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Lithium Deposits in Africa: A Synthesis of their Economic Geology and Metallogeny with Implications for Regional Mineral Exploration

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Abstract: Lithium minerals are critical raw materials in the production of lithium-ion batteries for electric vehicles and the energy storage infrastructure that drives the ongoing clean energy transition. The global surge in demand for lithiumhas sparked concerns about a potential future supply shortage, prompting a scramble to secure new resources. Currently, approximately 75% of the global lithium supply is derived from salt brines and clays, whereas 25% is obtained from hard-rock pegmatite deposits, which are generally considered a more reliable source of lithium. Africa is a continent endowed with abundant mineral wealth, including lithium, which is contained in the rare-metal pegmatites that were previously mined intermittently for tin and tantalum in many parts of the continent. Africa has now emerged as a destination of choice for several mining companies and investors in the “rush” for the “white gold”. Africa is currently a significant contributor to the global lithium supply chain, accounting for more than 10% of the world's production from several countries that host lithium deposits of varying sizes and ore grades. This paper provides an overview of the economic geology and metallogeny of lithium deposits in Africa, highlighting their geological settings, deposit types, spacetime distributions, ore-forming processes, and ore genesis in relation to orogenic cycles. The paper also discusses the potential for exploring lithium in Africa and identifying new frontier areas and mineral exploration strategies in tropical lateritic terrains.

Keywords: Lithium deposits, Africa, Zimbabwe, Nigeria, lithium pegmatites, metallogeny, lithium minerals, mineral exploration.

Introduction

In recent years, lithium has become a critical component in the production of batteries used in manufacturing electric vehicles, electronic devices such as smartphones, and energy storage systems. Consequently, lithium minerals have emerged as indispensable commodities to the global energy transition from fossil fuels to “green” energy sources, which are at the forefront of the fight against global warming and climate change (Christmann et al., 2015; Zubi et al., 2018; Balaram, 2024).

The global demand for lithium has increased sharply over the past decade, and a future supply shortage is anticipated (Christmann et al., 2015; Calderon et al., 2024). In 2010, when the single largest end-use of lithium was in ceramics and glass manufacturing, the global demand was approximately 23,000 metric tons per year. Still, it rose 4-fold to 93,000 tons in 2021 and is projected to reach 532,000 tons by the end of 2025, fueled by the increased demand for lithium batteries, electric vehicles and renewable energy infrastructure (USGS, 2024). According to the World Economic Forum, a sustained demand for lithium is expected to exceed one million metric tons (Mt) in 2030, and a market deficit is anticipated to persist until 2040, driven by significant demand and a very tight supply (Bloomberg, 2023; Calderon et al., 2024).

There are three significant sources of lithium: (1) salt brines (64%) and (2) sedimentary deposits (8%). and (3) hardrock pegmatites (25%). Four countries - Australia, Chile, Argentina, and China account for approximately 80% of the world's lithium production, which is expected to reach 240,000 tons by 2024. While salt brines are currently the dominant source of lithium, hard-rock pegmatite deposits are usually preferred due to their reliability, variety of minerals, high ore grades, and widespread availability (Bowell, 2020). Australia is the world's leading producer of lithium, with an output of 88,000 tons in 2024 (36% of world production), which is mainly derived from hardrock pegmatites, followed by Chile (20%). Recently, Africa has emerged as a significant player in the lithium supply chain, accounting for approximately 10% of global production in 2024, a notable increase from 4% in 2023. Most of this production came from pegmatites in Zimbabwe, Nigeria, and Namibia (USGS, 2024), driven by investments from China.

In an effort to secure future lithium supplies, several companies and investors, mainly from China, Australia and the United Kingdom, have focused their attention on Africa, a continent endowed with abundant mineral resources (Sharaky, 2014), including lithium, which is associated with tin and niobium-tantalum deposits and has been mined intermittently for several decades in many African countries (Clifford, 1966; von Knorring and Condliffe,1987). Africa has suddenly emerged as a new frontier in the "rush" for lithium, often referred to as the "white gold" (Amaranthi, 2024). Several papers have recently been published on the aspects of geology, mineralogy, and geochemistry of lithium-bearing pegmatites in Africa (Shaw et al., 2019; Nex et al., 2019; Goodenough et al., 2021, 2025; Kazapoe, 2023; Traoré et al., 2025). This review focuses on the economic geology and metallogeny of lithium pegmatite deposits in Africa, evaluating their spatial and temporal distributions, geological settings, ore-forming processes, and ore genesis, and highlighting their relationships with orogenic cycles. The implications for mineral exploration strategies in challenging tropical environments in Africa are discussed.

Table 1. Main lithium minerals and their properties.

Mineral	Mineral Formula	% Lithium	% Lithium Oxide	Density	Hardness
Spodumene	LiAl Si2O6	3.73	8.0	3.0 - 3.2	6.5 - 7
Lepidolite	K(Li,Al)3(Si,Al)4O10(F,OH)2	3.58	7.6	2.8 - 2.9	2.5 - 4.0
Petalite	LiAlSi4O10	2.09	4.9	2,4	6.5 - 7.1
Amblygonite	(Li,Na)Al(PO4(F,OH)	3.44	10.3	2.9 - 3.1	5.5 - 6.0
Polylithionite	KLi2AlSi4O10(F,OH)2KLi2AlSi4O10(F,OH)	3.01	5.5-8.0	2.7	2,5 - 4.0
Zinnwaldite	K(Al,Fe,Li)3(Si,Al)4O10(OH)F	2.92	6.2	3.0	2,5 - 4.0
Holmquistite	Li2(Mg,Fe)3Al2Si8O22(OH)	1,85	3.9	3.0 - 3.1	5.0 - 6.0
Hectorite	Na0.3(Mg,Li)3Si4O10(OH)2	0.54		2.0 - 3.0	1.0 - 2.0
Lithophyllite	LiMn(PO4)	4.4	7.1	3.4 - 3.5	4.0 - 5.0
Eucryptite	LiAlSiO4	5.51	11.8	2.6	6.6
Jadarite	NaSiB3O7OH	3.38	7.2	2.4	4.0 - 5.0

Table 2. Grouping of African lithium deposits by orogenic cycle.

1.	**Archean-Liberian Deposits (Neoarchean)**
Bikita, Zimbabwe	
Arcadia, Zimbabwe	
Zulu, Zimbabwe	
Sabi Star, Zimbabwe	
2.	**Birimian-Eburnean Deposits (Paleoproterozoic)**
Guolomina, Mali	
Bougouni, Mali	
Ewoyaa, Ghana	
Issia, Ivory Coast*	
Saraya, Senegal*	
Daboli, Niger*	
3.	**Kibaran Deposits (Mesoproterozoic)**
Kimitavi, Zimbabwe	
Murano-Kotolo, Zimbabwe	
Gatumba, Rwanda*	
4.	**Pan-African Deposits (Neooproterozoic)**
Karibib, Namibia	
Uis, Namibia	
Nasarawa, Nigeria	
Jupiter, Nigeria	
Oke-Ogun, Nigeria*	
Kenticha, Ethiopia*	
Alito-Ligonha, Mozambique*	
Blesberg, South Africa*	
(* Deposits under exploration or development)	

Lithium Characteristics and Deposit Types

Lithium is a lightweight, silverywhite metal with an atomic number of 3 and an atomic weight of 6.941 g/mol. It belongs to a group of elements known as “alkali metals” (including sodium, potassium, rubidium, and cesium) (Garrett, 2004; Christmann et al., 2015). They all have a valence (or charge) of +1, but lithium has the smallest ionic size. In nature, lithium does not exist in the metallic state but tends to bond preferentially with silicate minerals rather than sulfides or metals. Owing to its solubility as an ion, it is commonly dissolved in saline brines and present in oceanic water (Bradley et al., 2017).

Lithium, with its small ionic radius (0.68 Å), tends to replace magnesium (0.66 Å) in silicates rather than the much larger alkali ions, sodium (0.97 Å), potassium (1.33 Å), rubidium (1.47 Å), or cesium (1.67 Å), to which it has a closer chemical affinity. In nature, lithium possesses a wide range of unique properties that have contributed to its ascendancy as a metal of immense and critical value for a variety of industrial applications. These characteristics include its very high electrochemical potential, excellent electrochemical stability, and high energy density, which enable it to efficiently store and release a large amount of energy in a relatively small and lightweight package (Garrett, 2004).

Lithium is concentrated primarily on the sialic crust, with a crustal abundance of approximately 20 ppm. The concentration of Li in igneous rocks varies, but the average value is 29 ppm (Bradley et al., 2017). The values are higher in granitic rocks than in basaltic rocks because of their felsic composition and considerable variation due to alkali metasomatism. The average values are granites, 47 ppm; basalts, 16 ppm; and ultramafic rocks, 0.5 ppm. (Garrett, 2004).

Lithium occurs as a mineral deposit in several geological environments where it is extracted through various mining methods, depending on the location and composition of the ore deposit. Lithium is found in more than 100 minerals, still, those with economic value are few, of which the most important are spodumene ($LiAlSi_2O_6$), the principal ore with the highest lithium content (Table 1); lepidolite [$K(Li, Al,Rb)_2(Al,Si)_4O_{10}(F,OH)_2$]; and petalite ($LiAlSi_4O_{10}$). Other lithium minerals of lesser economic value are amblygonite [(Li, Na) $AlPO_4$ (F, OH), polylithionite, and hectorite - a lithium smectite found in volcanic clays (Todesse et al., 2018).

Lithium-bearing minerals in igneous rocks usually form during the late to post-magmatic phases of crystallization. They are 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, amphibole, and clay minerals (Bradley et al., 2017). There are three or (maybe) four main types of lithium deposits: (1) hardrock pegmatite deposits; (2) sedimentary deposits; (3) saltwater (brine) deposits; and (4) metamorphic deposits (Bowell et al., 2020) (Fig. 1).

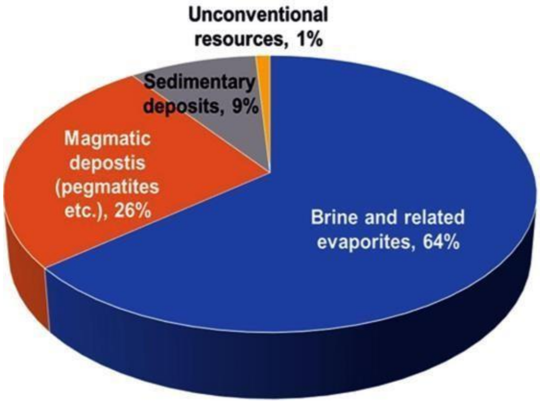

Fig. 1 Pie chart showing the types of lithium deposits and their global contributions.

Hardrock pegmatite deposits: Hardrock lithium deposits are accumulations of lithium minerals in igneous rocks, mainly pegmatites and granites. A variety of these rocks is “aplite–pegmatite,” which is a mix of fine-grained aplite and coarse-grained pegmatite. The lithium minerals in these deposits are usually spodumene, lepidolite, or petalite, which occur in various forms within the pegmatite bodies (sometimes indistinguishable from the pegmatite minerals), such as crystal disseminations, irregular or felted masses, and mineral veins. Most lithium-bearing pegmatites belong to the lithium-cesium-tantalum (LCT) family (London, 2003, 2008, 2012; Černý and Ercit, 2005).

Pegmatite deposits are the most common source of lithium and other rare metals, including Sn, Nb-Ta, and Be, in Africa (Nex et al., 2019; Goodenough et al., 2025). Hardrock lithium deposits account for approximately 25% of global lithium production (Balaram et al., 2024), with ore grades ranging from 0.6--7% Li_2O, particularly for spodumene-dominant deposits (Kesler et al., 2012). Australia, which is the world's leading producer of lithium, obtains its production solely from pegmatites. Other leading countries that produce hard rock lithium are Canada, Brazil, and Portugal. Africa also derives its lithium wholly from pegmatites in Zimbabwe, Namibia, the DRC, Mali, Ghana, and Nigeria.

Sedimentary deposits: Sedimentary lithium deposits are found as accumulations of lithium-rich clays in lacustrine sediments and evaporites, and volcanogenic clays formed by hydrothermal leaching and weathering of rhyolitic tufts and volcani-clastics (Bowell et al., 2020; Balaram et al., 2024). Lithium is found within smectites (illite and hectorite) and fine-grained lepidolite, in which the lithium is contained within the smectite lattice and absorbed ions on the surfaces. Several large deposits of volcanogenic clays containing low-grade lithium have recently been discovered in Serbia and Nevada, USA (Balaram et al., 2024). Clay or sedimentary deposits account for approximately 8% of known global lithium resources. (Fig. 5).

The leading producers of sedimentary lithium ores are China, Russia, Serbia, and the United States. In Africa, few or no lithium resources are derived from sedimentary deposits except for lithium-bearing alluvial clays in the Manono-Kitolo areas of Katanga Province in the DRC (Dewaele et al., 2016). However, there are reports of lithium-enriched volcanic clays in the Tertiary East African rifts in Tanzania, where volcanic rocks have yielded 1.76% Li2O, with residual soils containing up to 0.2% Li2O. (Putzolu et al., 2025).

Salt brine deposits: These deposits consist of saline water from saltwater lakes and saltwater flats containing soluble carbonate, hydroxide, and chloride salts of lithium, oil field water, and geothermal brine. They contribute approximately 68% of global lithium production and are formed by the evaporation of saltwater in arid regions. The source of lithium is believed to be the leaching of shales and volcanics in adjoining sedimentary basins. The world's leading producers of saltwater lithium are the three "lithium triangle" states: Argentina, Chile, Bolivia, and China. Although there is currently no known saltwater lithium occurrence in Africa, there is a good chance of finding it in areas within the East African Rift System with carbonate salts and salt pan, such as the Danakil depression in Ethiopia, the Makgadikgadi Salt Pan in Botswana and the Chott salt pans of the Saharan region of eastern Algeria (Zatout et al., 2020).

Metamorphic deposits: This deposit type is new and very rare. It is characterized by the enrichment of lithium in metamorphic rocks due to metamorphism or metasomatic alteration of Li-rich sediments within metasedimentary belts. Metamorphic deposits may have existed in Precambrian metamorphic belts but have not been recognized as such. In Africa, gneisses and metasediments of the Birimian in Ghana and Mali (Kazapoe et al., 2023) as well as mica schists in the Pan-African Schist Belts of Nigeria (Olade, 2020), contain such lithium enrichments due to the mobilization of metamorphic or metasomatic fluids, which could form low-grade lithium deposits.

Geologic and Tectonic Setting of Africa

Africa is a continent made up almost entirely of Precambrian rocks, except along its northwestern and southern margins. The geologic setting is characterized by a stable landmass of Precambrian basement rocks occupying more than 70% of the land surface and overlain by younger Phanerozoic (<500 Ma) sedimentary and volcanic cover rocks (Petters, 1991). Structurally, the Precambrian basement rocks are grouped into three main geo-tectonic domains: (a) *Cratons*, (b) *Mobile Belts*, and (c) *Cover Rocks*. The cratons are large masses of ancient basement rocks of Archean to Paleoproterozoic age that have remained stable since about 1.6 billion years (Ga) ago (Dirks et al., 1992; Banda, 2015).

There are six cratons: the Kaapval Craton, Zimbabwe Craton, Congo Craton, Tanzania Craton, West African Craton and Trans-Saharan Metacraton (Fig. 2). Each craton is made up of fragments of Archean (3.8--2.5 Ga) ancient crustal blocks surrounded or transected by younger Paleoproterozoic (2.5--1.6 Ga) and Mesoproterozoic (1.4--1.0 Ga) mobile (orogenic) belts (Dirks et al., 1992; Banda, 2015).

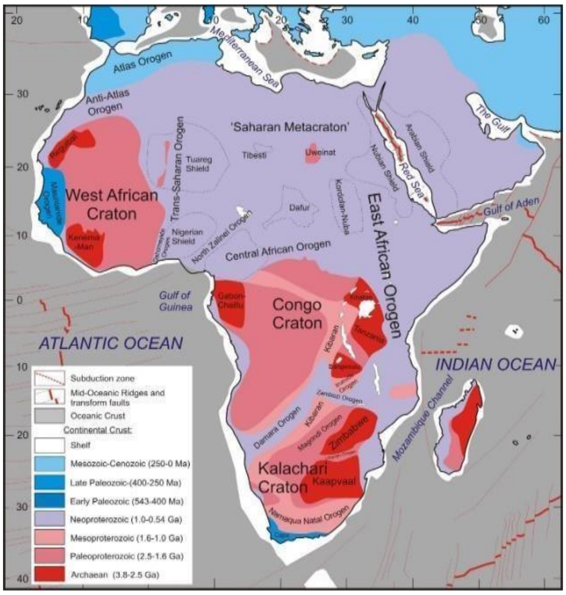

Fig. 2 Cratons and mobile belts in Precambrian Africa (after Van Hisbergen et al., 2015).

Each craton is composed of core zone(s) of Archean granite–greenstone belts (Dirks et al., 1992), which represent a complex assemblage of predominantly tonalite–trondhjemite gneisses (TTGs), granitoids, and greenstone belts of weakly metamorphosed volcanic rocks that are often intercalated with metasedimentary rocks (Attoh and Ekwueme, 1997). During the Paleoproterozoic era, the mobile belts surrounding the shields were composed primarily of metavolcanic and metasedimentary rocks, intruded by granitoids and pegmatites within deformed orogenic belts affected by the Eburnean orogeny (2.0–1.9 Ga). Examples include the Birimian Supergroup in West Africa (Ghana, Mali, and Burkina Faso) and the Magondi Supergroup in western Zimbabwe. (Dirks et al., 1992). Some parts of the cratons were covered by undeformed sedimentary sequences, such as the Witwatersrand Basin (Kaapvaal Craton) in South Africa and the Franceville Basin of Gabon (Congo Craton).

The cratons are separated from each other by some younger narrow mobile belts and sedimentary Mesozoic to Neoproterozoic-aged basins, some of which were deformed by orogenic events during the Kibaran Orogen (1.2--1.0 Ga) and/or the subsequent Pan-African (600--500 Ma) Orogeny (Banda, 2015). The Kaapvaal Craton, which underlies most of southern Africa, and the Zimbabwe Craton were welded together by the Paleoproterozoic Limpopo mobile belt, a zone of mostly reworked Archean rocks. To the south, the Damara mobile belt of Pan-African age in Namibia and South Africa joined the Kaapvaal Craton and Congo Craton via collisional orogeny (Dirks et al., 1992).

The Congo and Tanzania Cratons underlie most of Central Africa, and are flanked or joined by Paleoproterozoic orogenic belts, including the Ubendian Belt (Fig. 3). The craton is truncated or flanked by the Mesoproterozoic Kibaran and Irumide Belts. During the Neoproterozoic, several rifting events occurred along the southern margin of the Congo Craton in the Lufilian and Zambezi Belts, with localized volcanism and deposition of clastic sequences of the Katanga Supergroup across Zambia and the DRC. The Pan-African orogenic belts surrounding the Congo Craton include the West Congo Belt to the west, between Angola and Gabon, the Central African Belt to the north, between the Congo and Cameroon-Chad, and the Mozambique Belt to the east.

The West African Craton, which underlies most of western and northwestern Africa, comprises two Archean nuclei, the Reguibat Shield and the Man-Leo Shield, which are surrounded and joined together by the Paleoproterozoic Birimian Supergroup, which consists of thick sequences of metavolcanic and metasedimentary rocks deformed during the Eburnean orogeny (2.0 Ga) (Fig. 4). Archean rocks are separated from Paleoproterozoic rocks by significant shear zones, with the Sassandara fault marking the tectonic boundary between these two geological eras (Masurel et al., 2021; Traore et al., 2025). The Archaean rocks are predominantly tonalite–trondhjemite–granodiorite (TTG) gneisses, dated to 3.26-2.85 billion years (Petters, 1991; Goldfarb et al., 2017).

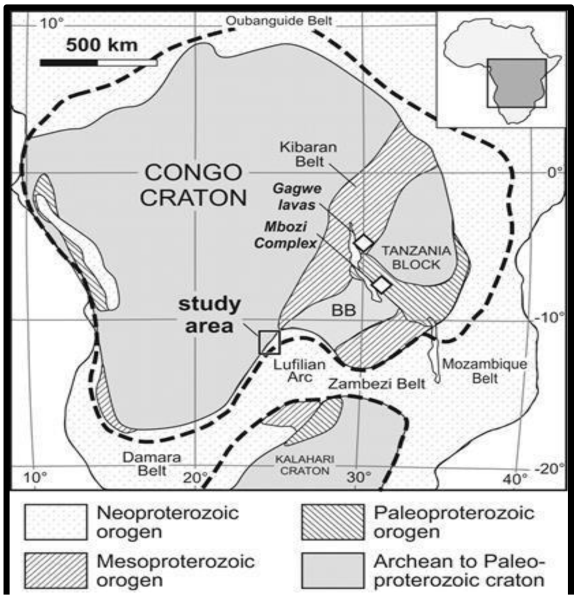

Fig. 3 Congo-Tanzania Craton and Mobile Belts.

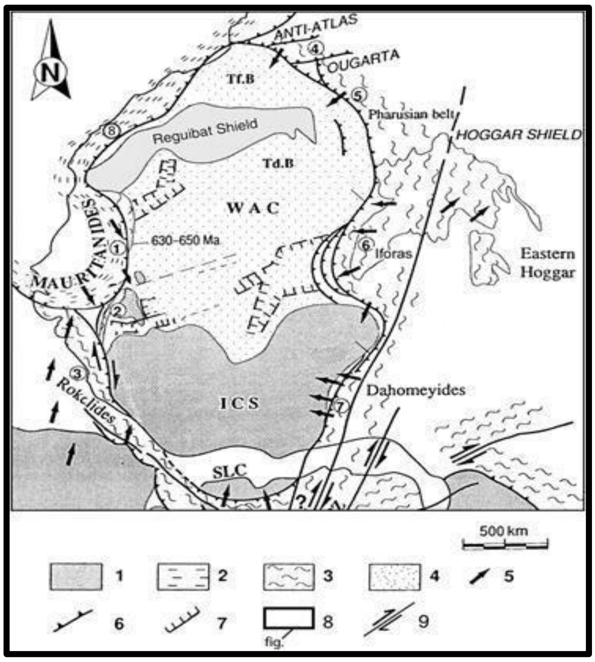

Fig. 4 West African craton and mobile belts.

The Paleoproterozoic Birimian Supergroup is composed of a lower sequence of metasedimentary rocks, comprising phyllites, schists, greywackes, conglomerates, and quartz-sericite schist. In contrast, the upper sequence of metavolcanic rocks is mainly composed of metamorphosed basaltic and andesitic lavas, as well as amphibolites, which form "greenstone belts". Mesoproterozoic sediments of the Tarkwaian conglomerates and quartzites lie to the east of the craton and are undeformed post-Eburnean molasse facies (Petters, 1991). The Dahomeyan-Ahaggar Belt, located to the west of Ghana and extending into Nigeria, represents a part of the Trans-Saharan Belt (Fig. 2), which is composed of zones with deformed metasedimentary rocks and the reactivation of older rocks during the Pan-African orogeny (Kroner, 1980; Dada, 2008). Pegmatites and granitoid intrusions emplaced during the late collisional phase of the Birimian orogeny are hosts to rare metal and lithium mineralization in Ghana, Mali, and Burkina Faso (Kazapoe, 2023). Lithium, tin, and tantalite deposits in Nigeria are also associated with pegmatites, which formed during the late phase of the Pan-African collisional orogeny (Kroner and Stein, 2004; Olade, 2025).

The Trans-Saharan metacraton is a large, disjointed mass of mostly reworked basement rocks that underlies most of the Sahara and Northeast Africa. The dominant rocks are Precambrian gneisses, granulites, and granites covered by Phanerozoic sedimentary rocks in Niger, Algeria, and Sudan. After the Precambrian era, Africa's stable geological platform was punctuated during the early Paleozoic by the formation of the Cape fold belt in South Africa, the Anti-Atlas belt in Morocco, and the Mauritanides in Mauritania along the northeast border of the older craton (Dirks et al., 1992).

Precambrian tectonics in Africa was characterized by stability in ancient cratons containing rocks that were more than 3.5 Ga old until at least 2.0 Ga, when narrow and linear Proterozoic mobile belts formed at the edges of cratons from the Proterozoic to Paleozoic (Dirks et al., 1992). However, the characteristics and composition of the Archean gneiss-granite–greenstone belts suggest that they were affected by thermo-tectonic activity involving metamorphism, structural deformation, and emplacement of granitoids.

Two orogenic cycles, the Leonian (3.1 Ga) and the Liberian (2.7 Ga), have been identified in the West African Craton (Rollinson, 2016), but little is known about their geological characteristics. The early Proterozoic mobile belts, which surrounded the Archean cratons, were strongly deformed and metamorphosed by tectonic events associated with convergent-subduction - accretional and collisional orogeny. Granitic rocks and pegmatites were emplaced during these thermo-tectonic episodes and used for isotopic dating and event timing.

Precambrian orogenic cycles: Orogenic events are tectonic activities in which portions of the Earth's crust are subjected to folding, deformation, and mountain building due to compressional forces associated with phases of metamorphism and igneous activity, usually along linear zones within limited time frames (Dirks et al., 1992; Attoh and Ekwueme, 1997). Orogenies are very important in the formation of mineral deposits because deformation, metamorphism, and plutonism provide sources of metals and structural features conducive to the accumulation, movement, and localization of mineral deposits such as lithium and rare metals. Africa has been subjected to several orogenic cycles throughout its geological history, starting from the Mesoarchean to the Paleozoic.

Orogenic belts develop from orogenic activity and are generally classified into three types: accretionary, collisional, and intracratonic belts (Cawood et al., 2009). The most significant orogenic cycles in Africa were in the Neoarchean and Proterozoic, namely, the Liberian (2.8–2.5 Ga), Eburnean (2.3–1.8 Ga), Kibaran (1.4--0.85 Ga), and Pan-African (0.75-0.50 Ga) cycles (Kroner and Stern, 2004). In the Phanerozoic, the only recognized orogeny that affected Africa along its northwestern and southern margins was the Hercynian Orogeny (0.45–0.25 Ga) (Banda, 2015).

Archean (Liberian) Orogeny - 2.7 Ga (Neoarchean): Relatively little is known about the nature of Archean orogenic activity (3.82.6 Ga), except for widespread structural deformation, metamorphism, and magmatism in gneiss–granitoid greenstone belts. Africa has experienced several orogenic cycles throughout its geological history (Dirks et al., 1992). The West African Craton has retained some records of Archean orogenic activity in the Leo-Man Shield that was affected by at least two orogenic cycles during the Archean, dated by isotopic methods: the Leonian Orogeny at 3.3–3.0 Ga (Mesoarchean) and the Liberian Orogeny at 2.9–2.7 Ga (Neoarchean) (Koffi et al., 2022).

The Archean rocks are characterized by tonalite–trondhjemite–gneisses (TTGs), which are infolded with greenstone belts that are composed of supracrustal metavolcanic and metasedimentary rocks and intruded by Neoarchaean granitoids dated at about 2.8 Ga (Rollinson, 2016). The Liberian Orogeny was mainly a thermo-tectonic event. Similar rocks affected by the Liberian Orogeny are probably present in the Zimbabwe and Kaapvaal Cratons (Rollinson, 2022).

Eburnean Orogeny - 2.1 Ga (Paleoproterozoic): The Eburnean Orogeny occurred during the Paleoproterozoic era and affected the West African Craton, particularly in Ghana, Côte d'Ivoire, and Mali. This orogenic cycle resulted in the formation of the Eburnean orogen (Petters, 1991), which stretched from Senegal to Ghana, containing the Birimian Supergroup - a thick sequence of metavolcanic and metasedimentary rocks that were deformed, metamorphosed, and intruded by granitoids dated as 2.1-1.9 billion years (Kazapoe, 2023; Traore et al., 2025). Tectonic activity during a similar period affected the Tanzania Craton

(Ubendian orogen) and Zimbabwe Craton (Magondi orogen) (Rollinson, 2022). The Eburnean Orogeny was associated with the formation of peraluminous granitoids and lithium-rich pegmatites in Ghana, Mali, Burkina Faso, Senegal, and Zimbabwe (Goodenough et al., 2025; Kazapoe, 2025). The Eburnean orogen has been described as a product of both convergent-subduction and collisional orogeny between continental blocks, with a suture zone marked by the Sassandra Fault Zone (Sakyi et al., 2024).

Kibaran Orogeny - 1.0 Ga (Mesoproterozoic): The Kibaran Orogeny was a series of tectono-magmatic events (Tack et al., 2012 spanning the period from 1.4--1.0 Ga (in the Mesoproterozoic era) that affected parts of the Congo Craton in the southeastern part of the Democratic Republic of the Congo (DRC), extending into parts of Rwanda, Burundi, Uganda, Namaqualand, and Natal in southern Africa (Thomas et al., 1994; Ballouard et al., 2020). This orogeny was characterized by the emplacement of large intrusive bodies dated at 1.39--1.35 Ga and 1.1--1.0 Ga and attributed to subduction and continental collision between the Congo and Tanzania Cratons (Tack et al., 2010) (Fig. 3).

Pegmatites dated from 930-950 Ma were emplaced during the late tectonic or post-tectonic phase of collisional orogeny (Dewaele, 2015). Other segments of the Central African Craton affected by the Kibaran orogeny were subjected to reworking and deformation from Archean to Paleoproterozoic provinces and minor intrusive activity during the final 1.1–1.0 Ga collision. These belts include the Karagwe-Ankolean, Burundi, and Magondi (Zimbabwe) belts (Petters, 1991). The Kibaran orogenic belt represents a metallogenic province for Sn, Nb-Ta, Li, and Be in rare-metal pegmatites associated with the collision-derived generation of granites and pegmatites (Dewaele et al., 2016).

Pan-African orogeny - 550 Ma (Neoproterozoic): The Pan-African Orogeny was the most pervasive orogenic cycle that occurred in the Neoproterozoic era and affected various parts of Africa, including the Sahara Desert, Dahomey-Nigeria belt, Damara belt in Namibia, Mozambique belt in East Africa, and Eastern orogenic belt in Ethiopia. The Pan-African Orogeny was, in places, a thermo-tectonic event and collisional orogeny that involved the metamorphism of supracrustal sediments, such as those found in Nigeria and the emplacement of granitic rocks and pegmatites in Nigeria and the Niger Republic (Kroner, 1980; Petters, 1991; Olade, 2025).

This tectonic event resulted in the formation of lithium-rich pegmatites in Namibia, Mozambique, Ethiopia, and Nigeria. The Pan-African Orogeny was a collisional event that brought together all the old continental cratons in Africa, including West Africa, Congo, Kalahari, and Tanzania, to form Gondwana and subsequently the supercontinent Pangea by the late Paleozoic (Kroner and Stern, 2004).

Major Lithium Deposits in Africa

Africa is blessed with significant deposits of lithium, which are localized solely within pegmatites or aplite-pegmatites of different ages and orogenic cycles (Taylor et al., 2005; Nex et al., 2019). In 2024, unlike other lithium deposits in Europe and Asia, Africa's lithium was not found in granites or granitoids.

Africa produced approximately 25,000 metric tons of lithium in 2024 (Statista, 2025), primarily from Zimbabwe (22,000 tons), Namibia (2,000 tons), and other countries (1,000 tons), which account for about 10% of the world's lithium production (Wikipedia, 2025). The six countries with significant lithium deposits are Zimbabwe, Namibia, Nigeria, Ghana, Mali, and the Democratic Republic of the Congo (DRC) (Fig. 5).

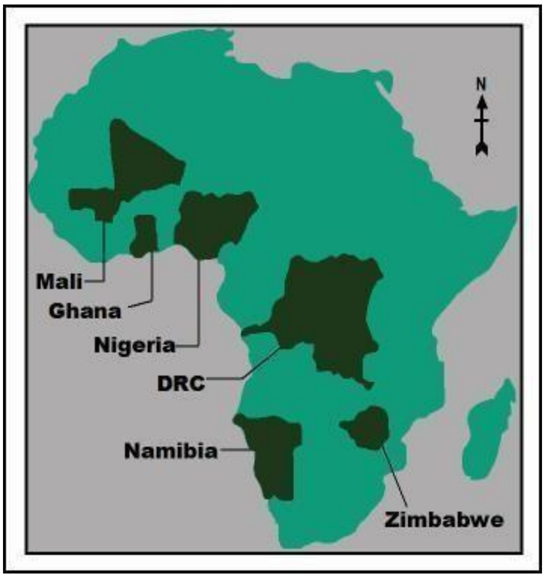

Fig. 5 African countries with major lithium deposits.

Other countries with lithium prospects that are being explored or developed are Burkina Faso, Senegal, Ethiopia, Rwanda, Mozambique, Madagascar, South Africa, and Niger (Fig. 6). Figure 7a shows the network of lithium deposits and prospects in southern, central, and eastern Africa. However, this review is limited to ore deposits with published information.

Zimbabwe is the 5th leading producer of lithium in the world. The country is blessed with some large

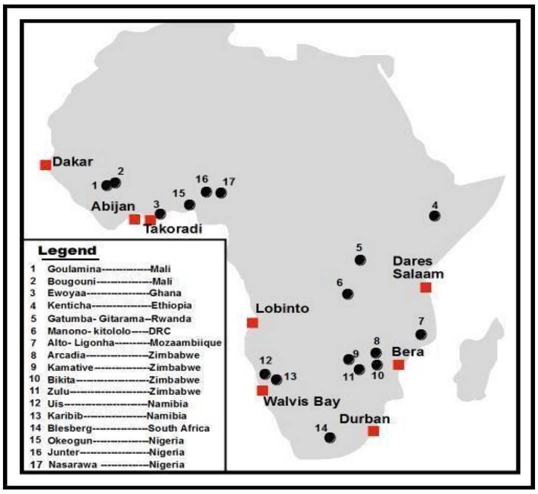

Fig. 6 Lithium deposits and prospects in Africa.

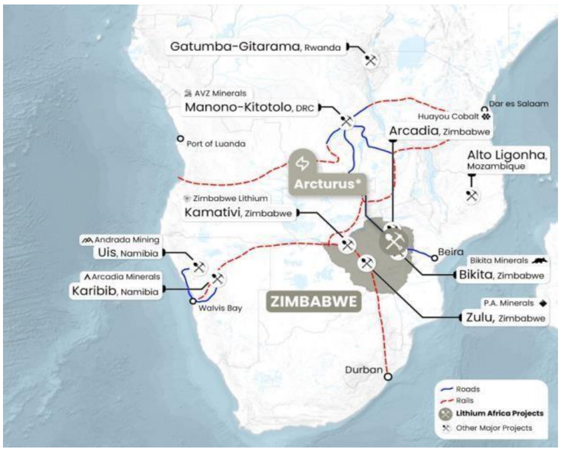

Fig. 7a Map showing the network of lithium occurrences in southern, central and eastern Africa (after Lithium Africa, 2025).

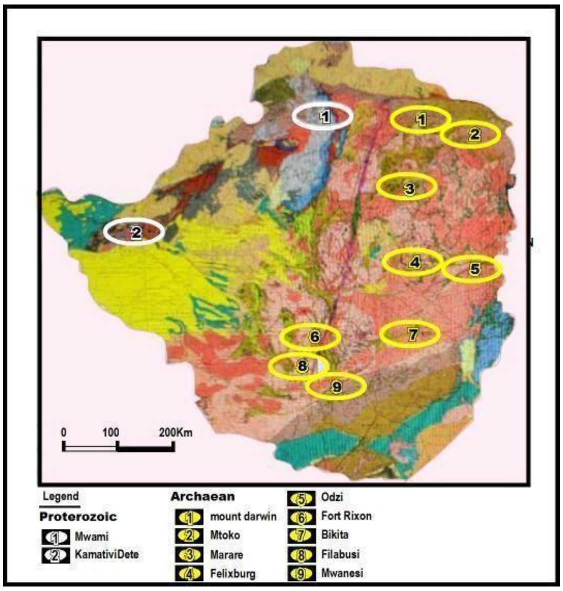

Fig. 7b Archean and Proterozoic pegmatite fields, Zimbabwe (after Martin, 2019).

Lithium and rare-metal pegmatite deposits, including Africa's currently active lithium mines at Bikita and Arcadia (Fig. 7a) (Dittrich et al., 2019), and historical mining in the Kamativi pegmatite. Active exploration is underway at several pegmatite fields and other localities, as illustrated in Figure 7b, which is leading to the development of mining activities and processing at Zulu and Sabi Star Mines (Figure 8). There are other mining projects, such as Sardawana and Mature that are likely to be productive (Goodenough et al., 2025). The Archean lithium-bearing pegmatites in Zimbabwe, which are most commonly mineralized with tin and tantalite, are found within greenstone belts intruded by Neoarchean granites of the Chilimanzi and Razi suites, dated at approximately 2.6 Ga (Dittrich et al., 2015).

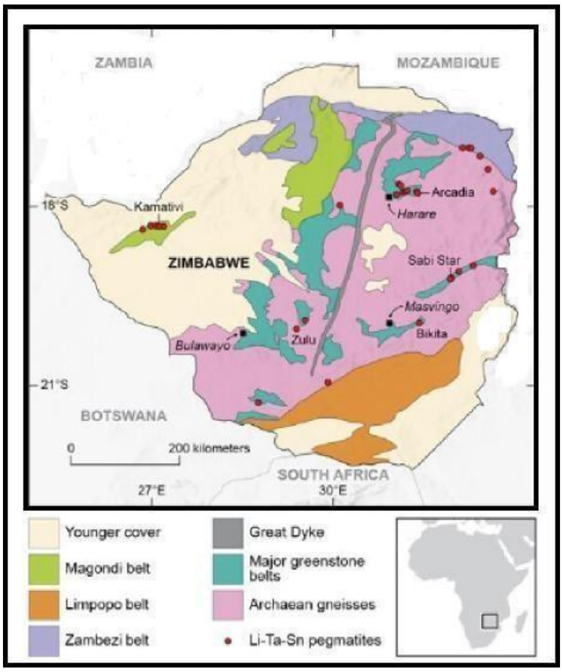

Fig. 8 Simplified geological map of Zimbabwe showing lithium deposits (after Goodenough et al., 2025).

Archean lithium deposits: The Archean gneiss-greenstone belts in Zimbabwe are a depository of world-class lithium deposits hosted by rare metal pegmatites, such as those in Bikita, Arcadia, Zulu, and Sabi Star. The Zimbabwe Craton is very rich in lithium pegmatites, with up to 29 occurrences identified by Bartholomew (1990) and corroborated by Goodenough et al. (2025).

Martin (2019) identified up to 9 pegmatite fields within the Archean craton alone, many of which are lithium-rich (Fig. 7b). These pegmatites are found solely within the Archean greenstone belts. It is believed that the geological setting and presence of shear zones in the host rocks also influenced the distribution and localization of the pegmatites

(Koopmans et al., 2025). Several other pegmatite fields with potential for mineralization are dispersed within the Archean rocks. No other craton in Africa has such a concentration of lithium pegmatites (Goodenough et al., 2025). Other rare metals, such as Sn, Nb-Ta, and Be, occur along with Li in varying quantities. Four significant deposits at Bikita, Arcadia, Zulu, and Sabi Girl are in production at various levels (Mining Weekly Africa, 2024).

The geological setting of Zimbabwe is characterized by a cratonic nucleus of the Archean basement, composed of greenstone-schist belts dispersed within an ancient high-grade gneiss terrain, consisting mainly of orthogneisses, intruded by granitoids and pegmatites, dated at approximately 2.6 Ga (Herzog et al., 1960; Stagman, 1978; Rollinson, 2022). The craton is bordered to the south and west by the Paleoproterozoic belts of Limpopo and Magondi, respectively. (Fig. 8).

Along the northern and eastern margins are the Neoproterozoic Zambezi and the Mozambique Belts, respectively. The prevalent rocks are mainly granitic gneisses, tonalitic-trondhjemitic-granodioritic granitoids, schists, and “greenstones”, which are metamorphosed mafic, ultramafic, and felsic volcanics. Magmatism culminated during the Neoarchean with the emplacement of abundant potassic granites and pegmatites (Rollinson, 2022).

Bikita deposit: The Bikita lithium deposit is in Masvingo Province in southeastern Zimbabwe, approximately 80 km east of Masvingo town and 180 km southeast of Harare (Fig. 8). The mineralized zones are localized within a large pegmatite body known as the Bikita Main Pegmatite (BMP), the largest of a swarm of 15 dikes of Neoarchean age (Fig. 9) (Melcher, 2015). They were emplaced in the Masvingo Greenstone Belt and adjoining Victoria Schist Belt, which is surrounded by Archean gneisses (Cooper, 1964). The lithology of the host rocks comprises mafic metavolcanic rocks (amphibolite and mafic schists), with interbedded metasedimentary rocks consisting of calcareous and semipelitic schist, as well as banded ferruginous quartzite (Martin, 1964).

The Bikita Pegmatite is exposed over a length of approximately 1700 m and an average width of 50 m (ranging from 40-70 m), with a dominant N-S strike and shallow dip to the east (Cerny et al., 2003). Structural analysis by Godogo (2022) suggested that the NE–SW-trending Gono fault and the N–S-trending Popoteke fault may have exerted regional-scale control on the emplacement of the pegmatites and served as conduits for migrating pegmatite melts (Godogo, 2022). The Bikita pegmatites are highly fractionated LCT pegmatites enriched in Li, Cs, Ta, Be, and Sn (Dittrich et al., 2019; Goodenough et al., 2025). They appear as lenticular bodies with aplitic to coarse-grained textures and heterogeneous and complex mineralogy. An exceptional assemblage of lithium-bearing minerals, including petalite, spodumene, lepidolite, amblygonite, bikitaite, eucryptite, and hectorite, occurs in the deposit. Pollucite, a cesium mineral, and tantalite are found in the Bikita pegmatites. Mineralogical and textural zoning is manifested by the distinct development of border, intermediate and core zones (Fig. 10), with a paragenetic sequence of early-stage minerals characterized by euhedral plagioclase, K-feldspar, middle-stage minerals characterized by petalite, spodumene, and other minerals. In contrast, later stages include pollucite and spodumene in the core zone, all of which are characterized by magmatic crystallization (Goodenough et al., 2025).

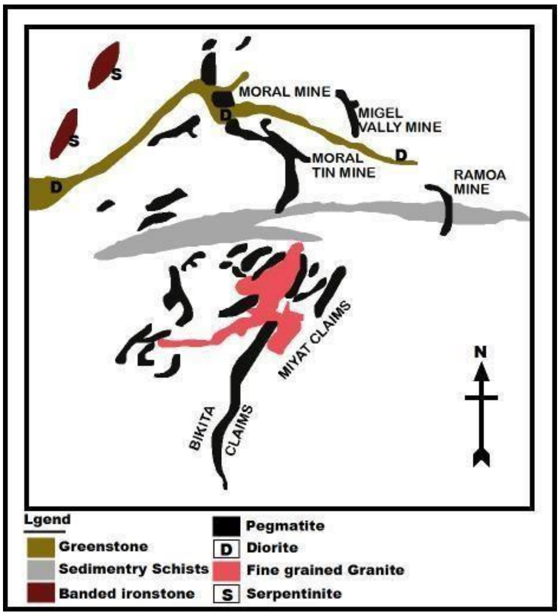

Fig. 9 Sketch map of a lithium pegmatite swarm in the Bikita deposit (after Cooper, 1964).

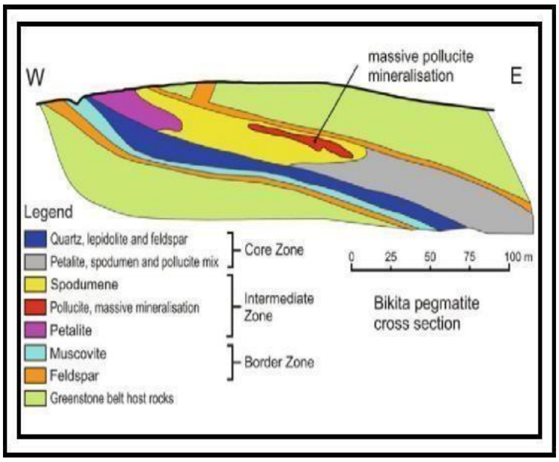

Fig. 10 Mineral zoning at the Bikita mine (after Cooper, 1964).

The origin of the Bikita pegmatites has been attributed to extreme fractionation of residual melts derived from the crystallization of granitic melts (Martin, 1964; Melcher et al., 2015), although it is not possible to link the pegmatites to any individual granite intrusions in the area. The concentration of cesium and the formation of substantial pollucite are indications of extreme fractionation of pegmatite melts (Dietrich et al., 2019). The alternative genetic model of anatectic origin should not be ruled out because of a lack of obvious parental granites.

The Bikita lithium deposit is currently mined in two opencast pits in the Bikita Main Pegmatite (BMP) at Bikita and Al Hayat. The BMP has been mined periodically since tin was discovered in 1910, and mining of petalite (for lithium) started in the 1950s. Petalite is the dominant primary lithium mineral, with spodumene and some tantalite as the main ore minerals currently produced at Bikita. Petalite is a versatile additive used in glass, ceramics, and glaze but not in lithium-ion battery manufacturing (Goodenough et al., 2021). Bikita, which started a new phase of production in 2020, has estimated ore reserves of 29.41 million metric tons and an average ore grade of 1.05% Li_2O (Table 3).

In 2022, the ownership of the deposit changed when the Sinomine (Hong Kong) Resource Group acquired Bikita Minerals, previously controlled by African Minerals Ltd., for US$180 million. The company has also invested an additional US$300 million in expanding the existing plant and constructing a new lithium processing plant, aiming to produce a total of 300,000 metric tons of spodumene concentrate and 480,000 metric tons of petalite per year. In July 2023, Sinomine announced the completion of its spodumene concentrate plant, which will produce battery-grade lithium. According to available statistics (Mining Review Africa, 2025), Zimbabwe's lithium mine production from the Bikita Mine has been steadily increasing since 2020, reaching a new high of 22,000 metric tons in 2024, a nearly 50% increase from the previous year.

Arcadia deposit: The Arcadia lithium deposit is located 38 km east of Harare in the Mashonaland East Province, northeastern Zimbabwe (Fig. 9). It is described as probably the largest world-class, hard-rock lithium deposit in Africa, with reserve estimates (JORC compliant) of 72 Mt of 1.06 Li_2O (Mining Technology, 2023). The lithium deposit occurs in a series of stacked (14) subparallel pegmatites emplaced within rocks of the Arcturus Formation, a part of the Harare Greenstone Belt (Tyler, 2019). The surrounding host rocks are mafic metavolcanic and serpentinites with intercalated metasedimentary rocks and iron formation.

Lithium mineralization primarily consists of petalite and spodumene, in which petalite is believed to have formed before, or cogenetic with, spodumene (Tyler, 2019). Secondary minerals, such as eucryptite, bikitaite, lepidolite, and tantalite, are also present as alteration products of primary petalite and spodumene. Like in the Bikita deposit, Arcadia lithium also contains significant cesium concentrations due to pollucite, although in lesser quantities.

Subsurface drilling intercepts pegmatites with an average thickness of 15 m and extends up to 3.5 km in strike length (Mining Technology, 2023). The pegmatites belong to the LCT family and are enriched in lithophile and rare elements. The proven and probable reserves at Arcadia are estimated at 72.7 Mt, grading 1.06% Li_2O and 121 ppm Ta_2O_5 (Mining Technology, 2023).

The Arcadia lithium project is currently owned by Zhejiang Huayou Cobalt, which bought assets from Prospect Resources and its partners in 2022. The groundbreaking ceremony for the Arcadia lithium project was held in December 2018. Since then, the ore body has been further explored, and substantial mining commenced in 2023, with an average production of 212,000 tons of spodumene and 216,000 tons of petalite concentrates per annum.

Arcadia is considered one of the world’s largest hard rock lithium resources. Zhejiang Huayou Cobalt commissioned its US$300 million lithium concentrator plant at Arcadia in July 2023, and the plant has the capacity to produce 450,000 MT of lithium carbonate per year.

Zulu deposit: The Zulu lithium-tantalum deposit is another significant pegmatite mineralization associated with the Archean greenstone belts of the Zimbabwe Craton. The pegmatite deposit is located approximately 80 km from Bulawayo in southern Zimbabwe and 200 km west of the Bikita deposit (Fig. 9). It was first mined in 1961 for petalite. The Zulu deposit is a well-mineralized pegmatite swarm emplaced within the Fort Rixon Greenstone Belt along the contact of a serpentinite body with metabasalts and metasedimentary rocks, controlled by a NNW-trending fault system (Fig. 11).

The pegmatites trend approximately N20° and steeply dipping and are 10 to 25 m wide with a discontinuous strike length of a few kilometers. Structural control by shear zones and host rock lithology likely influenced the emplacement of the pegmatite deposit (Koopmans et al., 2025). Petalite and spodumene are the main lithium minerals with minor amounts of lepidolite, amblygonite, and Mn-tantalite (Premier African Minerals Report, 2025).

The Zulu lithium deposit is currently under development by Premier African Minerals, which operates a small lithium-tantalum mine and has several more minor lithium pegmatite prospects in eastern Zimbabwe (Amaranti, 2024). In 2022, a Chinese company, Canmax Technologies, invested US$35 million to help with the construction of Zulu's processing plant, which is expected to have an annual output of nearly 50,000 Mt of spodumene concentrate. It is now fully commissioned and has been producing spodumene concentrate since April 2024. A mineral resource estimate in 2024 yielded reserves of 24.75 million tons of 0.45% Li2O and 44 g/ton Ta2O5 (Premier African Minerals Report, 2025).

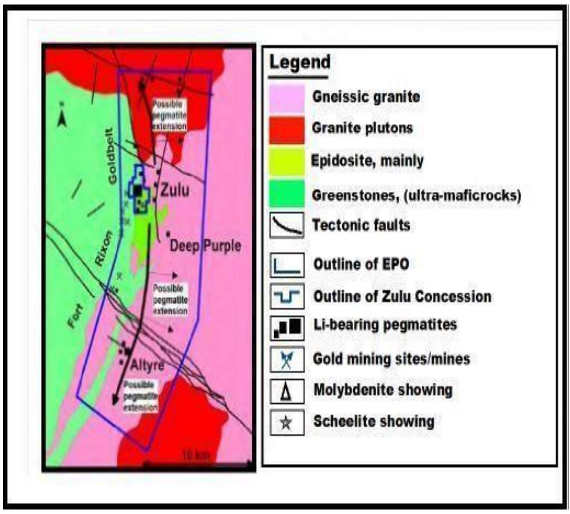

Fig. 11 Geological map of the Zulu mine, Zimbabwe (after Premier African Minerals).

Sabi Star deposit: The Sabi Star lithiu (-tantalum) deposit is located in the Buhera district of Eastern Masvingo Province, approximately 80 km west of Mutare. Lithium mineralization is found within a swarm of LCT pegmatites intruding the (gold-mineralized) Mutare Greenstone Belt, which is an E–W synclinorium that contains Archean mafic metavolcanics, schists, banded iron formations, and metasediment, intersected by granites, dolerites, and aplite-pegmatites (Chenjerai, 1991).

The Sabi Star deposit lies at the southern limb of the regional syncline along a NE–SW belt of mineralization in the Mutare greenstones (Fig. 13). Relatively little is known about the Sabi Star pegmatites, except that they are LCT pegmatites enriched in Nb, Ta, Be, Li, Cs, and Rb. The dominant lithium mineral is spodumene, with minor amounts of lepidolite and substantial quantities of tantalite. The estimated reserves are 15 Mt of lithium grading 1.48% LI2O, one of the highest grades among lithium mines in the greenstone belts (Mining Review Africa, 2023). Li3, an exploration company, has recently discovered lithium mineralization over a 1.2 km long zone, targeting the Nels Luck Pegmatite near Mutare, just a few kilometers northeast of Sabi Star (Fig. 12). The Mutare Greenstone Belt is considered an emerging lithium district, with numerous lithium exploration and mining projects underway.

The owner and operator of the Sabi Star Mine is MaxMind Investments, a subsidiary of China's Chengxin Lithium Group. Mine production commenced in 2023, with an annual capacity of 900,000 tons of lithium rock that could yield about 300,000 tons of spodumene concentrate (Amaranthi, 2024). The area where the Sabi Star deposit is located has a history of mining for tantalite in the past. The published literature on the Sabi Star pegmatites is sparse, but the mineralized pegmatites contain spodumene, lepidolite and tantalite.

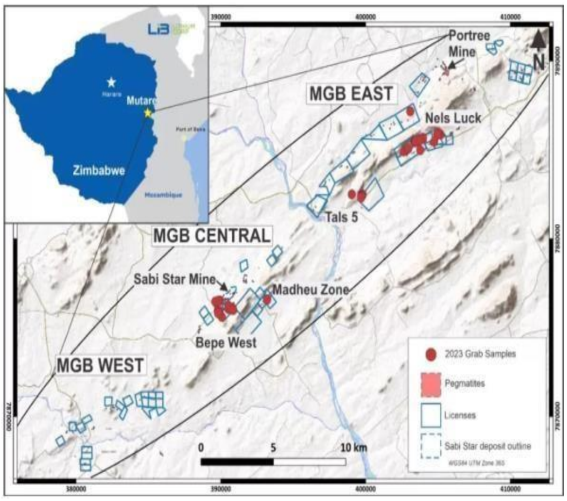

Fig. 12 Location of the Sabi Star mine along a zone in the mature greenstone belt (after Li3 Lithium project Mutare).

Birimian lithium deposits (Ghana, Mali, Burkina Faso): The West African Craton contains the most extensive exposures of Paleoproterozoic rocks in Africa. Instead of narrow and elongated mobile belts typical of other cratons, the Eburnean Orogeny was associated with extensive deposition over a broad area and deformation of rocks of the Birimian Supergroup, which separated and surrounded the Archean cratonic nuclei. After the end of the Eburnean Orogeny, the Paleoproterozoic Birimian metasediments and metavolcanics, which formed between 2.3 and 2.0 billion years ago, became a significant part of the West African Craton (Fig. 13).

These Proterozoic rocks were intruded by at least two phases of granitic rocks and two families of pegmatites. Eburnean granites and granitoids include Na-rich, leucocratic, and peraluminous types with ages ranging from 2.1 to 1.9 Ga, representing the late phase of igneous activity during collisional orogeny (Traoré et al., 2025).

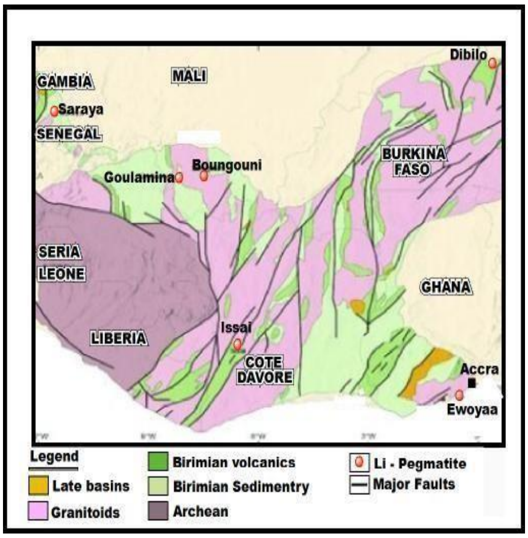

Fig. 13 Simplified geological map of the West African Craton and Birimian lithium deposits (modified after Goodenough et al., 2025).

The two families of Birimian pegmatites consist of an earlier phase, which is lithium-poor, and a younger phase, which is lithium-rich and dated at 2.02 to 2.05 Ga (Sanogo, 2022) and approximately 2072 Ma in Ghana (Kazapoe, 2023). They are lithium-rich and considered products of a late tectonic collisional orogeny (Traore et al., 2025). Several significant lithiumdeposits have been found within pegmatites intruding the Paleoproterozoic Birimian rocks and granitoids in Mali (Goulamino and Bougouni) and Ghana (Ewoyaa), with similar but lesser-known occurrences in Burkina Faso, Niger (Dibilo), Ivory Coast (Issia), and Senegal (Saraya) (Fig. 13) (Nex et al., 2019). Mali is currently the most significant producer of lithium in West Africa.

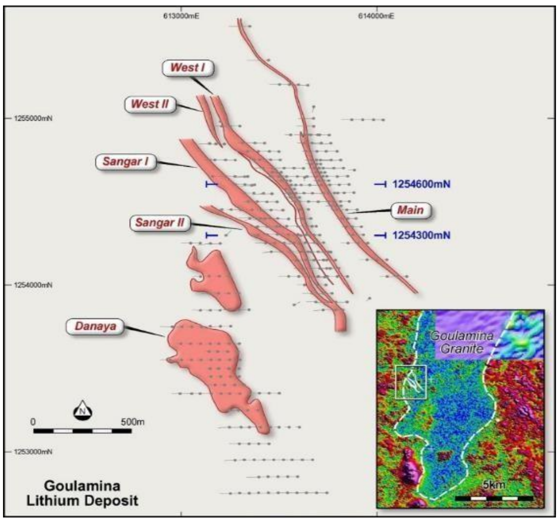

Fig. 14 Geology of the Goulamina pegmatite field, Mali inset showing the relationship with the Goulamina granite (after Wilde, 2021).

Goulamina deposit: The Goulamina lithium deposit is in the Bougouni region of southwestern Mali approximately 150 miles south of Bamako, the capital city (Fig. 13). This deposit is described as one of the largest hardrock lithium ore bodies in Africa, with estimated reserves of 52 million metric tons of 1.45% Li2O (Mining Technology Report, 2023) and a resource base (which includes inferred reserves) of 103 million Mt at 1.32% Li2O (Wilde et al., 2021).

Lithium mineralization is found within a swarm of subparallel, NW–SE-trending, steeply dipping pegmatite dikes approximately 10-80 m wide and over 1 km long. They are enclosed entirely within the Goulamina Granite, a large, elongate intrusion extending for more than 20 km in a north–south direction (Fig. 15) and intrude a sequence of Birimian rocks composed of metapelites, metagraywacke, and metaconglomerates (Wilde et al., 2021). Approximately 70% of the Goulamina lithium is hosted by five of the pegmatites, namely, Main, West, West II, Sangar I, and Sangar II (Fig. 14). These pegmatites belong to the younger family of pegmatites described as products of late or post-tectonic collisional Eburnean Orogeny (Traore et al., 2025).

Spodumene is the dominant, if not the only, lithium mineral that occurs in both the pegmatite and the associated aplite layers. It ranges in size from small to large disseminated crystals up to 15 cm in length. The typical mineralogical assemblage in the pegmatites is simple, consisting of quartz, K-feldspar, muscovite, and abundant albite, with no obvious mineral zoning (Wilde, 2021). There is evidence that metasomatic albitization affected the pegmatites, leading to a decrease in lithium concentration. The Goulama pegmatites belong to the LCT family and are enriched in Li, Rb, Cs, and Ta (Sonogo, 2022). The geochemical similarities between the Goulamina Granite and the numerous pegmatites within it have led to the suggestion that the granite and the intruding pegmatites are cogenetic and share a common magmatic origin (Kazapoe, 2023).

Leo Lithium, an Australian-based company, and Fintech Ltd. originally owned and explored lithium deposits until June 2021, when China-based Ganfeng Lithium, a world-leading producer of lithium, acquired the deposits as a joint venture to promote quick development of the project. The Goulamina lithium mine commenced production in January 2025, with Ganfeng Lithium owning 65% and the Malian government owning 35%. The first phase of operation currently involves the production of approximately 500,000 tons of spodumene concentrate annually, which increases to a million tons of lithium concentrate in the second phase. (Mining Review Africa, 2024).

Bougouni deposit: The Bougouni lithium deposit is also located in southern Mali, in the same Bougouni region as the Goulamina deposit, but lies slightly to the east, approximately 180 km south of Bamako (Fig. 13). The geology of the area is characterized by sequences of the Birimian Supergroup intruded by Eburnean granitoids and pegmatites. The pegmatites are described as steeply dipping (~90°) sheets that predominantly trend E–W or SE–NW with sharp contacts with the country rocks (Sanogo, 2022).

They pegmatites are relatively coarse-grained, and the main lithium mineral is spodumene, with quartz, muscovite, and a high content of albite, which also indicates extensive albitization, similar but not as intensive as the Goulamina deposit, but no granitic rocks exist in the vicinity of the pegmatites. Tourmaline, beryl, cassiterite, fluorite, tantalite, apatite and rutile occur as accessory minerals. The estimated reserves of the Bougouni lithium deposit in 2023 were 31.9 million tons of 1.06\% Li2O (Kodak Minerals, 2024). The Bougouni lithium mine is 65% owned by Kodak Minerals, a UK-based company, and Hainan Mining (from China), with the remaining 35% owned by the Malian government. The mine commenced spodumene production in 2025, with an estimated 125,000 tons per annum of raw lithium rock.

Ewoyaa deposit: The Ewoyaa lithium deposit is located in the Cape Coast Province in southern Ghana, about 100 km southwest of Accra. It is the only known significant lithium mineralization in Ghana and is currently being exploited. According to Adams et al. (2023), the coastal region between Accra and Cape Coast in southern Ghana is underlain by steeply dipping sequences of metasedimentary and metavolcanic rocks of the Birimian Supergroup, which are intruded by many Eburnean granitoids and pegmatites, some of which are mineralized with lithium, niobium-tantalum, and tin.

The country rocks are mostly quartz-mica and/or hornblende schists that have strong northeasterly foliation with nearly vertical dips. Lithium mineralization occurs within pegmatite dikes that intrude a variety of host rocks, including biotite schist and mafic schist, granodiorite, and other granitoids (Adams et al., 2023). The lithium pegmatites dip steeply with two dominant trends, namely, NNE and WSW, and range in thickness from less than 1 m to 60 m with variable strike lengths from 150 to 600 m. The Ewoyaa deposit is associated with one of the large pegmatite dikes.

Pegmatite mineralogy is simple, characterized by an assemblage of quartz, feldspar, muscovite, apatite, and spodumene, but it is devoid of mineralogical zoning. (Adams et al., 2023). Spodumene is the main lithium mineral, with two recognized forms (Wilde et al., 2021): one is coarse-grained with crystals >20 mm in size and forming 20–80% of the rock, whereas the other is medium- to fine-grained, constituting approximately 50% of the rock (Adams et al., 2023). There is some metasomatic albitization leading to the formation of secondary minerals and a decrease in lithium concentration (Agyekum and Adomako-Ansah, 2025).

The Ewoyaa Mine consists of an aggregate of eight small deposits, of which Ewoyaa is the largest. Others include Okwesi, Anokyi, Grasscutter, Abonko, Kampakrom, Sill, and Bypass (NS Energy Report, 2024). The deposits are 100% owned by Atlantic Lithium, an Australian mining company specializing in the development of mineral resources in Africa. The estimated reserves are 36.8 million metric tons of 1.32% Li2O. Following Ewoyaa, further development of the related Abonko and Kaampakrom lithium spodumene deposits took place. The first production of lithium concentrate from the mine is expected in the second quarter of 2025 (Atlantic Lithium, 2024).

Kibaran lithium deposits: Kibaran lithium deposits formed in pegmatites emplaced during the Kibaran tectono-magmatic event spanning the period from 1.2--1.0 Ga in the Mesoproterozoic. The orogeny affected the southeastern part of the Democratic Republic of the Congo (DRC), which extended into Rwanda, Burundi, Tanzania, Uganda, northwestern Zimbabwe, and Namaqualand in South Africa and was marked by the emplacement of monstrous intrusive bodies dated at 1.39–1.35 Ga and 1.1–1.0 Ga (Melcher et al., 2015). The Kibaran Orogeny may have involved subduction and continental collision between the Congo and Tanzania Cratons (Tack et al., 2010).

The DRC is widely known for its large, mineralized pegmatites, which were previously mined for tin, columbite, tantalite, and lithium deposits within the Mesoproterozoic metasediments of the Kibara mobile belt along the eastern margin of the Congo Craton. This belt extends across 1,000 km through Katanga and into southwestern Uganda.

The Kibaran rare metal pegmatites, previously mined for tin, are now known to contain significant lithium deposits, particularly in the Manono-Kitotopo areas of the Tanganyika Province of southeast DRC, approximately 600 km north of Lubumbashi. They were discovered in 1910 and were mined for tin until 1982.

The well-known Kamativi Pegmatite in the Magondi Mobile Belt of northern Zimbabwe was emplaced during the Kibaran and is associated with lithium deposits. In Namaqualand, some lithium-bearing pegmatites are known. Unlike the pegmatites from the Archean and Paleoproterozoic eras, the Kibaran lithium pegmatites are relatively rare but form large bodies instead of swarms or clusters of smaller pegmatite dikes. They seem to be lithologically controlled and confined to specific stratigraphic units in the low-grade metasedimentary rocks. Two significant lithium deposits in Kibaran pegmatites are Murano-Otukolo in the DRC and Kamativi in Zimbabwe. Other lithium pegmatite occurrences, explored in Rwanda and Tanzania within the Karagwe-Ankole belt, may also belong to this group.

Manono-Otokolo deposit, DRC: The Manono-Kitotolo lithium deposit is hosted by a huge and complex rare-metal pegmatite dyke (or system of pegmatites) situated in the northern part of the Katanga province of the DRC (Dewoele et al., 2016). It is considered a world-class deposit of Sn, Nb-Ta, and Li mineralization, with the Manono area being a separate zone from the Kitotolo area. For several decades, the pegmatite system has been exploited mainly for cassiterite and columbite–tantalite but is now believed to contain one of the world's largest reserves of lithium (Goodenough et al., 2025).

The mineralized pegmatite is approximately 300 m thick, crops out over a length of 15 km, and is emplaced along the foliation of a series of Paleoproterozoic pelitic schists and amphibolites (Hakansson Group) of the Kibaran Supergroup (Kokoyangin et al., 2006), which were intruded in several places by granites and pegmatites of Mesoproterozoic age during the late phase of the collisional Kibaran Orogeny (Fig. 15). The Manono pegmatite is dated to between 0.95 and 0.93 billion years old (Dewaele et al., 2016). The Kibaran granites were emplaced in two phases: the early syntectonic lithium-poor granites yielded ages of 1.5–1.1 Ga, whereas the later phase Sn-bearing granites were dated at 1.1-0.97 Ga, which is almost coeval with the lithium pegmatites (Zeng et al., 2024).

There are three types of lithium deposits in the Manono-Kitotolo area: (1) hard rock pegmatite deposits that were originally mined for tin and coltan, (2) mine tailings derived from previous mining, and (3) alluvial clay deposits. The hard rock pegmatite deposit is exposed in several quarries in two main zones at Manono and Kitolo with mining operations that stretch along a corridor approximately 15 km long and 800 m wide, extending from Kitotolo in the southwest to Manono in the northeast (Dewaele et al., 2016). Four main pegmatite deposits in the area have been worked for tin in the past. The Manono-Tokolo pegmatite appears as sheet-like bodies striking SW–NE and gently to steeply dipping that are emplaced along the foliation of the host rocks (metasediments), which

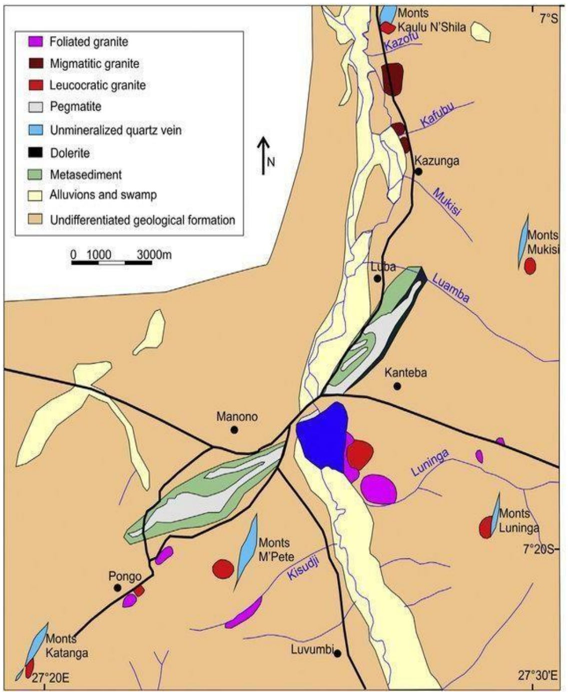

Fig. 15 Detailed geological map of the larger Manono-Kitolo area (after Daewale, 2016).

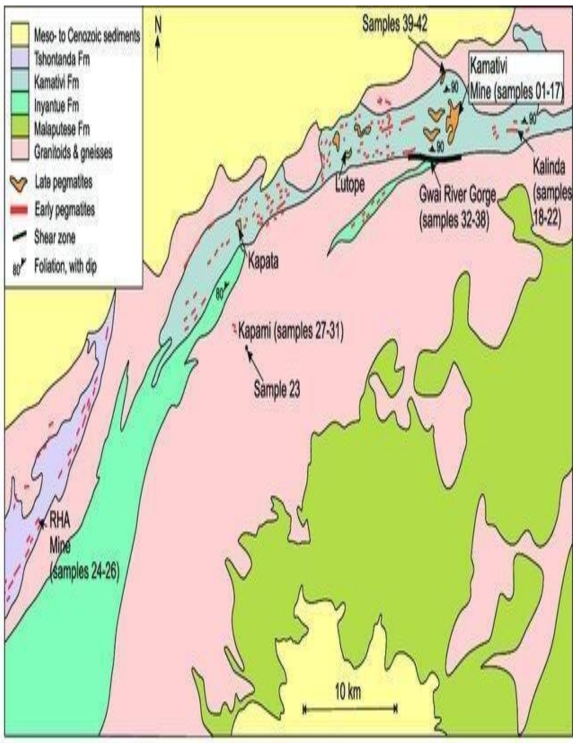

Fig. 16 Simplified geological map of the Kamativi pegmatite deposits (after Shaw et al., 2019).

This process resulted in intense hydrothermal alteration, characterized by the formation of muscovite, tourmaline, and silicification (Dewaele et al., 2016). As shown in Figure 16, some small intrusive bodies of leucogranites and dolerite occur in the area. The predominant lithium mineral is spodumene, with minor petalite and lepidolite.

The mineralized pegmatite belongs to the LCT family, and lithium mineralization is believed to have occurred during the late stage of the Kibaran orogeny, when the lithium-rich pegmatites and granites were emplaced. However, there is no specific indication of a parental relationship. The proven and probable reserves of lithium in the Manono hard rock deposits are estimated at 93 million tons, with a Li2O content of 1.58% as of April 2020 (Mining Technology, 2024), and a resource estimate of 400 million tons, with a Li2O content of 1.65%.

The Manono lithium tailings created from previous mining and beneficiation of tin and tantalite ores from the Manono-Kitolo deposit between 1919 and 1986 accumulated in eleven large heaps, mostly on the northeastern flanks of the quarries. The tailings stockpiles have now been evaluated for lithium and tin and estimated reserves of 5.46 million tons of 0.72% Li2O have been obtained (Mining Weekly, 2022). Alluvial clays containing sedimentary lithium also occur in drainage systems around mining areas.

AVZ Minerals owns a 75 percent interest in the Manono lithium deposits and is working in a joint venture with the China-based Zijin Mining Group to develop the lithium deposit. The remaining 25% interest is held by the state-owned company Cominiere. A definitive feasibility study published in 2020 indicates a mine with a 20-year lifespan and the capacity to produce 700,000 metric tons (MTs) of high-grade SC6 lithium and 45,375 metric tons of primary lithium sulfate annually.

There is currently a dispute around the ownership of Manono, which has resulted in AVZ Minerals suspending trading on the ASX pending a resolution that will allow it to move forward with the project (Mining Review Africa, 2024). Canadian Tantalex Lithium Resources owns the Manono tailings and has produced 112,167 million tons per year over a 6-year life span.

Kamativi deposit, Zimbabwe: Kamativi rare metal pegmatites are in Matabeleland North Province in northwestern Zimbabwe. They were first mined for tin from 1936-1994 and produced 37,000 tons of tin and 3,000 tons of tantalum ore, but lithium minerals were never extracted. In recent years, the hard rock tin-bearing pegmatites exposed at the Kamativi mine and the associated tailings piles have been explored for lithium by the Zimbabwe Lithium Company in conjunction with the Zimbabwe Mining Development Corporation. The mine tailings consist of fine-grained quartz, plagioclase, K-feldspar, muscovite, and a range of lithium minerals, of which spodumene is the most abundant (Shaw et al., 2019).

The mineralized pegmatites are localized within the Paleoproterozoic metasedimentary rocks in the Dete-Kamativi inlier of the Magondi mobile belt in western Zimbabwe (Fig. 8). Magondi is a NE-SW-trending belt of low- to medium-grade amphibolite-facies metasedimentary rocks deformed during the Magondi Orogeny at 2.1-1.8 Ga, which is equivalent to the Eburnean Orogeny. The rocks overlie the Archean basement gneisses and are intruded by Paleoproterozoic granitoids, dated to 2.08–2.01 Ga (Shaw et al., 2019). The mineralized pegmatites in the Dett-Kamativi inlier are almost entirely confined to the Kamativi Formation of the Magondi Supergroup, which is dominated by pelitic schists (Fig. 16).

The pegmatites are therefore epigenetic but conformable to the foliation of the host rocks but may be locally discordant (Shaw et al., 2019). They have been dated by Pb–Pb methods in columbite, yielding ages of approximately 1030–930 Ma (Melcher et al., 2015; Glynn and Master, 2017), suggesting a Kibaran age of mineralization (Shaw et al., 2022). However, the nearby granitic plutons yielded ages of approximately 2060-2020 Ma, which suggests that the pegmatites are relatively young and not genetically connected to the granites that formed during the Magondian orogeny.

The mineralized pegmatites are relatively large bodies (up to 30 m thick) that dip gently. Spodumene is the principal lithium mineral, with minor petalite and lepidolite. Initially, the pegmatites were considered related to granitic intrusions, but isotopic dating revealed that the granites are much older than the pegmatites (Shaw et al., 2019). Consequently, in the absence of parental granites, the origin of the Kamativi lithium pegmatites has been attributed to partial melting of the metasedimentary host rocks (Shaw et al., 2019).

A mine tailings project, initiated by the Kamativi Mining Company (KMC), was launched by the Zimbabwe Lithium Company in 2016 to extract and process lithium from mine tailings and open-pit mining. The results of the mineral resource evaluation indicated that the Kamativi mine tailings contained significant quantities of lithium, estimated as 26 Mt of 0.56 Li2O.

The old hard rock tin mine has recently been brought back into production by the KMC, its current

Chinese owners, which is a joint venture between Sichuan PD Technology Group and Kamativi Tin Mines (Private) Limited. The Kamativi lithium-tin mine operation is currently in the first phase of production, with an annual output of 300,000 tons of raw spodumene ore and 50,000 tons of spodumene concentrate. The second phase is expected to commence in June 2025, with production increasing to 2.3 million tons of raw ore and 300,000 tons of spodumene concentrate annually.

Pan-African deposits: The Pan-African Orogeny was a widespread thermos-tectonic event that affected large regions in Africa during the Neoproterozoic (Fig. 17). This activity resulted in the formation of narrow and elongatedmobile belts of metamorphosed, folded, and uplifted crustal blocks, accompanied in places by the emplacement of rare ophiolites and syn-subduction or collision granitoids and pegmatites aged 600–500 Ma (van Hinsbergen, 2011). These Pan-African belts can be grouped into three types as follows:

1. Narrow to wide belts of Neoproterozoic supracrustal sedimentary and igneous rocks that have been regionally metamorphosed, deformed, and intruded by granites, e.g., Nigerian Schist Belts (Trans-Saharan Belt), Arab-Nubian Shield (Ethiopia), and the Damara Belt in Namibia.

2. Areas of reworked and highly deformed, high-grade metamorphic rocks of Archean to Proterozoic age (Kroner and Stern, 2004), e.g., the Zambezi Belt, the Mozambique Belt, and the Dahomey Shield.

3. Intracontinental rift basins and mobile belts containing thick, weakly metamorphosed and deformed sediments, e.g., the Lufilian Arc (Katanga Belt) and West Congolian Belt.

Notably, Pan-African mobile belts include the Mozambique Belt along the east coast of Africa, the Damara-Kaoko-Gariep belt in Namibia, and the Trans-Saharan Belt in western Africa (Fig. 17). The Trans-Saharan belt formed because of the collision between the converging West African craton, the Congo craton, and the Sahara metacraton continental blocks.

The belt, with significant exposure in Tuareg and Dahomeyan regions, consists of pre-Neoproterozoic basement that was thoroughly reworked during the Pan-African Orogeny. They are associated with Neoproterozoic supracrustal metasedimentary and metavolcanic rocks as well as syn-tectonic Pan-African granitoids and pegmatites, which intrude some reworked Archean and Paleoproterozoic rocks.

Except for the Mozambique Belt, most of the Pan-African rare metal pegmatites are found within the first type of Pan-African mobile belt, where sedimentation and magmatism were accompanied by deformation, metamorphism, and emplacement of synorogenic granitoids and late tectonic to post-tectonic pegmatites (Caen Vachette and Mathias, 1983). Significant lithium deposits occur in Namibia, Nigeria, and Ethiopia. Other notable occurrences have been reported in Mozambique and Madagascar.

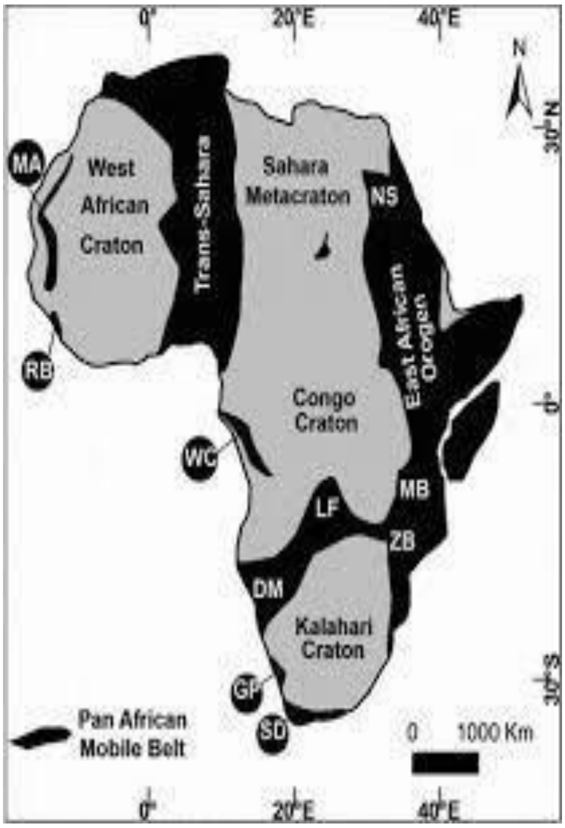

Fig. 17 Pan-African mobile belts.

Namibia deposits: Namibia is known to contain substantial lithium deposits that are localized within pegmatites of the Damara Belt. The Damara belt is the intracratonic Pan-African orogenic belt that extends from the coast of Namibia into southern Africa and is formed by the collision of the Kaapvaal and Congo cratons (Fig. 18). Five pegmatite belts striking NE–SW have been identified in Central Namibia (Fig. 19). Each pegmatite belt contains numerous pegmatite swarms that occur as zoned or unzoned. They carry significant amounts of rare metals and lithium minerals, including spodumene, petalite, and lepidolite (Kropp and Bong, 2023).

The pegmatites trend NE–SW, which is consistent with the regional foliation of the rocks, and regional structures might have contributed to the emplacement of the pegmatites. Two of these pegmatite belts, the Karibib Pegmatite Field and the Uis Lithium-Tin Field, have demonstrated considerable mineralization potential and have been explored and exploited over the years for lithium and tin (Kropp and Borg, 2023).

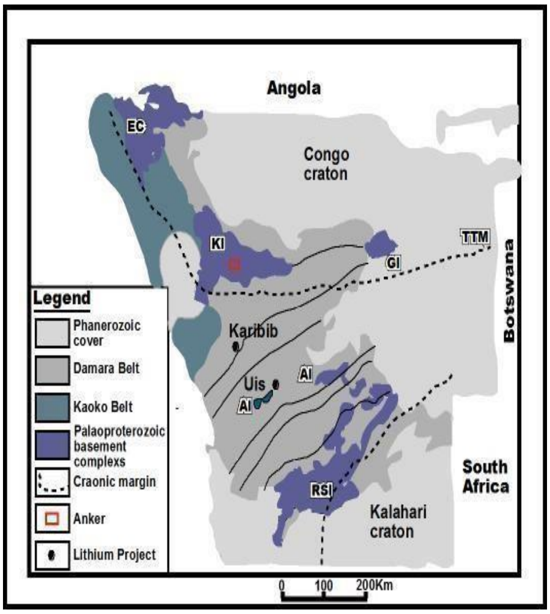

Fig. 18 Damara belt in Namibia.

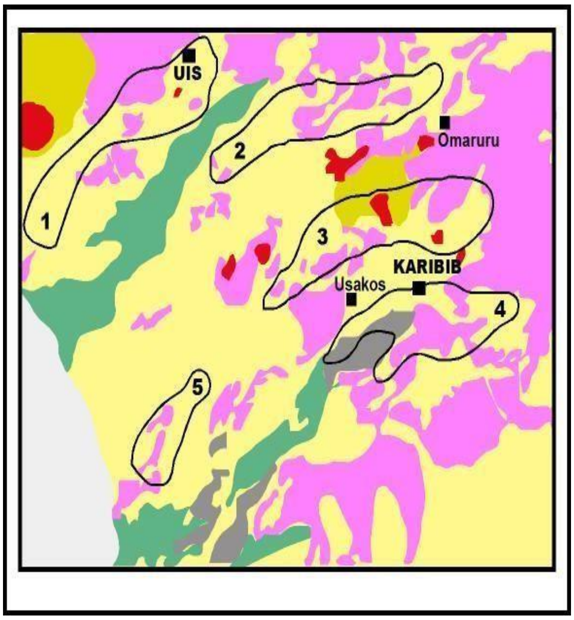

Fig. 19 Pegmatite fields in the Damara belt of Namibia.

Karibib deposit: The Karibib deposit is the most significant of the known lithium occurrences in Namibia. It is located in the southernmost pegmatite belt (Fig. 19) called the Karibib pegmatite field in the Erongo Region. The field comprises a swarm of pegmatites and granites that intrude host rocks of dolomitic marble and minor schists from the Karibib Formation, which contain significant amounts of lithium minerals.

Two pegmatite groups in the Kharibib field are identified as the Rubicon and Helikon pegmatites. They are an LCT family of pegmatites that are partly hosted and associated with granites of Pan-African age intruding Damaran rocks (Ashworth, 2020). These pegmatites have all been exploited for rare metals at different times since their discovery in the 1930s.

The Rubicon group of pegmatites appears as stacked mineralized bodies hosted within pegmatitic granites and granodiorites. The main Rubicon pegmatite is gently dipping and strikes NW--SE for about 1000 m in length and 25 to -35 m in width (Ashworth, 2020). The mineralized pegmatite is highly zoned the lithium minerals lepidolite, petalite, and amblygonite, along with accessory beryl and tantalite. The deposit has a long history of small-scale extraction of petalite, amblygonite, and lepidolite.

The Helicon pegmatites are a sub-parallel swarm of stacked, variably dipping pegmatites hosted within marbles and calc-silicate rocks with a cumulative strike length of approximately 1,500 m. The main lithium minerals are lepidolite and petalite (Ashworth, 2018).

Lepidico Mining Company holds 80% interest in lithium deposits in central Namibia, which are well served by existing infrastructure. The Karibib deposit is relatively small and has an ore reserve estimate of 6.74 million tons grading 0.46% Li2O and a resource estimate of 11.24 million tons grading 0.45% Li2O. The main product will be a lepidolite concentrate, and the mine is projected to produce 773,000 tons of lithium concentrate over a 14-year lifespan.

Uis deposit: The Uis lithium-tin deposit is located in a NE-trending zone within the northernmost region of the five pegmatite fields shown in Figure 20. The deposit is hosted by a swarm of dikes intruding the Damara Neoproterozoic metasediments in the Erongo Region of Central Namibia. The Uis pegmatite swarm belongs to the northern part of the Cape Cross-Uis pegmatite belt in a field that consists of more than 120 individual pegmatites, each with a NE to E-striking direction and a NW dip of 30° to 70° (Ashworth, 2018).

The town of Uis is known for a historic tin mine that was once regarded as the largest hardrock cassiterite mine in the world. The mine now contains significant lithium resources in large mineralized pegmatites, including the very prominent V1/V2 pegmatites (Fuchsloch et al., 2018; Ashworth, 2018). The host rocks of the pegmatites are a variety of schists and quartzites that have, in places, been severely altered, partly by pegmatite emplacement.

Lithium mineralization is characterized by petalite and spodumene with minor amblygonite and lepidolite. The grab assay results indicate up to 3% Li2O (Askari Metals Report, 2023).

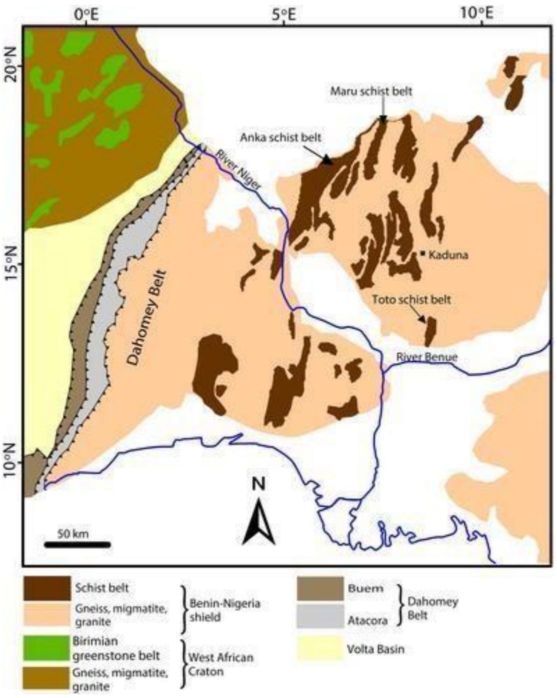

Fig. 20 Nigerian schist belts within the Trans-Saharan Shield.

The Andrada Mining Company is the operator of the old Uis mine extracted tin and petalite, which was restarted in 2020, and the company produced its first lithium concentrate in the form of a high-purity petalite concentrate of 10 tons in May 2023. Moreover, Andrada is conducting further development test work to explore the production of lepidolite for the battery market. Assay results from initial sampling include 3.3% Li_2O, 3.2% Sn, and 4280 ppm (Andrada Mining Report, 2024). The updated resource estimate for the V1/V2 pegmatites includes 27,38 Mt of lithium ore with an average grade of 0.82% Li2O and 0.15% Sn (Andrada Mining Report, 2025).

Nigerian deposits: Several lithium deposits of commercial value have been discovered in the Pan-African pegmatites of Nigeria, which were emplaced in the N–S trending Neoproterozoic Schist Belts in the Precambrian basement complex (Okunola, 2005; Oyebamiji et al., 2021; Olade, 2024). These pegmatites have been known since the 1910s, and some of them were previously mined for tin, columbite, and tantalite in the Wamba, Jema'a, Egbe, Ijero-Ekiti, and Osogbo districts of north-central and southwestern Nigeria (Jacobson and Webb, 1946). They belong to the LCT family of pegmatites, as defined by their geochemical characteristics (Adekeye and Akintola, 2007; Adetunji and Ocan, 2010; Oyebamji et al., 2021). They are closely associated with a series of Pan-African granites known as Older Granites, which are different from the Jurassic Younger Granites of the Jos Plateau. Nigeria lies within the southern portion of the Trans-Saharan Shield situated west of the West African Craton (Fig. 20). The mobile belt is a significant tectonic structure extending north–south 3000 km and formed between 750 and 500 Ma. (Kroner and Stern, 2004). The Nigerian sector of the Trans-Saharan mobile belt consists of N–S-trending supracrustal metasedimentary and metavolcanic rocks called the Schist Belts overlying a basement of reworked Archean and Proterozoic gneisses (Turner, 1983).

The Schist Belts represent a group of low-grade metasedimentary and metavolcanic rocks that occur as narrow, intensely folded belts confined mostly to the western half of the country (Fig. 21). They were deformed and metamorphosed and intruded by granitic rocks during collisional orogeny (Dada, 2008). The dominant lithologies are mica schists, quartzites, phyllites, and amphibolites with serpentinite lenses (Olade and Elueze, 1979).

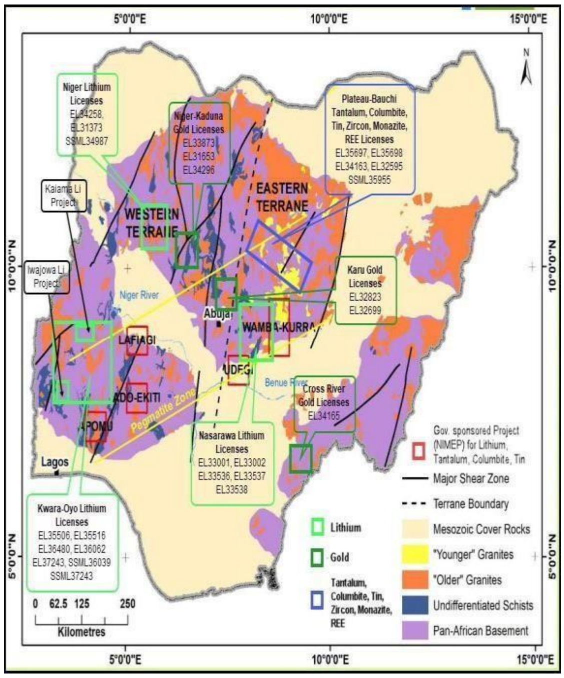

Fig. 21 Map of Nigeria showing rock types and the pegmatite belt.

Pan-African pegmatites occur widely within Nigeria's Precambrian basement complex, and more than 3000 pegmatites have been identified (Nex et al., 2019), but the majority are barren of mineralization. They have been dated between 560 and 450 Ma (Caen Vachette and Mathias, 1983; Mathias, 1987; Melcher et al., 2015), whereas the associated granites are slightly older, with isotopic ages of 650 to 500 Ma (Van Breenen et al., 1977). The lithium-bearing pegmatites are hosted mainly by rocks of the N–S-trending Schist Belts within a 500 km long, NE–SW-trending zone defined as Nigeria's 'pegmatite belt' (Fig. 21) (Okunlola, 2005, 2008). Within this belt, there are 3 types of rare metal associations: (a) Li (only) - spodumene, lepidolite, amblygonite; (b) Sn-Ta-Nb - cassiterite, tantalite, and columbite; and (c) Be-(Li) - beryl, kunzite, aquamarine, emerald. Further analysis of the distribution of mineralization shows that the main lithium deposits are concentrated in a zone lying slightly north of the well-known Sn-Nb-Tan enriched zone (Olade, 2024) (Fig. 22).

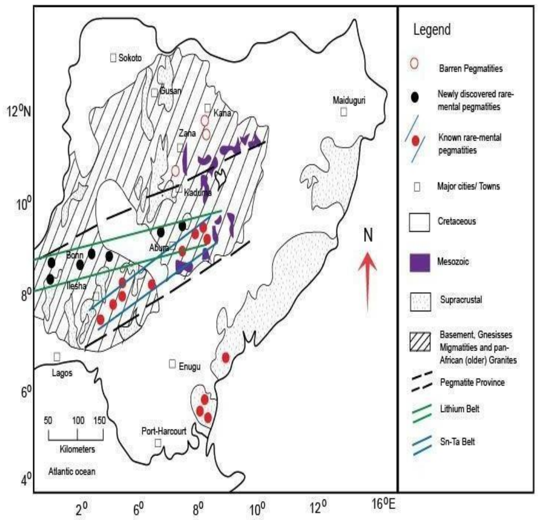

Fig. 22 Schematic map of lithium and rare-metal belts in Nigeria (after Olade, 2025).

The Nigerian pegmatites occur predominantly as vertical to subvertical dykes and subhorizontal bodies that are structurally controlled by faults, fractures, and shear zones, trending mostly NW–SE or NE–SW, with occasional N–S or E–W orientations. They are found in varying sizes, ranging from a few meters to 1.5 km long and from <1 m to 150 m wide. The pegmatites may appear as isolated bodies or in groups that are subparallel or in swarms (Okunlola, 2008; Adekeye and Akintola, 2007).

The main lithium minerals in Nigerian deposits are spodumene and lepidolite, with minor amounts of amblygonite, petalite, and polylithionite. Kunzite, a gem spodumene, is often found with beryl as scattered or discrete crystals in pegmatite bodies. The lithium minerals are dominated by medium-sized to large crystals that are either scattered or clustered or felted masses within the pegmatites. At subsurface intersections, mineralized pegmatite bodies may appear as continuous sheets or tabular zones several meters thick of course spodumene and lepidolite (Olade, 2024). Many of the mineralized pegmatites are unzoned, whereas the zoned pegmatites are associated more with Sn, Nb-Ta, and gemstones. In some occurrences in Nasarawa and Oke-Ogun deposits, albitization, which is a late-to-post-magmatic phenomenon, is manifested by the addition of fine-grained albite, which may be accompanied by the conversion of lepidolite to polylithionite (loss of Li), as observed in the Keffi area, and the solid-state transformation of spodumene to lepidolite in Nasarawa deposits does not increase the lithium concentration (Table 1). This phenomenon is typically observed in areas where the albite-spodumene subtype of lithium pegmatite is well-developed. The individual lithium deposits are not described in this article because they have been presented in detail elsewhere by Olade (2025). Significant Tier 1 lithium deposits in Nigeria include Nasarawa Endo, Nasarawa Udege, both in Nasarawa State, Jupiter in Kaduna State, and probably the Komu-Oke-Ogun deposit (Fig. 23). Several other occurrences are known and are being mined at Oyo, Ekiti, Kwara, Kogi, and Osun States. Lithium deposits in Nigeria are relatively high grade, with values ranging from <2% to as high as 9% Li2O, with an average of 4-5% Li2O. Annual production of lithium ore is estimated as 1000 metric tons. Accurate ore reserve estimates are difficult to obtain in Nigeria because only a few companies are conducting JORC-compliant exploration drilling. Many of the deposits are exposed near the surface, which allows the commencement of lithium extraction without completing subsurface exploration by corporate and artisanal miners.

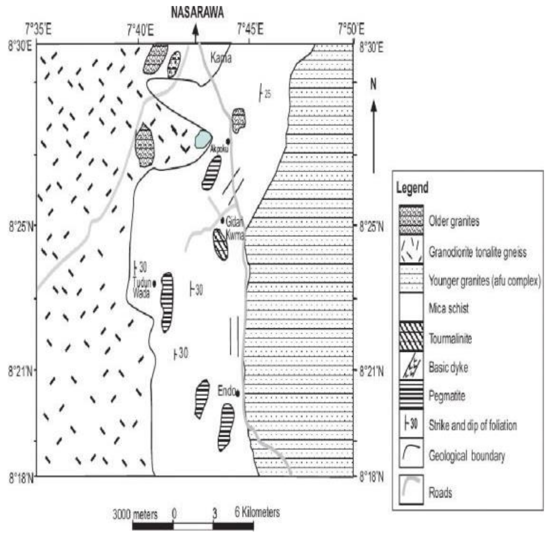

Fig. 23 Simplified geological map of lithium pegmatites in Nasarawa State (after Akintola & Asekeye, 2008).

The origin of lithium mineralization in Nigeria is controversial, but the consensus of opinions is that the lithium pegmatites are products of enhanced fractionation from silicate melts but not sourced from the Pam-African granites, with which the pegmatites only have compositional but no spatial, temporal, or genetic relationships (Can Vachete and Mathias, 1983; Mathias, 1987; Olade, 2025). An alternative explanation is to attribute the lithium pegmatites to partial melting and anatexis of Al-rich pelitic schists (host rocks) followed by fractionation of the peraluminous LCT pegmatite melts during the waning and post-tectonic phases of the Pan African collisional orogeny.

Ethiopia deposits: Significant lithium deposits in pegmatites exist in Ethiopia, particularly in the Kenticha area, approximately 400 km south of Addis Ababa in southern Ethiopia. The Kenticha Pegmatite field comprises several groups of pegmatite swarms distributed over a large area of about 2500 km^2 and situated within the Kenticha ophiolitic fold belt, which is part of the Pan-African Arab--Nubian Belt (Adoia Belt) of southern Ethiopia (Fig. 24). The area is composed of two groups of Neoproterozoic rocks: granite–gneiss complexes and ophiolitic folds and thrust belts (Yibas et al., 2003).

The Kenticha pegmatite swarm trends mostly N–S to NNW–SSE and intrudes greenschist to lower amphibolite facies talc-tremolite schists, serpentinites, and pelitic to graphitic mica schists of the Kenticha ophiolitic fold and thrust belt. The individual pegmatites show considerable differences in size, varying from a few tens of meters to >1 km in length, with shapes that range from steeply dipping dykes to almost flat-lying sheets. Individual pegmatites also have variations in internal zoning and mineralogy (Polyalev et al., 1991). Isotopic dating has yielded Neoproterozoic ages for these ophiolitic rocks.

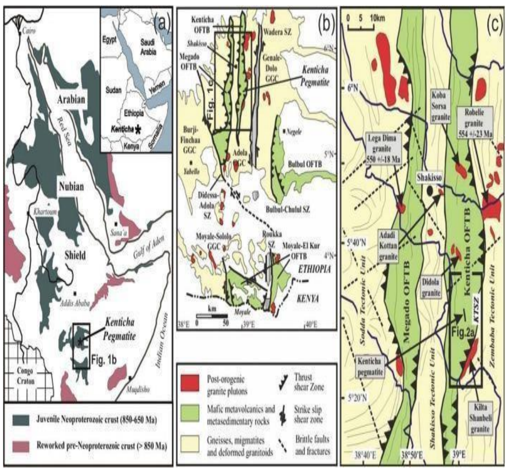

Fig. 24 Geology of northeastern Africa and Arabia showing major crustal segments and locations of lithium and tantalum mineralization (Mohammedyasin, 2017).

The Main Kenticha pegmatite (MKP) is a large spodumene-bearing LCT rare-metal, quartz-feldspar-muscovite pegmatite with complex internal zonation enclosed within a serpentinite body (Fig. 25) (Mohammedyasin, 2024). The pegmatite is structurally controlled and exposed over a 2 km length and 400-700 m width on the western flank of a north–south ridge. It forms a flat-lying, N- to NNE-striking, moderately eastward-dipping sheet-like dyke with variable thickness, ranging from 40 to -100 m (Poletayev et al., 1991). The isotopic age of the Kenticha pegmatite is 530 Ma, whereas the surrounding undeformed biotite granite plutons were emplaced between 550 and 500 Ma (Worku and Schandelmeier, 1996; Teklay et al., 1998; Yibas et al., 2002). These igneous rocks were emplaced during the late tectonic phase of the Pan-African collisional orogeny, which completed the assembly of Godwanaland (Kuster et al., 2009).

The Kenticha pegmatite is rich in columbite and tantalite. Lithium mineralization is characterized by spodumene as the ore mineral with minor lepidolite and subeconomic concentrations of tantalite enriched by metasomatism (Mohammedyasin, 2017). The pegmatite exhibits textural and mineralogical zoning, as well as post-magmatic alteration, characterized by the development of albite, amazonite, and sericite. According to Mohammedyasin et al. (2017), based on mineralogical assemblages, tectonic setting, and geochemical signatures, the Kenticha rare-metal pegmatites were formed by the partial melting of metasedimentary rocks during the late- or post-collisional Pan-African orogeny. Columbite and tantalite are enriched by metasomatic albitization.

Abyssinian Metals Limited owns the Kebticha Mine in partnership with Oromia Mining Share Company. The company is conducting further exploration to establish JORC-compliant resources and is working towards restarting mining operations. Lithium resources are estimated at 87.7 million tons of 0.78% Li2O. The tailings from past production are estimated to yield a total of 5.4 million tons of lithium and some tantalite ore (Abyssinian Metals Annual Report, June 2023).

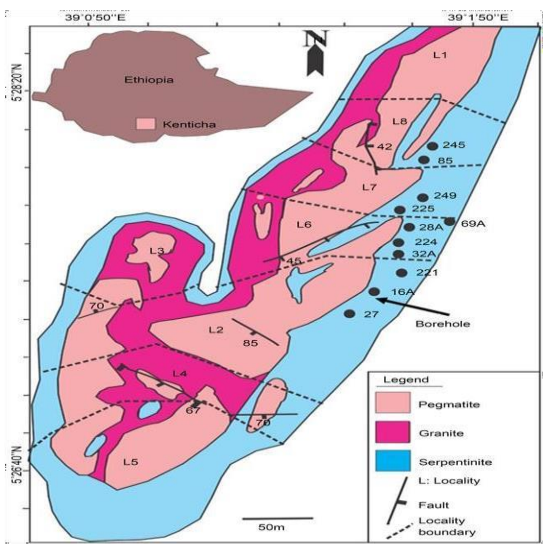

Fig. 25 Geology of the Kenticha pegmatite (after Mohammedyasin, 2017).

Metallogenic Analysis and Discussion

Metallogeny has been widely used for several decades to analyze ore-forming processes and understand the genesis and spatiotemporal distribution of mineral deposits in relation to orogenic or tectonic events (Pohl, 2022). With the inception of modern-style plate tectonics (Frisch et al., 2011), metallogenic analysis has incorporated the principles of global geodynamics (Turcotte and Schubert, 2014; Wyborn et al., 1994). Orogenic events play a significant role in the formation of mineral deposits, primarily due to their association with tectonic deformation, regional metamorphism, and magmatism, which provide sources and structural features conducive to the accumulation, movement, and localization of mineral deposits (Taylor et al., 2005; Stanton, 1972).

Africa has been subjected to numerous orogenic cycles throughout its extensive geological history, and the continent preserves nearly 75% of the Earth's geological record in its rock sequences (Burg and Ford, 1997; Van Hisbergen et al., 2011). Relatively little is known about the nature of orogenic activities during the Archean (3.8-2.6 Ga). Still, the Proterozoic era has provided ample evidence that can be used to decipher the processes that form ores. The geochemical composition and isotopic dating of intrusive rocks associated with orogenies have helped provide information on the timing of tectonic activities (Teixeira et al., 2017).

A review of lithium metallogeny in Africa will examine the spatial and temporal distribution of lithium deposits across the African continent, aiming to foster a deeper understanding of ore deposit types, processes, and origins, as well as their relationships to tectonic processes. This analysis will be used to identify favorable geologic settings and evaluate economic potential for lithium mineralization.

Lithium Deposits and Orogenic Events

The geological characteristics of the lithium pegmatite deposits in Africa are summarized in Table 4. This confirms the well-known fact that lithium deposits in LCT pegmatites formed as pulses (Tkachev, 2011) throughout geological time, starting from the Neoarchean through the Proterozoic to Paleozoic orogenic cycles in Africa (Von Knorring and Condliffe, 1987; Tkachev et al., 2016; Nex et al., 2019; Goodenough et al., 2025). Thus, orogens can be considered the initial generators of lithium through accumulation in crustal melts, which are transported by pegmatites to shallow levels to concentrate in ore deposits (Tkachev, 2011). The close temporal and spatial relationships between lithium pegmatites and orogeny are well documented worldwide (Beus, 1982; Stanton, 1972; Clifford, 1966; Sha et al., 2024).

The formation of lithium pegmatite deposits during orogenesis may be attributed to the unique geological and tectonic processes that occur through dynamic events that cause crustal thickening and provide the energy, heat, and fluids needed for crustal melting and the production of magmatic and pegmatitic melts rich in lithium (Koopmans et al., 2023; Gardiner et al., 2024). The output of these lithium-rich pegmatitic melts seems to have occurred mainly during the late-tectonic and post-tectonic phases of the collisional orogeny and not during the preceding synorogenic phase or convergence-subduction, which also generated granitic magmas rich in other metals, such as Cu, Mo, and Sn (Turcotte and Schubert 2014; Sillitoe, 2024; Gardiner et al., 2024).

Lithium is a fluid mobile element during endogenic processes and possesses specific unique properties, including small ionic size, low charge, high solubility in fluids, incompatibility, etc., that may promote its ability, unlike other metals, to generate and concentrate in crustal melts in deep-seated environments (London, 2018; Simmons and Weber, 2008). Lithospheric thickening during collisional orogeny has been proposed as a favorable process for concentrating lithium (Goucerol et al., 2019; Chen et al., 2020).

Temporal and Spatial Distributions of Lithium Deposits

The time-space distribution of lithium deposits in Africa during the Precambrian era was controlled by the frequency, intensity, and extent of orogenic cycles that affected the continent. Lithium deposits are nonuniformly distributed through geologic time. They were only formed during the waning phases of tectonic events, which affected their formation and concentration. Some of the associated processes, such as the emplacement of granitic plutons, have been dated via radiometric methods.On the basis of information from isotopic dating, the specific periods or timings of lithium metallogenesis in Africa are as follows: the Liberian (2.65–2.60 Ga), the Eburnean (2.10–2.05 Ga), the Kibaran (1.00–0.95 Ga), and the Pan-African (0.55--0.50 Ga). These pulses of lithium generation fromthe crust are similar to the global higher activity peak periods identified by Tkachev (2011) and Tkachev et al. (2016) at 2.65--2.60, 1.90--1.85, 1.00--0.95, and 0.30--0.25 Ga. The only period 0.30–0.25 not identified in this review is the Paleozoic (Permian) lithium deposits associated with the Hercynian Orogeny in Africa, briefly described by Goodenough et al. (2025).

The Neoarchean (Liberian) orogenic cycle, characterized by Archean Zimbabwe lithium deposits, represents a relatively productive period for lithium generation in Africa and worldwide (Tkachev, 2011). In contrast, the Paleoproterozoic cycle is the least productive for lithium. Lithium productivity increased during the Mesoproterozoic Kibaran and Neoproterozoic Pan-African periods, with the latter exhibiting the most significant productivity potential due to the widespread occurrence and generally higher lithium grades in pegmatites compared to other periods (Table 4).

This distribution compares favorably with the lithium productivity pulses through geologic time (Tkachev et al., 2004). The locations of the significant lithium deposits in Africa are confined to the following areas, starting from the Neoarchean to Neoproterozoic:

- Southern Africa (Zimbabwe)
- Western Africa (Mali, Ghana, Burkina Faso, Ivory Coast, Senegal, and Niger);
- Central Africa (DRC, Zimbabwe, Rwanda, Burundi, Namaqualand); and
- Pan African (Namibia, Nigeria, Ethiopia, Mozambique, Madagascar).

It is unclear why the currently known Archean lithium ore deposits are confined to the Zimbabwe Craton. However, this may be attributed to a lithium-enriched source or unusual thickening of the Archean crust beneath the craton.

The factors that control the localization of lithium pegmatites and associated deposits are not well known (Goodenough et al., 2025), and any suggestions presented in this article may be speculative. As summarized in Table 4, the Archean lithium deposits are found almost exclusively within greenstone belts (Goodenough et al., 2025), and none are found in the surrounding gneisses (TTGs). The possible controls of Archean mineralization include a combination of lithologic (greenstone lithologies) and structural factors (faults, fractures, and shear zones). For example, in Zimbabwe, there is evidence of structural features controlling the emplacement of pegmatites at Bikita (NNW faults) (Godogo, 2022) and at Zulu (N–S shear zones) (Koopmans et al., 2025).

In the absence of parental granites, the potential sources of lithium in the metasedimentary rocks could be a contributing factor to the localization of Archean lithium deposits in Africa. Clays and mica in metasediments can act as initial carriers of lithium and volatiles, as well as other materials needed for the formation of lithium pegmatites. (Nex et al., 2019; London, 2018; Kunz et al., 2022).

The Eburnean lithium pegmatites are scattered across the West African Craton in a variety of Birimian rocks without any pattern of localization. The expectation that lithium pegmatites generated by collisional orogeny should be found closer to the collision zone has not materialized. The main controlling factor for the localization of the lithium pegmatites seems to be their close spatial, temporal, and compositional associations with the younger phase of the Eburnean granites (Kazapoe, 2023; Adams et al., 2023). The Kibaran lithium deposits seem to be confined to specific stratigraphic units within a mobile belt sedimentary sequence (Treloar, 1988; Kokonyangi, 2006).

Consequently, stratigraphic control could be a significant factor in the emplacement of the lithium pegmatites, which lie mainly parallel to the foliation. This is coupled with the lithologic affinity for pelitic schist host rocks, which may contribute to the localization of ore. There is no evidence of structural control on the emplacement of the Kibaran lithium pegmatites. The Pan-African orogenic pegmatites are confined to mobile belts comprising metavolcanics, metasedimentary, and metavolcanic rocks that form “schist belts”. These rocks, which are the likely sources of pegmatitic melts in Ethiopia and Nigeria, where the pegmatites (Mohammedyasin, 2017; Olade 2025) notes that pegmatites are structurally controlled by faults, fractures, and shear zones, and are critical secondary factors in ore localization, as they often follow regional structural trends and are emplaced near faults and shear zones (Nex et al., 2019; Olade, 2025).

Comparative Analysis of Orogenic Lithium Deposits

A comparison of some of the features of the lithium deposits from various orogenic cycles reveals that the geotectonic settings for the Archean deposits are the primitive greenstone belts. In contrast, those for the Paleoproterozoic deposits are a broad island arc/back arc-type greenstone belt (Birimian type). The Kibaran deposits, alternatively, were set in intracratonic metasedimentary mobile belts, such as the Katangan belt, whereas the Pan-African deposits are found mainly within schist belts.

The mode of occurrence of the lithium pegmatites varies from mostly swarms or clusters during the Archean and Paleoproterozoic deposits to large pegmatite bodies (or systems of pegmatites), such as the Manono-Kitotolo (DRC) during the Kibaran Orogeny, whereas the Pan-African pegmatites are characterized by multiple (large numbers - in hundreds) of small pegmatite dykes in Namibia, Nigeria and Ethiopia. Mineralogical zoning is a common feature in complex mineralized rare-metal pegmatites (London, 2008; Bradley et al., 2017), and the presence of zoning has been considered an indicator of mineralization potential (Shaw et al., 2019; Goodenough et al., 2025). As summarized in Table 3, some mineralized lithium pegmatites are zoned, whereas others are unzoned. Many LCT pegmatites containing lithium ores have simple compositions, lacking mineral zoning, such as those found in Mali, Ghana, and Nigeria (Wilde et al., 2021; Kapazoe, 2023; Olade, 2025).

Occasional zoning may occur mainly in association with Sn and Nb-Ta mineralization within the same orebody. The Archean lithium pegmatites are characterized by distinct mineralogical zoning (e.g., Bikita lithium), but the Paleoproterozoic pegmatites in Ghana and Mali are usually unzoned. The Kibaran lithium pegmatites are weakly zoned, while some of the complex Pan-African pegmatites may show distinct mineralogical zoning that relates to the metasomatic crystallization of cassiterite and columbite-tantalite (Mohammedyasin, 2017; Olade, 2025; Gardiner et al., 2024).

The mineralogy of lithium pegmatites is typically complex, as diverse minerals form through the crystallization process. Most of the lithium pegmatites in Africa are also rare-metal pegmatites that contain mineralization of high field-strength metals, such as Sn and/or Nb-Ta, Be, Zr, and enrichment in the lithophile elements Cs, Rb, and Li, in all orogenic cycles except the Eburnean. Petalite is the dominant lithium mineral in the Archean deposits, accompanied by a suite of secondary minerals, including eucryptite and bikitaite. In contrast, the Paleoproterozoic and Mesoproterozoic deposits are characterized by the presence of spodumene.

The Pan-African deposits exhibit a more diverse mineralogy, with spodumene remaining dominant, but also featuring the emergence of lepidolite as an economic mineral in Nigeria, Ethiopia, and Namibia, as well as a resurgence of petalite in Namibia, accompanied by minor occurrences of amblygonite.

Apart from the associations of the lithium pegmatites with Sn and Nb-Ta minerals, a variety of gemstones, such as kunzite, Paraiba tourmaline, garnets, beryl, and aquamarine, are found in the Pan-African pegmatites in Nigeria, Ethiopia, Mozambique, and Madagascar. (Olobaniyi et al., 2019; Olade, 2020; Goodenough et al., 2025). The ore grade of lithium pegmatite deposits from the Archean to Neoproterozoic appears to show an increasing trend, with the highest grades found in Pam-African deposits, where up to 7% Li2O has been obtained in Nigerian deposits. The stability fields of the various lithium minerals have been used as indicators of the

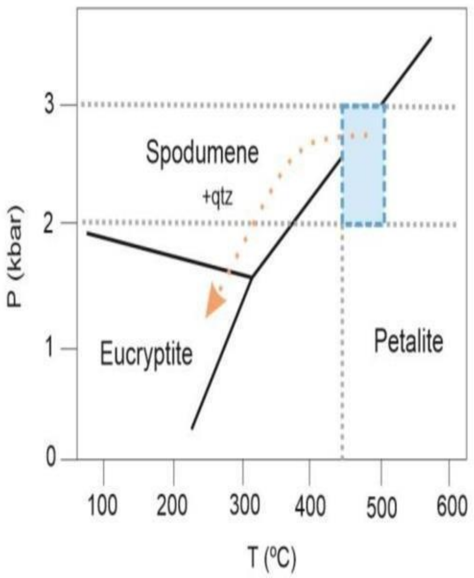

Fig. 26 Stability fields of lithium minerals (modified after London, 1984; Garate-Olave, 2024).

temperature, pressure, and chemical environment of lithium mineralization (Fig. 26) (London, 1984; Von Knorring, 1970; Shaw et al., 2022). Petalite generally crystallizes at low to moderate pressures and high temperatures, while spodumene is stable at high pressures and moderate temperatures. Eucriptite, a secondary mineral, is stable at low temperature and pressure.

At lower pressures, petalite can break down into spodumene and quartz, or into secondary eucryptite at lower pressures and temperatures (Von Knorring, 1970; Garate-Olava, 2024). According to Gardiner et al. (2024), the three minerals spodumene, petalite, and eucryptite can be considered near-polymorphs of each other, representing distinct stability fields where petalite is a relatively high-temperature phase and spodumene has a relatively low-temperature phase (Fig. 26).

Goodenough et al. (2025) suggested that the conversion of magmatic petalite to spodumene and quartz, as well as eucryptite, in the Archean Bikita lithium deposit, Zimbabwe, may indicate lower pressure conditions and high heat flow during pegmatite emplacement at shallow levels in the crust. According to Figure 26, this could have occurred within the range of 450–500 °C and 2–3 kbar (blue rectangle with dashed line) (Garate-Olave et al., 2024). This is also consistent with the simultaneous crystallization of spodumene and petalite, as noted in the Arcadia deposit (Tyler, 2019), while secondary spodumene and eucryptite formed because of the replacement of primary petalite by spodumene + quartz intergrowth during cooling (London, 2008; Dias, 2016; Garate-Olave, 2024). However, Shaw et al. (2022) noted that the *P*–*T* conditions established by using these lithium.

Table 3. Significant lithium deposits in Africa and their characteristics.

Deposit	**Country**	**Company**	**Minerals**	**Age**	**Tonnage**	**Grade% Li2O**	Year
Arcadia	Zimbabwe	Huayou Cobalt	Petalite Spodumene	Archean	72.7	1.06	2021
Bikita	Zimbabwe	Sinomine Resources	Petalite Spodumene	Archean	29;41	1.05	2023
Zulu	Zimbabwe	Premier Afr Minerals	Spodumene Petalite	Archean	24.75	0.41	2024
Sabi Star	Zimbabwe	Chengxin Lithium	Spodumene Lepidolite	Archean	15.0	1.48	2024
Kamativi	Zimbabwe	Galileo Resources	Spodumene	Meso-Proterozoic	26,32	0.58	2018
Manono-Kitotolo	DRC	AVZ Minerals	Spodumene	Meso-Proterozoic	93.0	1.58	2020
Manono Tailings	DRC	Tantalex	Spodumene	Meso-Proterozoic	5.46	0.72	2822
Goulamina	Mali	Gangfen	Spodumene	Paleo-Proterozoic	52.0	1.45	2924
Bougouni	Mali	Kodai Minerals	Spodumene	Paleo-Proterozoic	31.9	1.06	2023
Ewoyaa	Ghana	Atlantic Lithium	Spodumene	Paleo-Proterozoic	36.8	1.32	2023
Karibib	Namibia	Lepidico	Lepidolite	Neo-Proterozoic	11.97	0.46	2022
Uis	Namibia	Andrada Xinfeng	Lepidolite Petalite	Neo-Proterozoic	81.0	0.73	2023
Kentacha	Ethiopia	Abyssinian Metals	Spodumene	Neo-Proterozoic	87.7	0.78	2023
Alto Ligonha	Mozambique	Deccan Gold	Spodumene	Meso-Proterozoic	N/A	1-3	2024
Nasarawa-Endo	Nigeria	Ganfeng Lithium	Lepidolite Spodumene	Neo-Proterozoic	12	6.0	2024
Nasarawa-Udege	Nigeria	Landmark Mining	Lepidolite Spodumene	Neo-Proterozoic	20	5.7	2023
Jupiter	Nigeria	Jupiter Lithium	Spodumene Lepidolite	Neo-Proterozoic	12 (?)	3.47	2023
Blesberg	South Africa	Marula Mining	Spodumene	Neo-Proterozoic	0,5	6.5	2024

Table 4. Comparison of the Geological Characteristics of Lithium Deposits of Different Age Groups.

Deposit	**Country**	**Host Rock**	**Lithology**	**Pegmatite Features**	**Control of Localization**	**Lithium Minerals**
Neoarchean Lithium Deposits (~2700 Ma)						
Bikita	Zimbabwe	Masvingo Greenstone	Metabasalts Metasediments	LCT Pegmatite. Swarm Zoned	Lithologic/Structural	Petalite Spodumene
Arcadia	Zimbabwe	Harare Greenstone	Metabasalts Metasediments	LCT Pegmatite. Swarm	Lithologic/Structural	Petalite Spodumene
Zulu	Zimbabwe	Fort Rixon Greenstone	Metabasalts Metasediments	LCT Pegmatite. Swarm	Lithologic/Structural	Spodumene Petalite
Sabi Star	Zimbabwe	Mutare	Metabasalts	LCT	Lithologic/Structural	Spodumene

		Greenstone	Metasediments	Pegmatite. Swarm		Lepidolite
Mutare*	Zimbabwe	Mutare Greenstone	Metabasalts Metasediments	LCT Pegmatite. Swarm	Lithologic/Structural	Spodumene
Birimian Lithium Deposits (~2000 Ma)						
Goulamina	Mali	Birrimian Greenstone	Mica schists Granitoids	Pegmatite Aplite Unzoned	Granitic Emplacement	Spodumene
Bougouni	Mali	Birrimian Greenstone	Mica schist Metavolcanics	Pegmatite Sheets Unzoned	Pegmatitic Emplacement	Spodumene
Ewayaa	Ghana	Birrimian Greenstone	Mica schists Granitoids	Coarse Pegmatite Unzoned	Granitic Emplacement	Spodumene
Kibaran Lithium Deposits (~1000 Ma)						
Manono-Tokolo	Dem.Rep. Congo	Kibara Belt	Phyllites Schists	Large Pegmatite ZoNed	Stratigraphic FLithologic	Spodumene Petalite
Kamativi	Zimbabwe	Magondi Belt	Mica Schists	Large Pegmatite Zoned	Stratigraphic Lithologic	Spodumene
Gatumna Gitarama	Rwanda	Karagwe Ankolean Belt	Phyllites Quartzites	Numerous Pegmatites Zoned	Stratigraphic Lithologic	Spodumene
Pan African Lithium Deposits (~550 Ma)						
Karibib	Namibia	Karibib Formation	Dolomitic Marble	Swarm Zoned	Lithologic-Structural	Lepidolite Petalite
Uis	Namibia	Karibib Formation	Schists Quartzites	Large numbers Zoned	Lithologic-Structural	Petalite Spodumene
Kamicha	Ethiopia	Adola Series	Mafic Schists	Swarm Zoned	Lithologic-Structural	Lepidolite Spodumene
Nasarawa	Nigeria	Nigerian Schist Belts	Mica Schists Amphibolite	Swarm Zoned	Lithologic Structural	Spodumene Lepidolite
Jupiter	Nigeria	Nigerian Schist Belts	Mica Schists Serpentinite	Large numbers Unzoned	Lithologic Structural	Lepidolite Spodumene

minerals may not match other information available from other regional parameters.

Magmatic vs Hydrothermal Deposit Type

Lithium deposits in pegmatites are generally considered magmatic in origin; that is, they were formed by direct precipitation from the cooling and crystallization of a magma or silicate melt (orthomagmatic type). Orogenic lithium deposits exhibit an intimate association with igneous rocks, characterized by textures and paragenesis indicative of crystallization from a magmatic or pegmatitic melt (Stanton, 1972). Lithium minerals are usually euhedral to subhedral and have similar crystal sizes and textures as the other silicate minerals in coarse-grained pegmatites. When aplites associated with pegmatites are mineralized, the lithium minerals also show similar fine-grained textures as the aplite. Some deposits may provide evidence that both magmatic and fine-grained textures as the aplite. Some deposits may provide evidence that both magmatic and hydrothermal fluids contributed to the formation of rare metal ores. Common evidence of post-magmatic metasomatic or hydrothermal activity involving hydrothermal alteration, chemical changes, and the formation of secondary minerals, sometimes accompanied by the deposition of new ore minerals. The magmatic-hydrothermal transition may take place during the formation of these minerals. The effects of this transition on lithium and rare-metal deposits often include (a) albitization, (b) greisenization, (c) veining, (d) hydrothermal alteration, e.g., sericitization, kaolinization, etc., and (e) the crystallization of new minerals or an increase in metal concentration.In African orogenic lithium deposits, lithium minerals, including spodumene, petalite, and lepidolite, are primarily formed through magmatic crystallization but are also affected by metasomatic albitization in several deposits, particularly those of the Birimian (Wilde et al., 2021; Kazapoe, 2023) and Kibaran (Shaw et al., 2022) groups. Albite is usually fine-grained and may be pervasive or represented by large sheets or masses of albite along with spodumene (albite-spodumene).

Albitization is rarely accompanied by greisenization, extensive mineral veining, or hydrothermal alteration. Spodumene may be altered at the edges or converted to lepidolite. Columbite or cassiterite may have formed by metasomatism, but lithium minerals were not created by metasomatism. There have been suggestions of a magmatic-hydrothermal transition in the pegmatite deposits in which the lithium could partly be of hydrothermal origin (Ballouard et al., 2020; Shaw et al., 2022). Albite crystallization in pegmatites can range from late magmatic (primary), such as albite-spodumene ores, to post-magmatic forms of albite that are secondary and confined mainly to cracks, veinlets, void spaces, and grain boundaries between spodumene and quartz (Bradley et al., 2017; Ballouard et al., 2020; Wilde et al., 2021).

The pervasive albitization observed in some Birimian, Kibaran, and Pan-African lithium pegmatites has not caused extensive changes in the primary lithium minerals except at the edges (Shaw et al., 2022), which does not alter the magmatic nature of the lithium deposit or increase the lithium concentration of the deposits (Halter and Webster, 2004; Ballouard et al., 2020). Consequently, in the absence of extensive greisenization, mineral veining, hydrothermal alteration, and the presence of volatile-rich minerals (e.g., boron and fluorine).

African lithium deposits are considered magmatic in origin. Gardiner et al. (2024) reached a similar conclusion that pegmatite lithium ore deposits containing silicate spodumene and petalite (including primary lepidolite) are magmatic in origin, and later-stage metasomatic processes may only be detrimental to the preservation of Li mineralization through alteration or replacement of primary lithium ore. My research on porphyry Cu-Mo deposits in granitic rocks of British Columbia and Sn-Nb deposits in the Younger Granites of northern Nigeria has influenced my opinion of the magmatic-hydrothermal transition in lithium deposits

Ore Forming Processes and the Origin of Lithium Mineralization

The ore-forming processes and origin of lithium deposits have been discussed extensively in the literature (Černý and Ercit, 2005; London, 2014; Shaw et al., 2019; Ballouard et al., 2020). There seems to be a consensus that the LCT pegmatites and associated lithium deposits formed from silicate melts through the process of extreme fractional crystallization, in which the residual melts became enriched in alkalis and (including Li), volatiles and other incompatible elements that later crystallized at relatively low temperatures as pegmatites that precipitated lithium minerals (Černý and Ercit, 2005; London, 2008, 2018; Bradley et al., 2017).

However, the central disagreement relates mainly to the source of the ore-bearing fluids. There are two schools of thought: One group considers the source as peraluminous or metaluminous granitic magmas generated in the lower or upper crust (Černý and Ercit, 2005; London, 2008; Černý., 2012; Bradley et al., 2017). Granitic melts, if highly fractionated, can accumulate incompatible elements and the fluxing compounds H2O, P, B, and F at high fugacities to facilitate the growth of very coarse crystals of silicate and ore (lithium) minerals in pegmatite (Bradley et al., 2017;London, 2018). Recent studies of fluid inclusions have shown that, in addition to fractionation, the separation of melt-fluid or fluid immiscibility, and filter pressing could play a critical role in the mineralization of Li-rich pegmatites (Fei et al., 2021).

However, because in many pegmatite fields , there are no obvious spatial, temporal or compositional relationships between mineralized pegmatites and supposedly parental granites (Shaw et al., 2019; Simmons et al., 2016; Miller et al., 2017), a second school of thought has developed with the suggestion that the pegmatites could be products of partial melting and anatexis of lithium-rich metasedimentary host rocks (Simmons et al., 2016; Shaw et al., 2019). This alternative anatectic model has been accepted worldwide (Knoll et al., 2023; Koopmans et al., 2023).

The pegmatite melts generated by partial melting have LCT compositions and can undergo further fractionation and metal enrichment as the pegmatite intrusion rises through the crust. Lithium and fluxing agents such as H2O, B, F, and P can be derived from evaporite-rich layers, illite clays, and muscovite in metasediments (Kunz et al., 2022). Alternatively, high-grade granulite-facies metamorphism can mobilize fluids rich in lithium and other rare metals through regional shear zones, forming pegmatite melts (Cuney and Barbey, 2014; Ballouard et al., 2020). Alternative models consisting of some combination of these processes have been proposed because single-stage enrichment processes alone are likely inadequate to achieve the required Li concentrations to saturate Li ore minerals (Koopmans et al., 2023; Gardiner et al., 2024).

While all African orogenic lithium deposits are considered products of the fractional crystallization of silicate melts, the sources of the pegmatites are based on the two genetic (source) models described in the previous section (Shaw et al., 2022; Goodenough et al., 2025). The Archean pegmatites in Zimbabwe are associated with several coeval orogenic granitic intrusions (Dittrich et al., 2019), such as those at the Bikita mine, which has led to the suggestion of a genetic relationship involving extreme fractionation of residual melts derived from the crystallization of granitic magmas (Martin, 1964; Melcher et al., 2015), although according to Godogo (2022), it has not been possible to link the pegmatites to any individual intrusions. The high concentration of cesium and the formation of pollucite in some of these deposits indicate extreme fractionation of the pegmatitic melts (Dittrich et al., 2019). The possible absence of parental granites for these lithiumdeposits may necessitate consideration of an alternative origin, such as anatexis of pelitic metasedimentary rocks in the greenstone belts.

The Birrimian lithium pegmatites have very close relationships with the Eburnean granites. For example, the Goulamina pegmatite is enclosed within Goulamina granite of similar age and composition (Wilde et al., 2021). Additionally, the presence of abundant primary albite is indicative of extreme fractionation of an alkali granitic magma during pegmatite formation (Adams et al., 2023; Agyekum and Adomako-Ansah, 2025). The occurrence of loellingite, an iron arsenide mineral (FeAs2) in the Ewoyaa deposit, Ghana, has been cited as evidence of a magmatic source for the lithium pegmatites (Adams et al., 2023).

However, Bonnetti et al. (2024) proposed, based on metallogenic analysis, that an anatectic origin for the Birimian LCT pegmatites is also possible in areas where pegmatites are not associated with granitic rocks, such as in the Ivory Coast. The deposits could have originated from partial melting of metasedimentary or igneous parent materials (protoliths) during the late tectonic phase of the Eburnean Orogeny, which involved the collision of the western edge of the West African Craton and volcanic island arcs (Kazapoe, 2022). Evidence of collision orogeny includes crustal thickening and the presence of collision structures (e.g., nappes) along the suture zone marked by the Sassandra fault zone (Ganne et al., 2012).

Kibaran lithium deposits are found within relatively enormous pegmatite bodies that are closely associated with numerous monstrous granitic intrusions. In the Manono-Kitotolo deposit, both the pegmatites and the late-phase granites are of similar age and composition. In contrast, Shaw et al. (2019) reported that the Kamativi pegmatites are far younger than the surrounding granites. Consequently, while granitic magma is accepted as the source for the Manono-Kitotolo deposit, a metasedimentary source was proposed for the Kamativi pegmatite. Kibaran lithium deposits formed during the late tectonic phase of the Kibaran Orogeny through the collision of the Congo and Tanzania Cratons (Dewaele et al., 2016).

The Pan-African LCT pegmatites occur as relatively small but numerous dikes emplaced within pelitic or mafic schists. Most pegmatites have no spatial or temporal relationships with parental granites (Muhammedyasin, 2017; Ashford, 2020; Olade, 2025) and are considered products of partial melting of metasedimentary rocks during the late phase of collisional Pan-African Orogeny in West Africa, East Africa, and Southwest Africa.

Implications of Metallogeny on Regional Exploration Strategies

Metallogenic analysis can be instrumental in mineral exploration because it helps geoscientists identify the temporal and spatial distributions of mineral deposits, as well as the nature of the ore-forming processes and factors responsible for ore localization. Additionally, metallogeny can help identify areas with high economic potential for mineral deposits. Hardrock Hard rock lithium is of mostly magmatic origin and is associated predominantly with orogenic pegmatites and occasionally with granites. Geochemical studies have revealed that mineralized lithium-bearing pegmatites belong to the LCT family of pegmatites, which are most enriched in lithophile elements and rare metals (Li, Rb, Cs, Be, Sn, Nb, Ta) (London, 2008; Bradley et al., 2017). Using metallogenic analysis in conjunction with geochemical criteria can be beneficial in developing exploration strategies for both Greenfield and brownfield exploration (Pohl et al., 2022).

From a metallogenic perspective, lithium pegmatite deposits in Africa were formed at specific geological times (metallogenic epochs) and in specific geological settings (metallogenic provinces), which can inform the planning of exploration programs (Sahoo, 2023). The Neoarchean and Neoproterozoic periods appear to be the leading metallogenic epochs for lithium generation in Africa. The areas underlain by the Neoarchean craton in Zimbabwe and the Pan-African mobile belts in West Africa and East Africa provide the most attractive regional targets for lithium exploration in Africa.

In these areas, their mineralization potential is attributable to the intensity and nature of lithium metallogenesis during associated orogenic events. Moreover, the number of potential lithium-bearing pegmatites in the indicated areas is large and could provide a vast and viable number of targets for lithium discoveries in each metallogenic province. Within identified metallogenic provinces, a series of prospectivity criteria can be used to delineate prospective prospects:

- Select areas underlain by greenstone and/or schist belts and associated lithologies
- Establish the ages and compositions of pegmatites
- or granites
- Select pegmatite fields with pegmatite dike swarms or known mineral occurrences
- Determine structural patterns and orientations from remote sensing and maps
- Utilize applicable gravimetric and magnetic
- signatures
- Conduct comprehensive rock, soil and sediment geochemical surveys

For the Archean-type mineralization in Zimbabwe, pegmatites emplaced in greenstone belts with metasedimentary or metavolcanic host rocks should be of primary interest. In the Pan-African belts, pegmatites in areas underlain by metasedimentary rocks (such as mica schists) or metavolcanic stones (such as mafic schists) should be targeted. Structural control of pegmatite mineralization, particularly through faults, fractures, and shear zones, should be considered at the district level when selecting targets.

Zimbabwe is a prime target for lithium mineral exploration in Africa because there are no other areas where mineralized Archean pegmatites are known to occur in abundance. Consequently, Zimbabwe is recognized worldwide as one of the most promising countries in Africa for pegmatite-hosted lithium because the country is blessed with several pegmatite bodies in well-defined pegmatite fields. In Pan-African orogenic belts, several countries of interest should include Namibia, Nigeria, Ethiopia, Egypt, Mozambique, and Madagascar.

The varying degrees of rock exposure and intensities of tropical weathering and lateritization in Africa can affect geochemical and exploration strategies and systematics. In some countries, particularly in Southern and Central Africa, many rocks are well-exposed, such as those in Zimbabwe and Namibia, where the mineralized pegmatites are not deeply weathered and may be visible at the surface because pegmatite bodies rich in quartz are relatively more resistant to tropical weathering than the surrounding schistose rocks. In contrast, many parts of West Africa, with a humid climate and heavy precipitation, develop thick lateritic caps and extensively leached lateritic soils.

In Pan-African domains, such as Nigeria and Ethiopia, with minimal lateritization, good outcrops and relics of weathered pegmatites are visible on the surface amidst deeply weathered soils. However, in other parts of West Africa where the country rocks are ferruginous, such as in areas underlain by Birimian stones in Ghana, the Ivory Coast, Guinea, and southern Mali, the lateritic terrain can be problematic for mineral exploration activities because of a lack of outcrops and impediments to soil sampling (Kazapoe, 2023; Bonetti et al., 2024).

Grassroots and brownfield exploration for target area selection should be conducted at the district or local level in tropical and lateritic environments via geochemical exploration methods to identify highly fractionated LCT pegmatites. The use of element ratios, such as K/Rb, K/Cs, Nb/Ta, Zr/Hf, and Rb/Sr ratios, in rocks (when available), soils, and stream sediments (when available), aids in detecting highly fractionated pegmatites (Bonnetti et al., 2024). The use of pathfinder and indicator elements in soils and stream sediments, including Li, Rb, Cs, Sn, Ta, Nb, Be, Mn, and F, can yield good results when the data are evaluated by statistical (factor) analysis in search of geostatistical element associations indicative of potentially mineralized pegmatites. (Olade, 2020).

However, in lateritic terrain, lithium minerals are completely disintegrated, and some elements, including Li, are entirely lost in the regolith. Panning for accessory minerals, such as muscovite, garnet, albite, beryl, tantalite, and tourmaline, in stream sediments helps identify favorable or fertile pegmatite targets in Africa. Portable field equipment for chemical analysis, such as a portable X-ray fluorescence analyzer and the newly developed portable LIBS (laser-induced breakdown spectroscopy) analyzer (for Li ores), has proven to be valuable tools for obtaining quick results during field exploration.

Conclusion

This qualitative metallogenic analysis of lithium pegmatite deposits in Africa strongly supported the well-known association of hard rock lithium mineralization in pegmatites with orogenic cycles. The peak periods of lithium generation occurred during the Neoarchean and Neoproterozoic orogenic events, as indicated by the spatial distribution, which reveals the concentration of lithium mineralization in Zimbabwe and western Africa.

Lithium is of the magmatic type with only minor metasomatic effects associated with albitization, which impacts lithium minerals a little negatively, but does not enhance the lithium concentrations, except for the Sn and Nb-Ta mineralization. Lithium can be found in three main magmatic minerals: spodumene, petalite, and lepidolite.

The factors controlling ore localization are varied but include lithologic, structural, and stratigraphic factors. Granitic emplacement and location can also influence the locations of metasedimentary source rocks, which could serve as additional controls quantification.

The quantification of metallogenic analysis by using models and mineral systems is a desirable tool. Still, it is data-driven and requires large databases that need to be created on deposits, which may not be easily obtained. Metallogenic analysis can help identify metallogenic provinces and exploration strategies by focusing on areas and geological structures that are most favorable for lithium mineralization in Africa.

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