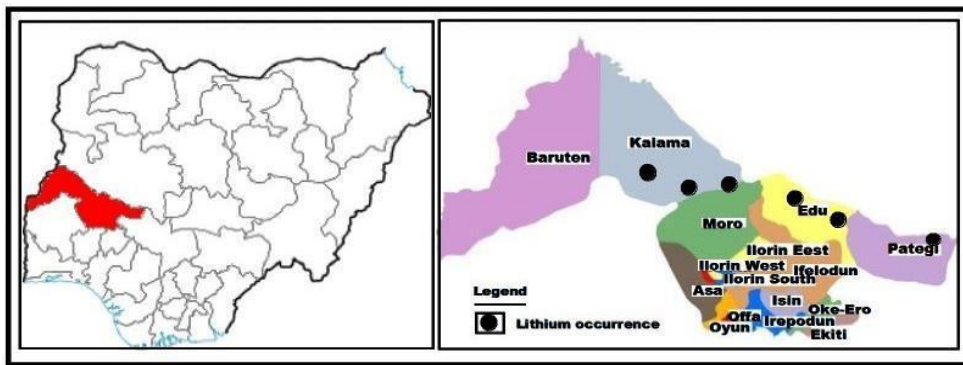


Figure 12: Location of Kwara State and Local Government Areas

The Kaiama-Bani lithium deposits are probably the most extensive in Kwara state, and are being mined from pegmatites in open pits and alluvials in villages around Kaiama, particularly at Bani, 10km to the south. Other occurrences can be found in the southeast and southwest of Kaiama town which is the headquarters of the LGA. The geology of the area has been described by Alepa et al., (2019). It lies within the Nigerian Schist Belt, and characterized by a

prominent biotite granite intrusive body that was emplaced along the geo-contact between the Proterozoic mica schist and amphibolite to the west and migmatite-gneiss to the east. Several pegmatite dykes and associated mineral or quartz veins trending NE-SW and NW-SE are shown to intersect the three host rocks. They are the source of the lithium deposits in the area although they don't seem to have emanated from the biotite granite.

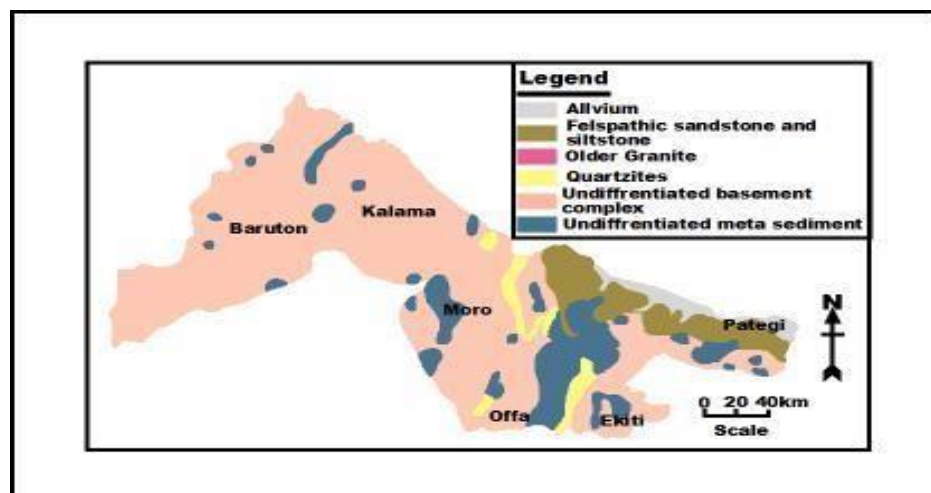


Figure 13: Generalized geological map of Kwara State

Geophysical investigations by Raji and Bale (2022) detected several of these pegmatites with tantalite mineralization at various depths below the surface at localities west and northwest of Kaiama town. Hand dug wells have also intersected these pegmatites. Towards the southeast of the Kaiama area, up to the southern border with Oyo State, there are several pegmatite dykes within the migmatites and mica schists. A large pegmatite body is exposed southwest of Shingelaya, (Fig. 14). Numerous variably-sized quartz veins, ranging in width from a few centimeters to tens of meters are emplaced within the porphyritic granite. It is probable that both the pegmatites and quartz veins are spatially and genetically related to the Older Granite intrusion. The Kaiama pegmatites range in size from a few cm to over 100 m wide and up to 800 m long, they cut across all major lithologies including granite, migmatite, amphibolite and schists,

and consist of both simple and complex pegmatites. The mineralogical composition of the pegmatites is characterized by large crystals of quartz, feldspar, biotite and muscovite. The pegmatites generally appear deeply weathered in several surface exposures (Fig. 15). Rare metals found in the pegmatites include disseminated crystals of tantalite, beryl and spodumene.

Cornerstone Mining Services Ltd, a Nigerian mining company is actively extracting lithium ores from pegmatites in the Bani area, south of Kaiama town. The following detailed description of the deposit was provided by the consulting mine geologist, Eng. Daniel Tuoyo Amiwero. The pegmatites in which the lithium is found are small dykes and veins that trend mostly N-S and NE-SW, with dimensions of 0.1-5m wide, and extending for several hundred meters.

A series of pegmatite dykes have been traced in the deposit extending discontinuously for over 2km along strike (Fig. 16). The surrounding host rock of the lithium pegmatites is migmatite-gneiss. The pegmatites are not complex or zoned, and composed

mainly of quartz, feldspar and mica, with spodumene and minor tantalite and beryl. Spodumene comes in different colors of white, green, pink or purple kunzite. Ore grades vary from 1 - 7% Li_2O , and the lithium resources are vast due to the lateral and vertical extent of the ore-bearing pegmatites.

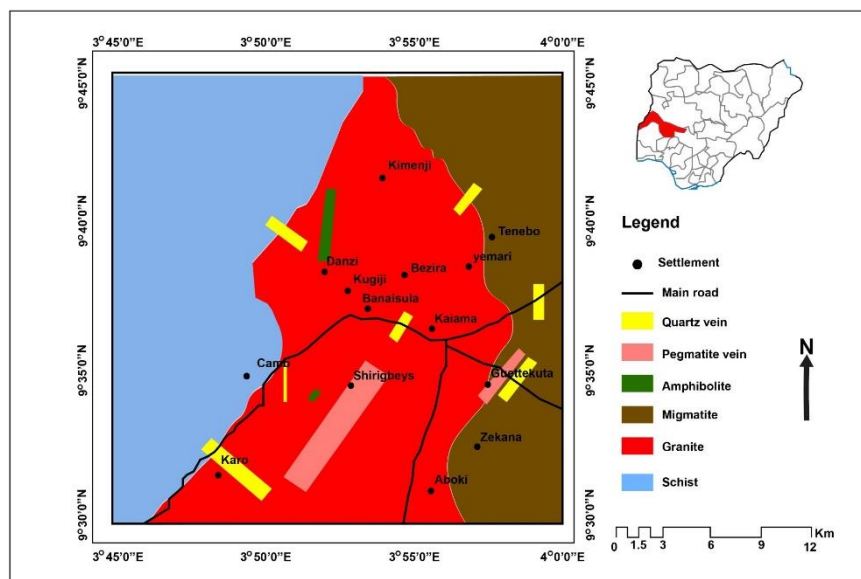


Figure 14: Geological map of Kaiama Area (After Alepa et al; 2019)

The Gbugbu-Lema- pegmatite district lies to the east of Kaiama in the northern part of Edu LGA. The area is associated with substantial lithium deposits in pegmatites and alluvial deposits in rivers and streams due to intense weathering. Lithium mineralization in pegmatites occurs as dykes and mineral veins of varying size and orientation emplaced within relict patches of schistose rocks surrounded by vast granite-gneiss terrains. Garba et al. (2019) described the rare metal pegmatites in the Gbu-Gbu area, indicating that the pegmatites occur mainly as fault-

controlled dykes and tabular bodies transecting mica schists, amphibolite and surrounding gneisses. They appear mostly as internally zoned complex pegmatites that are commonly associated with tourmaline, indicating some boron metasomatism accompanied pegmatite emplacement and mineralization. Geochemical characteristics of the pegmatites show considerable enrichment in lithium and other lithophile elements suggesting highly fractionated pegmatites (Garba et al., 2019).



Figure 15: Excavated weathered pegmatites in open pit at Shirigelaya (After Alepa et al; 2019)



Figure 16:(a) Open pit mine, Bani, Kaiama; (b) Broken Lithium ore, Kaiama LGA

Lithium deposits with spodumene and lepidolite were reportedly discovered in the Gbu-Gbu area by the National Integrated Mineral Exploration Program (NIMEP). Lithium concentrations were variable, ranging from 1-12% Li_2O , with an average of about 7% Li_2O . Continental Lithium, an Australian mineral exploration company, reported in August 2022 that the results of four exploratory samples of pegmatite with spodumene collected from artisanal mining pits in Gbu-Gbu gave favorable results of $>4\%$ Li_2O . Currently, Kian Smith Trade & Co is operating a lithium mine in Gbu-Gbu with focus on cooperative arrangement with artisanal and small-scale miners who are prevalent in the area. In the Lema pegmatite

field east of Gbu-Gbu, the mineralized pegmatites intersect amphibolite and schists, and are deeply weathered (Garba et al., 2019). Lepidolite and spodumene are commonly found within the weathered kaolinite-rich layer in association with minor petalite, beryl and tourmaline. The Lema lithium mine operated by Kian Smith Trade Ltd is one of the first mining operations in Kwara State, although local artisanal miners have been engaged in the rare metal mining business for several years. The Pategi-Share pegmatite district is located in the Pategi LGA on the eastern part of Kwara state that borders Kogi State to the east (Fig. 18).



Figure 17: High grade lithium ores from Gbu-gbu, Kwara State

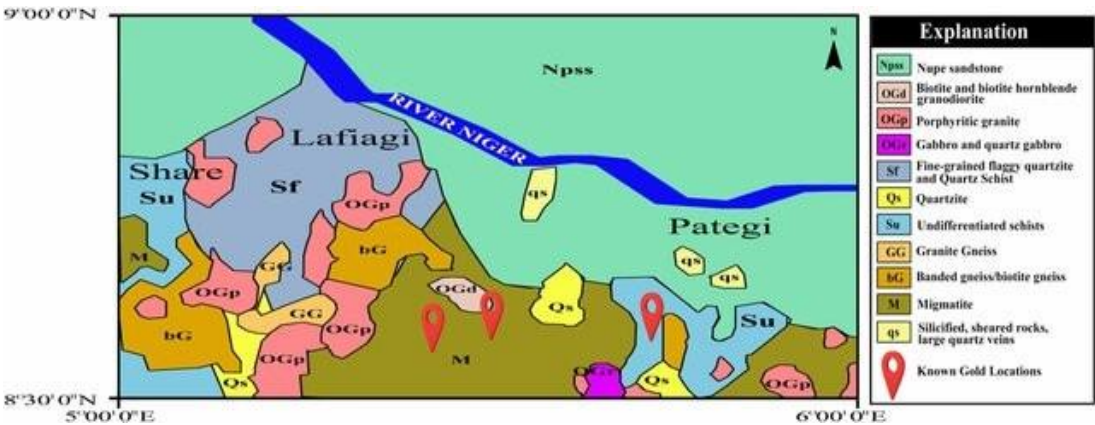


Figure 18: Simplified geological map of Share-Pategi areas



Figure 19: Stockpiles of crushed lithium bearing pegmatites at Lade, Pategi

The geology of the area is characterized by Cretaceous sediments of the Bida Basin in the northern part while the southern portion is underlain by the crystalline basement complex composed of Precambrian migmatite-gneisses with isolated pockets of pelitic schists, amphibolites and granites lying within deeply eroded terrain. The main areas with lithium mineralization are at Share and Kakafu. The Share lithium mine operated by Kian Smith Trade & Co. is one of the largest lithium mining operations in Kwara state. Local artisanal miners are engaged in small-scale mining while Bluefield Resources Ltd is conducting exploration and some mining activities. In the Pategi LGA at Kakafu village near Lade township as described by Tanko et al., (2024), the lithium pegmatites, occur as swarm of dykes and veins about

20 to 500m long and 0.2 to 5m wide, trending mostly NW-SE and intruding mostly schistose rocks with minor gneisses. There are bodies of granite in the area but with no spatial association with the pegmatites.

Ekiti Lithium Occurrences

Ekiti State is located in southwestern Nigeria, lying northeast of Oyo State and bordered to the northeast by Kogi State and to the south by Osun State. The Ijero-Ekiti area has long been associated with rare metal pegmatites that were mined in the late 40s and 50s for cassiterite and tantalite. These pegmatites have become exploration targets for lithium mineralization. Lepidolite has long been known to occur as an accessory mineral in Ijero pegmatites (Jacobson and Webb, 1946; Okunlola, 2005).

Lepidolite occurrences have been found in three areas: (1) Ijero-Ekiti, (2) Aramoko-Ekiti, and (3) Ikere-Ekiti. The geology of Ekiti State is dominated by the

Archean migmatite-gneiss complex with isolated relics of schist belts and quartzites (Fig.20). One of such relics occurs in the western portion of the state in Ijero and Aramoko LGAs where the schists are intruded by granites and pegmatites (Akinola et. al., 2014).

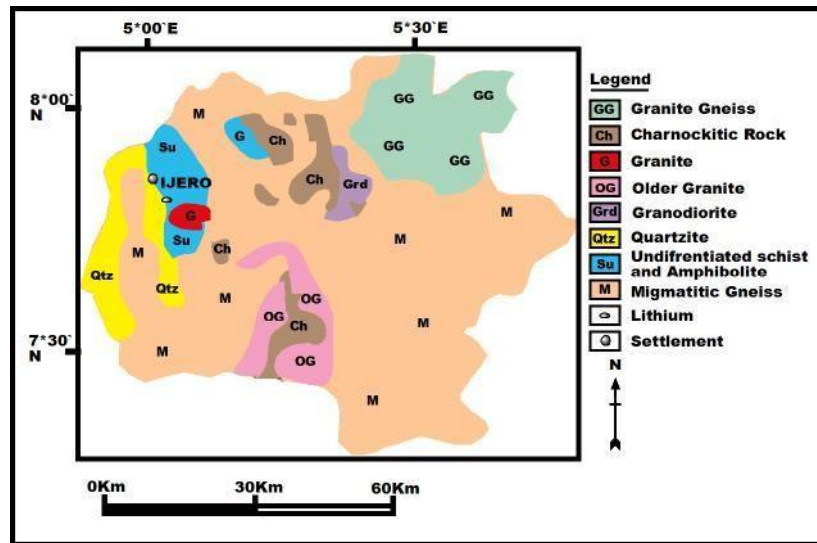


Figure 20: Geological Map of Ekiti State

Several pegmatite bodies occur in the Ijero area of which some are mineralized. They trend mostly NE-SW and are found mostly within the mica schists and amphibolite (Fig. 21). Lithium in the Ijero pegmatites occurs as lepidolite, and It is unique that the lepidolite (Fig. 22) is not associated with spodumene but occurs commonly in association with topaz and tourmaline

(Akinola et. al., 2014). Workable quantities of lithium about 2 meters thick are localized within the intermediate zone of the Ijero pegmatite body in three localities around Ijero-Ekiti (Fig. 23) These are, Ilukuno zone (Oke Igbo-Aba), Ijero zone (Ateokuta and Ijero), and Olumere Camp area (Oke-Asa) (Okunlola and Akinola, 2010).

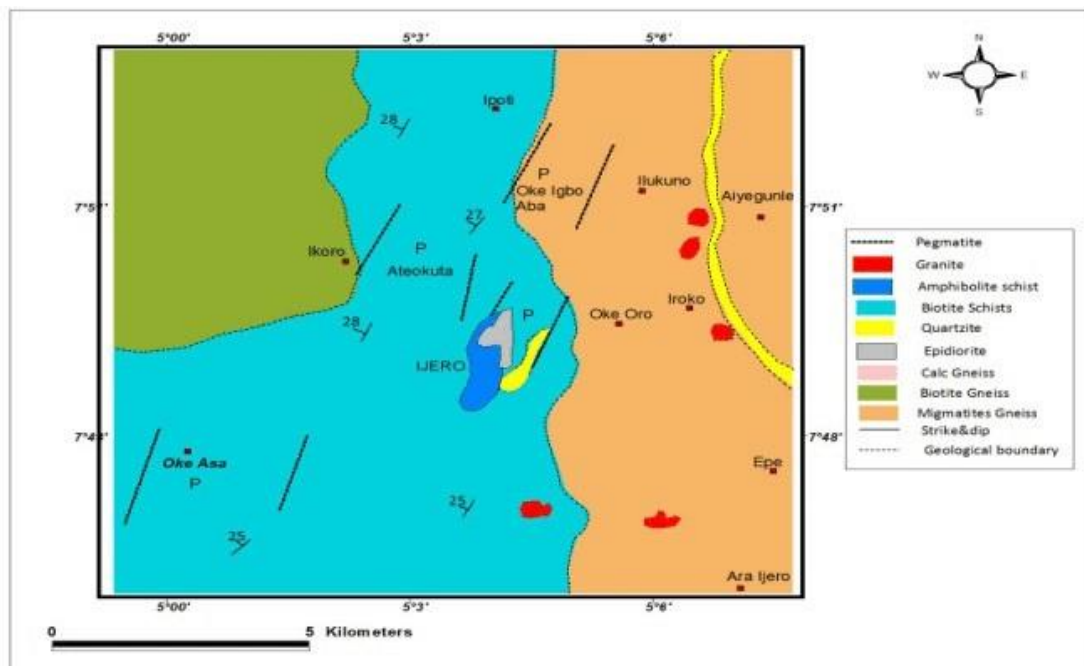


Figure 21: Geological Map of Ijero Area (After Akinola et al., 2014)



Figure 22: (a) Coarse pegmatite mined for lepidolite (b) Lepidolite crystals (Courtesy of Ale et al., 2014)

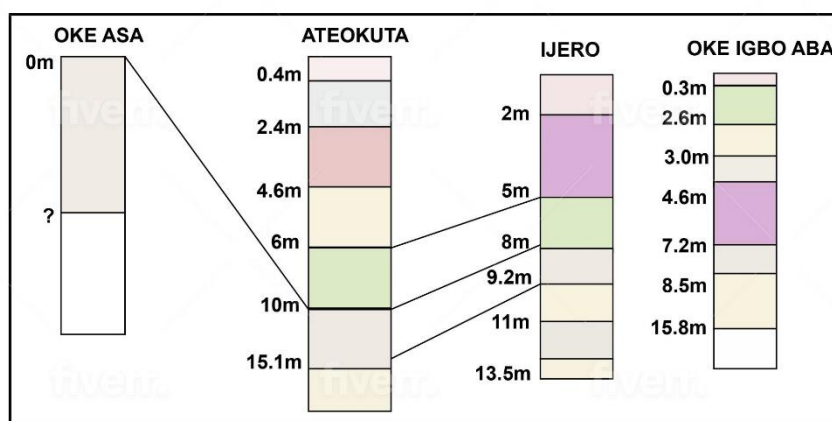


Figure 23: Vertical Section Across Lepidolite Mineralization (After Ale et al., 2014)

Samples from each locality are distinguished by its unique color and texture. Lepidolite from Ilukuno is pinkish and fine-grained, that of Ijero is medium-grained with silvery white resinous-lustred flakes, while In the Oke-Asa area, the mineral occurs as coarsely grained bodies. Lepidolite in the Ijero area occurs in close association with tourmaline and other pegmatite minerals in the albitized zones of the complex pegmatites (Akinola and Talabi, 2023). It appears the lepidolite was formed in two phases. Other ore minerals associated with lepidolite are cassiterite and columbite-tantalite. The grade of lithium in the mineralized pegmatites varies considerably in accordance with lepidolite concentrations, usually ranging from less than 0.2% to as high as 4.0% Li_2O . Thor Explorations, a Canadian mineral exploration company is conducting systematic exploration for lithium in the Ijero area. Results of preliminary analyses of 3 pegmatite samples obtained at Ijero and Ikoro yielded 2.56%, 3.01% and 4.69% Li_2O respectively.

Kogi Lithium Deposits

Kogi State is located west of Kwara State and bounded in the west by Kwara State and in the south by Ekiti and Edo State (Fig. 24). Mineralized pegmatites have been known to occur in the area now known as Kogi State since the early 20th century, especially in the Egbe-Isanlu area where the first mining of pegmatites for Sn-Ta-Nb in Nigeria began in 1918 (Jacobson and Webb, 1946). The Isanlu-Egbe pegmatite district is located in the westernmost part of the state, in Yagba West and Yagba East LGAs (Fig. 24). The rocks belong to the well-known Egbe-Isanlu Schist Belt where gold and tantalum have been mined for several decades. The pegmatites at Egbe appear as steeply-dipping N-S trending dykes intruding the major rock types that include mainly the migmatitic gneiss, metasediments and the Older granites (Fig. 25). At Isanlu, the host rocks to the pegmatites are predominantly (90%) mica schists with amphibolites that are intruded by granites (Garba, 2003).

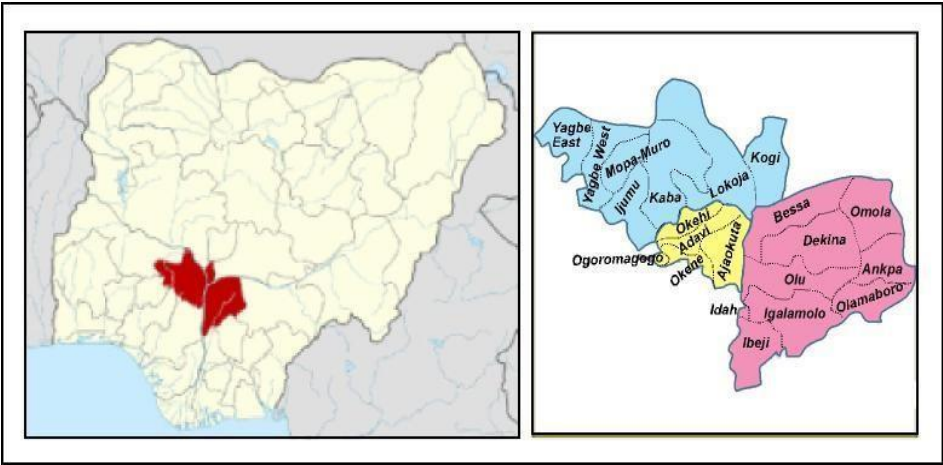


Figure 24: Map of Nigeria showing Kogi State and Local Government Areas

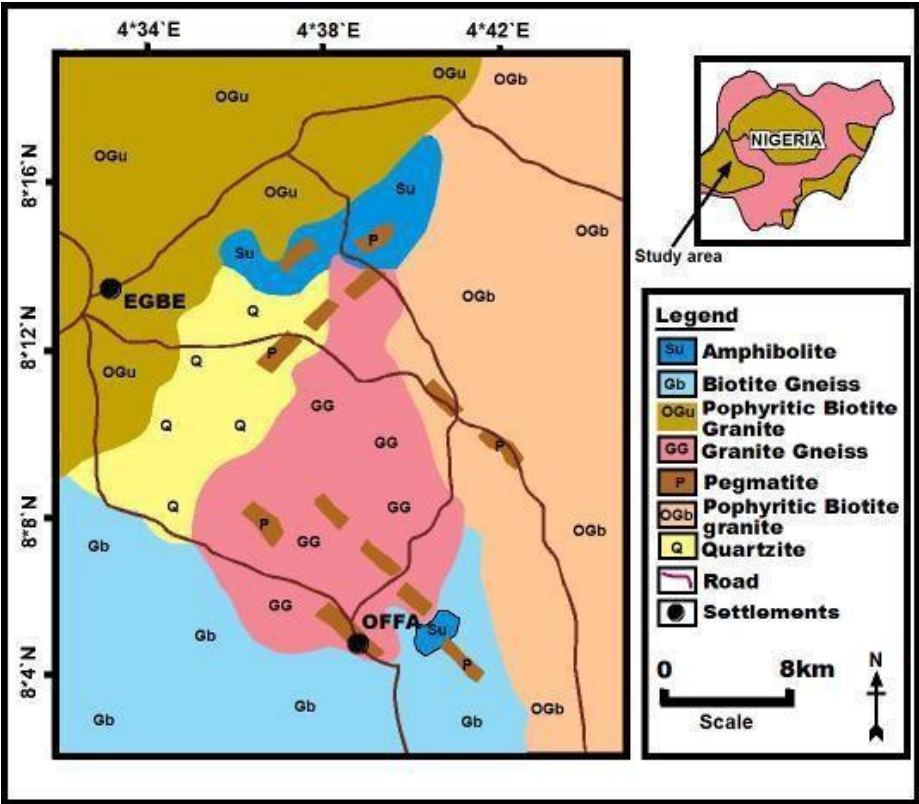


Figure 25: Geology of Egne Area, Kogi State (After Aderogbin and Okunlola, 2019)

According to Olobaniyi et al. (2019), the pegmatite bodies in the district are composed essentially of quartz, mica and K-feldspar, and are mined for dispersed cassiterite, Nb-Ta oxides and beryl. Lithium mineralization occurs in the pegmatites as disseminations and masses of mainly lepidolite, with minor spodumene. Mining activity is by open-pit extraction concentrated in the areas around Egbe-Iсанlu in Yagba West and Yagba East LGAs respectively. The deposits are relatively small but actively mined by artisanal miners and corporations. Kian Smith Trade & Co. is actively involved in lithium mining in Kwara State.

Another company named VAU, controls significant hard rock lithium deposits in Yagbaland and plans expansion of exploration efforts. At Odo-Eri, 10km northeast of Egbe in Yagba West LGA, lepidolite deposits are being mined at a grade of about 1 - 3% Li₂O (Olobaniyi, pers. comm).

Nasarawa State Lithium Deposits

Nasarawa State is located in north central Nigeria, bordered in the north by Kaduna State, in the east by Plateau and Taraba States, in the south by Benue and Kogi States, and in the west by the Abuja Federal Capital Territory (Fig. 26).

The name "Nasarawa" will be used in three ways to refer to a state, a local government area and a township, all bearing the same name. Nasarawa State was the first major hub for lithium deposits in Nigeria since its first discovery in 2018, and claims to have the largest reserves of lithium ores in the country. The Federal government of Nigeria has recently commissioned the largest lithium processing plant in the state (and in Africa) to harness the lithium georesources. Several good quality lithium deposits in pegmatites and associated alluvial deposits have

been discovered and mined, particularly in the Nasarawa and Karu LGAs. Nasarawa State lies within Nigeria's Schist Belts and its geological setting consists of about 60% Precambrian basement rocks in the west and northwest, and 40% sedimentary rocks in the eastern and southern parts of the state. The Archean migmatite-gneiss complex and Proterozoic metasediments and metavolcanics are intruded by isolated bodies of Pan-African granites and pegmatites. Outcrops of the Jurassic Younger Granites can be found in the southeast area of Nasarawa LGA (Fig.27).

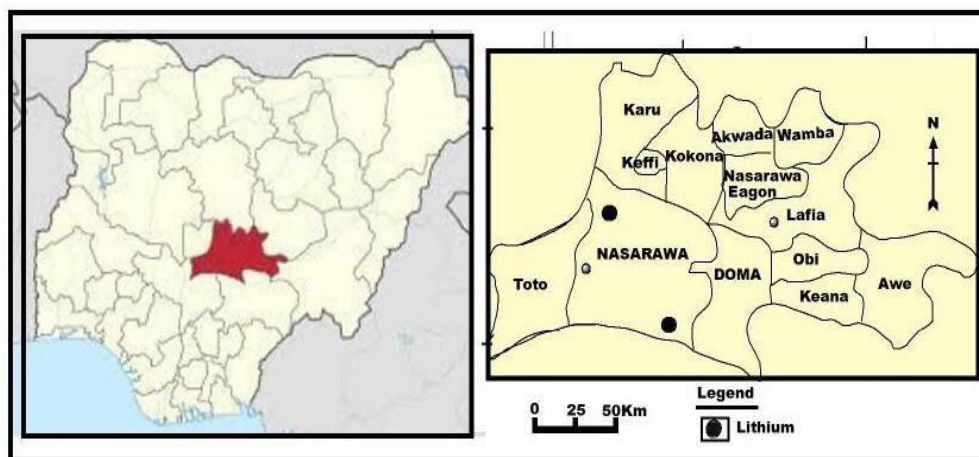


Figure 26: Map of Nigeria showing Nasarawa State and Local Governments

Rare metal pegmatites were mined in Nasarawa State from the early 1900s until 1950s when the extraction of columbite and cassiterite declined due to low prices. Some of these pegmatites have become the target of lithium exploration, and extensive lithium deposits have been discovered and mined in Nasarawa State since 2018. Nasarawa LGA has become one of the best known places in Nigeria with notable lithium mineralization. The deposits occur in various forms but three main types can be recognized: (1) hard-rock disseminations, veinlets and felted masses in albitized pegmatites, (2) colluvial deposits in deeply weathered pegmatite zones, and (3) alluvial deposits in old river channels. Lepidolite and spodumene are the dominant lithium ore minerals. Other minerals that have been reported include kunzite (spodumene), petalite, lithiophyllite, amblygonite and protolithionite (Olobaniyi et al., 2016),

The main lithium deposits are localized in four pegmatite fields: (1) Nasarawa-Endo/Udege, (2) Nasarawa-Township, (3) Karu, and (4) Keffi-Kokona. The Nasarawa and Karu pegmatite districts are best known for their lithium mineralization in which lepidolite and spodumene are the principal ore minerals. Lithium-bearing pegmatites in Nasarawa LGA occur as NNE-SSW trending, steeply dipping dykes that range in dimension from a few meters to over a kilometer in length, and 0.5 to 20m wide (Adekeye and Akintola, 2008).

Although the majority of the pegmatites appear as dykes with fairly constant dips and strikes, some of the richly mineralized pegmatites occur as sill-like bodies with pronounced pinch and swell structures that form the loci of intense albitization and rare metal mineralization. (Adekeye and Akintola, 2008). They are of the complex type of pegmatites, often albitized and composed of muscovite, quartz and microcline with abundant spodumene and lepidolite along with disseminated tantalite, cassiterite and beryl (Akintola and Adekeye, 2008.). These lepidolite-spodumene bearing pegmatites and associated mineral veins belong to the most fertile class of pegmatites that are rich in Li-minerals, plagioclase feldspars, lepidolite, schorl, spodumene, petalite, K-feldspar, quartz, as major minerals while cassiterite, columbite-tantalite, elbaite and beryl as minor minerals (Olobaniyi et al., 2019). They are hosted by mica schists and amphibolites, mostly distant from any granitic plutons. Wall-rock alteration involving tourmalinization, albitization and silicification is a common feature in the mineralized pegmatites (Adekeye and Akintola, 2007). The lepidolite-spodumene bearing pegmatites belong to the most fertile class of pegmatites that are rich in Li-minerals, in association with albite, tourmaline (schorl), K-feldspar, quartz, as major minerals, while cassiterite, columbite-tantalite minerals, elbaite and beryl as minor or accessory minerals (Olobaniyi et al, 2019).

In the Keffi area, several mineralized NW-SE trending, rare-metal pegmatites up to 0.5 km long and 50m wide have been identified but are not intensely mineralized with lithium. The Gidan Doka pegmatite which is the largest and best known contains substantial lepidolite that occurs within an orthogneiss host rock. Some of the other pegmatites such as the Angwan Doka pegmatite contain lithium concentrations of up to 0.7% Li_2O with identifiable polyolithionite and lepidolite as the ore minerals, but commercial accumulations have so far been elusive (Olobaniyi et al., 2019). In the Kokona LGA, east of Keffi, lithium occurrences have been found in Angwan Kade, Kware (Amba) and Agaza (Igwo) communities in pegmatite dykes.

As a result of intensive lithium exploration in the Nasarawa LGA, some mining companies have discovered large deposits of lithium, particularly in the Udege CDA of Nasarawa LGA which has become a major hub for lithium mining in Nigeria. Two major deposits which are being mined are well known in the southeastern corner of Nasarawa LGA (Fig. 27); the first is at Endo Village while the other is at Udege

some 20km from Nasarawa town and 10km northwest of Endo, both in Nasarawa LGA. Other lithium occurrences are known around Nasarawa township at the following localities; Angwan Mada, 25km away, with substantial low grade lithium deposits, Akiri and Gidan Umoro. These deposits are being exploited by corporate small-scale and artisanal miners, while lithium processing plants are under construction near the lithium deposits in Endo, Udege and Nasarawa township..

The Endo deposit is being mined in a deep open pit in a combination of hard-rock and weathered ores by a Chinese company named Ganfeng Lithium Mining Company. The deposit is large with an estimated production rate at maximum capacity of 20,000 tons per day. The lithium minerals are spodumene, lepidolite and polyolithionite. Avatar New Energy Materials Co. Ltd has recently commissioned the largest (4000 tons/day) capacity lithium processing plant in Africa located near the lithium deposit at Endo Village. Avatar has also proposed a second processing plant for nearby Udege township. Estimated reserves are about 20 million tons of 6% Li_2O .

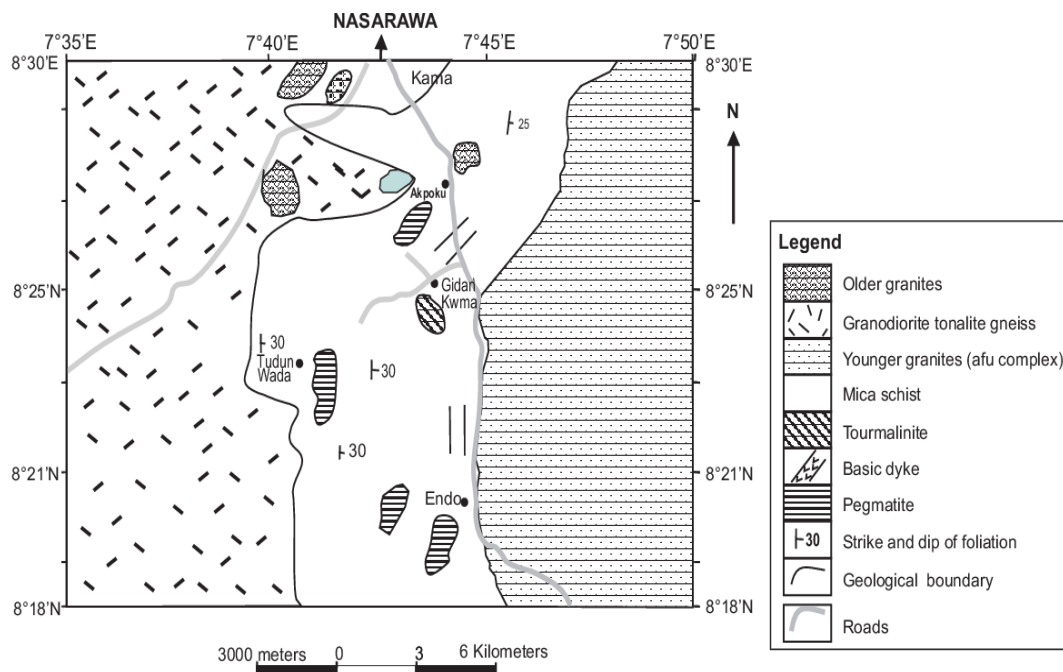


Figure 27: Geological Map of Southern Part of Nasarawa LGA

The second company, Landmark Mining Company, is mining a lithium pegmatite deposit in the Udege community, Nasarawa LGA, 30km from Nasarawa town. The lithium ore will be obtained from the Udege mine to feed a processing plant under construction in Nasarawa town that will ultimately produce 3000 tons of lithium per day. Open pit mining has reached a depth of 60 m in one of the pits and is expected to reach a final depth of 200m. The lithium ores are

lepidolite, polyolithionite ($\text{LiAl}_2\text{Si}_3\text{O}_8$) and spodumene. Reserves are estimated as 2 million tons. Small-scale and artisanal miners are extracting lithium minerals from colluvial and alluvial deposits in many parts of the LGA using hydraulic and gravity methods to separate ore from waste rock, soil and sediment. Several abandoned pits along river beds are used in alluvial mining. Another processing factory will be built in Udege by Avatar Energy.



Lepidolite Lepidolite Spodumene Ore Weathered Spodumene

Figure 28: Samples of Lithium Ores from Nasarawa LGA

Jupiter Lithium Deposits (Kaduna State)

Jupiter lithium deposits are located in Jema'a pegmatite district in southern Kaduna State, in the north-central region of Nigeria. Pegmatites are widespread particularly in the southeastern part of the state and have become targets for lithium exploration.

The geology of Kaduna state is characterized by the presence of the three major rock groups of the Precambrian basement: the migmatite-gneiss complex, schist belts and Pan-African granitoids (Fig. 29).

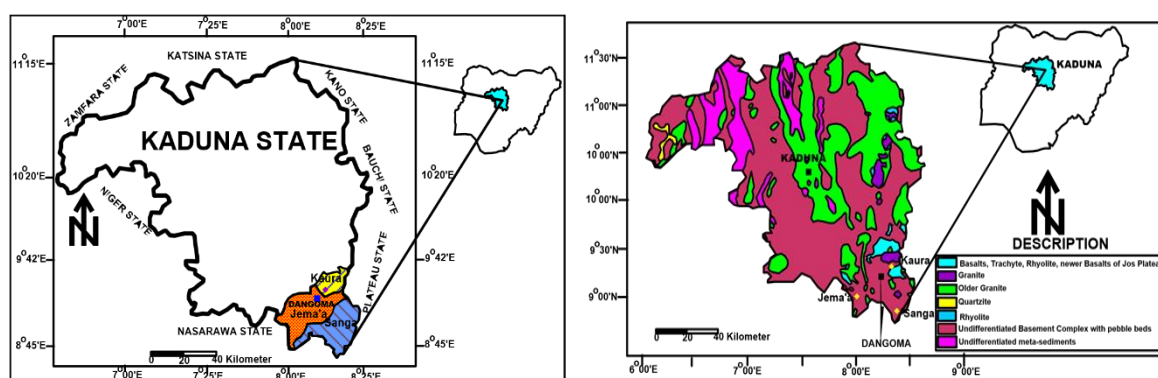


Figure 29: Location and Geological Map of Kaduna State (After Olade, 2019)

Rare metal pegmatites are known to occur in dykes and tabular bodies particularly in the Jemaa area where cassiterite-tantalite were first mined in Nigeria in 1918 (Jacobson and Webb, 1946). The first lithium deposit of commercial value in Nigeria was also first reported from this area 100 years later in 2018. The Jema'a LGA is an area of low relief with slightly undulating topography and low-lying outcrops with a few prominent ridges of weathered granites and pegmatites scattered over the landscape. In the Dangoma and Kagome areas, the pegmatites intersect mostly migmatites and gneisses, as well as some metamorphosed amphibolites and serpentinites (some containing nickel balls) (Olade, 2019). The pegmatites trend mostly NW-SE and range in width from a few centimeters to 15m, and length of up to 400m. They sometimes form ridges up to 70m high that are strewn with boulders.

Exploration activities by the Jupiter Project discovered large lithium deposits in commercial quantities in the

Dangoma area of Jema'a LGA. Dangoma is situated about 20km from Kafanchan and 100km from Abuja, the Federal Capital (Fig 30). Information from the Jupiter Project indicates that the lithium mineralization occurs within unzoned pegmatites that contain large quartz crystals, feldspar and muscovite. The pegmatites are felsic, deeply weathered and highly fractured, and they are mixed up with serpentinite host rock in places, and the lithium minerals are spodumene along with lepidolite and minor amblygonite and petalite (Fig. 31). As the deposits are exposed in surface outcrops 40 to 70m high, initial mining has been operated by open pit excavation at a production rate of about 20,000 tons per month, with proposed future expansion to 50,000 tons. However, recent efforts of collaboration with other major leading lithium producers, Jupiter Lithium Ltd and US-based ReElement Technologies Corporation commenced a project for lithium exploitation across 442 square kilometers of lithium-rich terrain with targeted

production of 167,000 tons within the first two years expected to yield a minimum of \$6.2 billion. The lithium minerals are lepidolite and spodumene (Fig. 31), and ore grade ranges from about 2% to 7% Li_2O with an average of 3.47%. The mineral reserves are extensive and exploration

continues on about 30 outcropping pegmatite targets. Jupiter Lithium plans to expand its operations, currently at contract mining, to include a spodumene concentrator facility that will produce 55,000 tons of 6% lithium spodumene concentrate annually by the first quarter of 2025. (Source: Jide Babalola, The Nation Newspaper, July, 19, 2024)\



Figure 30: (a) Jupiter Lithium Mining Site: (b) Exploration drilling (courtesy Jupiter website)



Figure 31: Spodumene: with Lepidolite Mineral Samples at Jupiter Mining Site

PLATES



PLATE 1: Artisanal Mining of Weathered Lithium Pegmatite Nasarawa Area



PLATE 2: Exposure and Excavation of Lithium Pegmatite, Nasarawa State:



PLATE 3: Artisanal Mining Hand Dug Pits and Holes Nasarawa State



Lithium Occurrences in the Federal Capital Territory

The Federal Capital Territory of Nigeria is located in the central part of the country, bordered to the west and northwest by Niger state, to the northeast by Kaduna state, to the east and south by Nasarawa state, and by Kogi state to the southeast. All the surrounding states have lithium occurrences that seem to extend into the FCT. Geologically, the area is underlain mostly by Precambrian migmatite-gneiss, granite-gneiss with lenses of supracrustal metasediments (schists, marble, quartzites) and amphibolites, intersected by Pan-African granites

pegmatites and quartz veins. Several lithium bearing pegmatites have been reported in the FCT, particularly in Kuje (Takushara), Kwali, Gwagwalada and Abaji council areas. The pegmatites are similar to those described in Nasarawa and Kaduna states, but are less weathered. The principal lithium mineral is spodumene with some lepidolite. Artisanal and small-scale mining is ongoing in these areas with substantial illegal mining of lithium-bearing pegmatites (Fig. 32). A lithium processing plant is under construction near Abuja to provide value added processing for the lithium deposits in the FCT with a production target of 1.5 million tons per annum.



Figure 32: Lithium Stockpile by Illegal Mining in the FCT

Lithium Occurrences in Other States

Lithium occurrences or mineral showings have been reported in other states of Nigeria that are underlain by Precambrian rocks with pegmatites and pelitic schists or amphibolites. However, they have not been described in this paper either because the mineral occurrences are small or have not been fully verified as viable economic deposits. The applicable states are; Bauchi, Niger, Plateau, Cross River and Taraba states. Other states in the southwest are Edo and Osun.

The following local government areas provide potential exploration targets for lithium deposits in the following states based on their geological setting and the presence of intrusive pegmatites within mica schist host rocks.

Bauchi State: Alkaleri, Tafawa Balewa and Bogoro LGAs.

Cross River State: Biase LGA. Potential alluvial deposits at Obubra, Ikom and Yala LGAs.

Niger State: Borgu, Agwara and Mangana LGAs.

Taraba State: Wukari and Donga LGAs

Edo State: Afenmai LGA

DISCUSSION AND SUMMARY

Since the discovery of commercial quantities of lithium in 2018, Nigeria has become a focus of interest in the exploration for hard rock lithium deposits. These efforts have led to the discovery of several high quality deposits, both large and small. The host rocks of these deposits are exclusively the Precambrian (Pan-African) pegmatites also containing varying amounts of Ta, Nb, Sn and Be. They were emplaced during the late tectonic to post-tectonic phases (520-450 Ma) of the Pan-African Orogeny (700-500 Ma). Most of the pegmatites have no spatial, temporal or genetic relationship with the Pan-African granites (Older Granites) dated as 650-500 Ma old. The lithium pegmatites are structurally controlled and emplaced mostly within mica schists and amphibolites of the Proterozoic "Schist Belts" during the Pan-African Orogeny.

Several hundreds of these pegmatites have been identified along a well-defined WNW-ESE zone that has now been found to extend over a much larger area than earlier known, and now designated as a "pegmatite province" rather than a "pegmatite belt". The "Nigerian Pegmatite Province" trends WSW-ENE stretching from the southwest corner of Oyo State through Kwara, Ekiti, Kogi, Nasarawa and south Kaduna states into the Jos Plateau and south Bauchi State. The new metallogenic province covers a swath of landmass approximately 700 km long and 200 km wide, representing a northeastern extension of the "East Brazilian Pegmatite Province" in NE Brazil,

The lithium-bearing pegmatites are relatively small in dimensions averaging about 20 m wide and 500 m long. They trend predominantly in the N-S and NW-SE or rarely NE-SW directions. Geochemical composition indicates they are peraluminous and belong to the LCT family which is the main carriers of lithium

deposits worldwide. Mineralogically, they are composed mainly of quartz, K-feldspar, mica and accessory minerals such as beryl, tourmaline, apatite, spodumene, cassiterite and tantalite. Mineralized pegmatites almost exclusively are found intruding mica schists and amphibolites within the Proterozoic Schist Belts.

Commercial lithium deposits have so far been reported mainly from six Nigerian states, namely: Oyo, Kwara, Ekiti, Kogi, Nasarawa and Kaduna and the FCT. Some occurrences and mineral showings of lithium have been observed in other states including Bauchi, Cross River, Niger, Taraba, and Edo states but no reliable information is currently available for evaluating their economic viability. Several important lithium pegmatite districts have been identified namely: (1) Oke-Ogun, (2) Kaiama-Bina, (3) Ijero-Ekiti, (4) Share-Pategi, (5) Egbe-Isanlu, (6) Nasarawa-Karu, (7) Keffi-Kokona and (8) Jemaa-Sanga. A schematic distribution map of the major Li occurrences has resulted in the delineation of a distinct WSW-ENE trending mineral belt for Li that is separate and slightly to the north of the well-known SW-NE trending Sn-Ta-Nb: belt, both of which tend to merge in the north central region.

The lithium minerals that occur in the Nigerian pegmatite deposits are mainly spodumene (Li pyroxene) and lepidolite (Li mica), with minor amounts of polyolithionite (Li-mica), amblygonite (Li phosphate) and petalite (Li-feldspathoid). The minerals may occur together or as discrete crystals that are either scattered or in clustered or felted masses, or mineral veins within the pegmatites and adjoining areas. In subsurface intersections, the mineralized pegmatite bodies may appear as sub-horizontal or dipping continuous sheets or tabular zones several meters thick of coarse spodumene and lepidolite.

Lithium concentrations in mineralized pegmatites are variably but relatively high, ranging from <0.5% to as high as 13% Li₂O (recommended cut-off grade is 0.4% Li₂O). The very high values exceeding about 9% Li₂O may be attributed to some form of surface enrichment, as most deposits that are currently mined are exposed at the surface. The Information regarding tonnage and ore reserves is currently not available because for most of the known deposits, detailed exploration involving subsurface drilling has not been completed. The richest deposits are probably found in Oyo, Nasarawa, Kwara and Kaduna States. However, considering the fact that most of the host pegmatites are relatively small to medium-sized bodies, the average tonnage will be in the same range of small to medium in size. Using an average dimensions of 500m x 20m x 100m for a spodumene pegmatite orebody of 4% Li₂O, the estimated tonnage of pegmatite rock will be in the range of 2 to 3 million metric tons. A rough estimate of lithium concentrates derivable from such pegmatites will be about 600,000 to 900,000 metric tons at typical 6% Li₂O, depending on mineralogy,

processing conditions and other factors, The mode of origin of the Nigerian lithium pegmatites is relevant to its economic potential and exploration strategy. The preferred model espoused in this article is by partial melting and anatexis of Al-rich pelitic schists and metavolcanics, followed by some fractionation of the LCT-type pegmatite melts generated by low to medium grade metamorphism during the waning and post-tectonic phase of the Pan African orogeny. Currently, the best prospective areas for lithium are the Proterozoic Schist Belts characterized by N-S trending relics of supracrustal mica schists and amphibolites that were deformed and metamorphosed during the Pan-African orogeny when the pegmatitic melts were generated. The schist belts are mostly confined to the western half of the country. An alternative genetic model involving derivation of pegmatitic fluids by extreme fractionation of granitic magma is not supported by the fact that there are no granitic bodies within reasonable distance from most of the pegmatites.

Implications for Mineral Exploration

In conducting mineral exploration programs in Nigeria for lithium pegmatites, the well-known but slightly modified “Steiner’s workflow” process should be utilized for grassroots LCT pegmatite target generation, as it follows well established systematic pathways used in the exploration for other deposit types (Fig. 33). The steps to follow are; desk-top study, regional surveys, detailed surveys and geological mapping, followed by targeted drilling and sampling (Steiner, 2019). The genetic model proposed in this paper for the Nigerian pegmatites implies that in selecting target areas for exploration, either on regional or district scales, the areas that are underlain by the Proterozoic “Schist Belts” are the most favorable for lithium exploration. The areas adjacent to the Older Granites are not considered relevant. Field information indicates that most of the discovered lithium-bearing pegmatites were exposed at the surface due to the fact that pegmatite bodies rich in quartz are relatively more resistant to tropical weathering than surrounding schistose rocks. Grassroots exploration in target area selection

should be initiated by identifying pegmatite districts or fields through the desk study of geological maps and published reports including those on bulk and mineral geochemistry to select highly fractionated pegmatites. Areas with pelitic metasediments and metavolcanics should be of high priority in finding LCT pegmatites that have significant potential for mineralization.

Several geological techniques can be used to locate potential targets, including reconnaissance geological mapping, assisted by field traversing and remote sensing analysis. Visual inspection and the identification of indicator pegmatite minerals in weathered soil and stream sediments, can be applied, and assisted by the use of a portable XRD (pX-Ray Diffractometer) for mineralogical identification. Indicator minerals useful for identifying LCT pegmatites include muscovite, garnet, albite, beryl, tantalite and tourmaline. Lithium minerals may be difficult to detect in intensely weathered soils and sediments. Due to the weak magnetic and conductive properties of LCT pegmatites, geophysical surveys cannot readily distinguish between pegmatite and adjacent country rocks due to the weak magnetic and conductive properties of LCT pegmatites (Steiner, 2019).

Detailed evaluation of soil and exposed pegmatite rock by rock-chip (lithogeochemical) sampling and analysis for pathfinder and indicator elements should be widely used. The incompatible elements (Li, Be, B, Rb, Zr, Nb, Sn, Cs, Hf, Ta, and W) are currently used as pathfinder elements (Phelps-Barber (2022)). The non-destructive portable XRF (pX-Ray Fluorescence) analyzer has become popular for in-situ analysis but the equipment does not determine Li or Cs because the elements are too light to generate enough detectable fluorescent radiation. Occasionally, the *in-situ* analysis of Sn, Ta, W and K/Rb using aqua regia extracts, as well as testing for Li by the newly developed portable LIBS (Laser Induced Breakdown Spectroscopy) analyzer have proven to be valid techniques for additional field exploration. All these activities may be followed by subsurface evaluation of prospective targets by drilling of cored holes at multiple angles and depths.

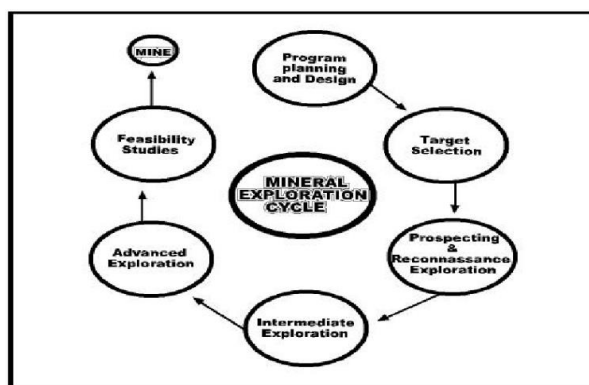


Figure 33: Mineral Exploration Cycle (After Olade, 2020)

CONCLUSIONS

Global demand for lithium for use in batteries of electric vehicles and energy storage systems has soared in the past decades. To meet future demand, Nigeria, amongst others with lithium pegmatite resources, have become the focus of extensive mineral exploration. While lithium-bearing brines from South America are a major source of lithium, more traditional mineral exploration has focussed on unexplored LCT pegmatites in hard rocks particularly in African countries such as Nigeria, Mali, Ghana, Zimbabwe, Namibia and Ethiopia as sources of lithium. The rush for the “white gold” has created some challenges for Nigeria, particularly in managing and regulating artisanal and small scale miners, eliminating the surge in illegal mining, armed banditry and corruption among others. However, considerable progress is being made in Nigeria to regulate the mining industry, control illegal mining, and enhance the value chain by ensuring the establishment of lithium processing plants and battery manufacturing facilities. Four lithium processing factories and two battery manufacturing facilities are under construction or have completed construction, particularly in the north central states of Kaduna, Nasarawa and Abuja FCT. Nigeria has proved to be a major player in Africa in the development of lithium as an alternative energy source.

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