GRAPHITE RESOURCES IN AFRICA: CARBON FOR DECARBONISATION

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Abstract

Graphite is a crystalline form of carbon, a native element and one of the softest known minerals (less than 1 on the Mohs scale). Flake graphite is the main commercial form of graphite, with the other commercial forms being amorphous and vein graphite. As well as the long-standing use of graphite in applications such as refractories, brake linings, lubricants and pencils, it is also much sought after as a 'battery raw material' for use as the anode in lithium-ion batteries.

China dominates the supply chain as it produces 65% of the worlds graphite and is the only country that produces High Purity Spherical Graphite (HPSG) used to make anodes. The demand for graphite is expected to quadruple from 1.1 million tonnes in 2020 to 4 million tonnes by 2030. New sources and supply chains are needed to bridge the gap between supply and demand caused by the increasing need for battery raw materials.

This is where Africa enters the picture. Historically Africa is an established producer of graphite. Madagascar has been producing graphite for over 100 years and Zimbabwe was a significant producer in the 1980s and 1990s. In the last 5 to 10 years, exploration and development of graphite resources in Africa has exploded with advanced exploration projects across the continent, especially in eastern Africa. The Mozambique belt in eastern Africa is the focus of much of the attention. It consists of high-grade metamorphic rocks such as schist, gneiss and marble that are host to graphite deposits in Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Tanzania and Zambia. Balama in Cabo Delgado Province in northern Mozambique is claimed to be one of the largest graphite deposits in the world with a JORC-compliant resource of 1.4 billion tonnes at a grade of 10% graphite and has a production capacity of 350,000 tonnes per year of flake graphite concentrate. The plan is that small flake graphite (75-150 µm) will be exported from Balama to a battery anode plant currently under construction in the USA. This will be the first major integrated producer of natural graphite HPSG outside of China.

By 2030, it is likely that Africa will have overtaken China as the leading global producer of graphite. However, it is equally likely that the production of HPSG for lithium-ion batteries will remain outside of Africa in China, Europe and the USA. This means that, unless the capacity to produce HPSG and battery anodes is developed in Africa, much of the economic benefit arising from their graphite resources will also remain out of Africa.

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Introduction

Graphite is a crystalline form of carbon (C) and one of only a handful of naturally occurring native elements (i.e. uncombined with any other elements). It is one of the softest known minerals, in stark contrast to the other main form of carbon, diamond, which is the hardest naturally occurring mineral.

Graphite has physical and chemical properties that are valuable for many industrial and advanced technology applications, such as a high melting point in non-oxidising conditions, and thermal conductivity and electrical resistivity that make it ideal as a conductor of heat and electricity. It is an industrial mineral which has, for many years, been used as a raw material for refractory products particularly in steel manufacture, as well as in metal bearings, brake linings, lubricants, paint and pencil lead (Mitchell, 1992). However, in recent years, its use in lithium-ion rechargeable batteries, where it is the dominant choice as anode material, has significantly increased the demand for graphite. This has put pressure on the established supply chain especially because the global trade and production of graphite anode materials is dominated by China. This poses a significant supply risk that is driving the current surge in exploration activity in places such as eastern Africa.

Graphite Ocurrence

The economic value of some industrial minerals such as graphite relies not just on their mineralogical and chemical properties but also on their physical properties. Those properties considered important for the industrial use of graphite include graphite purity, particle size, electrical and thermal conductivity, degree of crystallinity, expandability, lubricity and bulk density (Kogel *et al*, 2006). The specifications drawn up between mineral producers and consumers have considerable significance for mineral exploration companies as they are a clear guide to the types of graphite that are suitable for different applications.

Graphite occurs in three natural forms, each with different commercial applications:

- **Amorphous graphite**: finely crystalline graphite that is mostly formed by the metamorphism of carbonaceous rocks such as coal. It is typically used in low-value applications, such as foundry sand mould coatings, pencils and paint, and in lubricants and some refractory products. The main global suppliers are China, Mexico, Russia and Austria.
- **Flake graphite**: crystalline flakes of graphite that have a maximum dimension between 75 microns and 4 cm. They were formed by the recrystallisation of carbon in sedimentary rocks and are found in Archean to late Proterozoic age metamorphic rocks such as gneiss, marble and schist. Flake graphite is the main commercially traded form of graphite. Flake graphite is preferred for use in clay-graphite crucibles and magnesia-carbon refractories, for the production of High Purity Spherical Graphite (HPSG) used to manufacture Active Anode Material (AAM) for lithium-ion batteries, high purity refractory bricks used to line steel kilns, vehicle brake and clutch linings and high purity lubricants.

  The fine-grained (<75 microns) product of flake graphite mining is also used as a substitute for amorphous graphite. The main global suppliers are China, Brazil, India, Canada, Madagascar, Mozambique and Ukraine.
- **Vein (lump) graphite**: highly crystalline, massive form of graphite that is deposited in veins by fluids during metamorphism. It is often closely associated with flake graphite and occurs in similar geological settings. It is mostly used for lubricant and refractory applications. It is also used in high-quality electrical motor brushes and other current-carrying carbon products, which benefit from the high purity and crystallinity of vein graphite. The main global supplier is Sri Lanka.

Supply Chain For Battery-Grade Graphite

The global supply of graphite is dominated by China. In 2020, China produced an estimated 650 000 tonnes, representing 65% of global production of graphite (BGS, 2022). The other main graphite producers in descending order of production in 2020 were: Brazil, Madagascar, North Korea, India, Mozambique, Russia, Austria, Turkey, Ukraine, Norway and Canada (British Geological Survey, 2022). The global demand for graphite is set to rise dramatically from 1.1 million tonnes in 2020 to 4 million tonnes per year by 2030 and will outstrip supply before 2030 (Mining Journal, 2021). New sources and supply chains will be needed to bridge the gap between supply and demand caused chiefly by the increasing need for battery raw materials.

The processing and manufacturing of battery materials and components take place in very few countries. China is currently the only country in the world to produce HPSG and one of a handful producing AAM, alongside Japan and South Korea (Grant *et al*, 2020). This concentration of key stages in the supply chain in a small number of countries is a potential risk to the security of global graphite supply. In addition, the lack of information on, and opportunities to scrutinise, the processing operations in China makes it difficult to guarantee that global environmental, social and governance (ESG) standards are met.

Given the large scale of the deposits and advanced development of some mining projects, Africa has the potential to become a leading producer of responsibly sourced and sustainable graphite. However, such opportunities will need to be carefully planned and managed in consultation with all stakeholder groups, especially in regions and in communities with little prior experience of mining and processing operations.

The graphite supply chain for batteries comprises the following stages (Figure 1):

1. Exploration: discovery, resource assessment, planning and commissioning of the mine.
2. Mining: mining and initial processing to produce graphite concentrates.
3. Processing: processing to make specialised graphite products such as spheroidisation to make HPSG and coating.
4. Manufacturing: manufacturing of AAM for lithium-ion batteries.
5. Use: production and use of consumer products.
6. End-of-life: scrapping, reuse or recycling of graphite, for example to produce graphene.

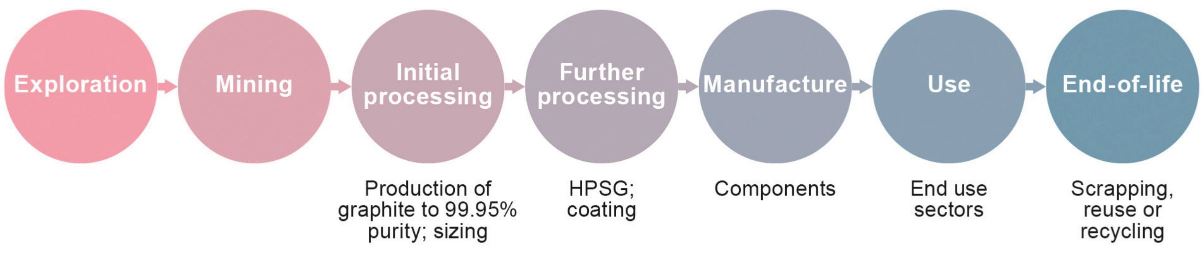

Figure 1. *The stages in the graphite supply chain.*

Graphite In Africa

Graphite resources and production

Graphite resources in Africa occur in ancient geological terranes that form the Precambrian 'basement' of the continent. These consist of large, tectonically stable blocks of continental crust ('cratons') surrounded by mobile orogenic 'belts' that were deformed by intense tectonic stresses. Graphite is typically hosted in high-grade metamorphic rocks such as schist, gneiss and marble. Across the continent, particularly in the Mozambique belt in eastern Africa, significant graphite deposits have been identified many of which have delineated reserves and resources.

Graphite production in Africa mainly takes place in Madagascar and Mozambique (Figure 2). In Madagascar there are three graphite mines:- Gallois (which processes ore from two sites, Antsirakambo and Marovintsy); Graphmada; and Sahamamy Sahasoa, with a combined production in 2020 of 48,500 tonnes. In Mozambique there are two mines, Ancuabe and Balama, with a combined production in 2020 of 18,159 tonnes (BGS, 2022). Graphite production is due to restart in Namibia in 2023 (Northern Graphite Corporation, 2022).

Current exploration projects have identified significant deposits of graphite in Botswana, Ghana, Guinea, Madagascar, Malawi, Mozambique, Namibia, Tanzania and Uganda. Graphite is also known to occur in

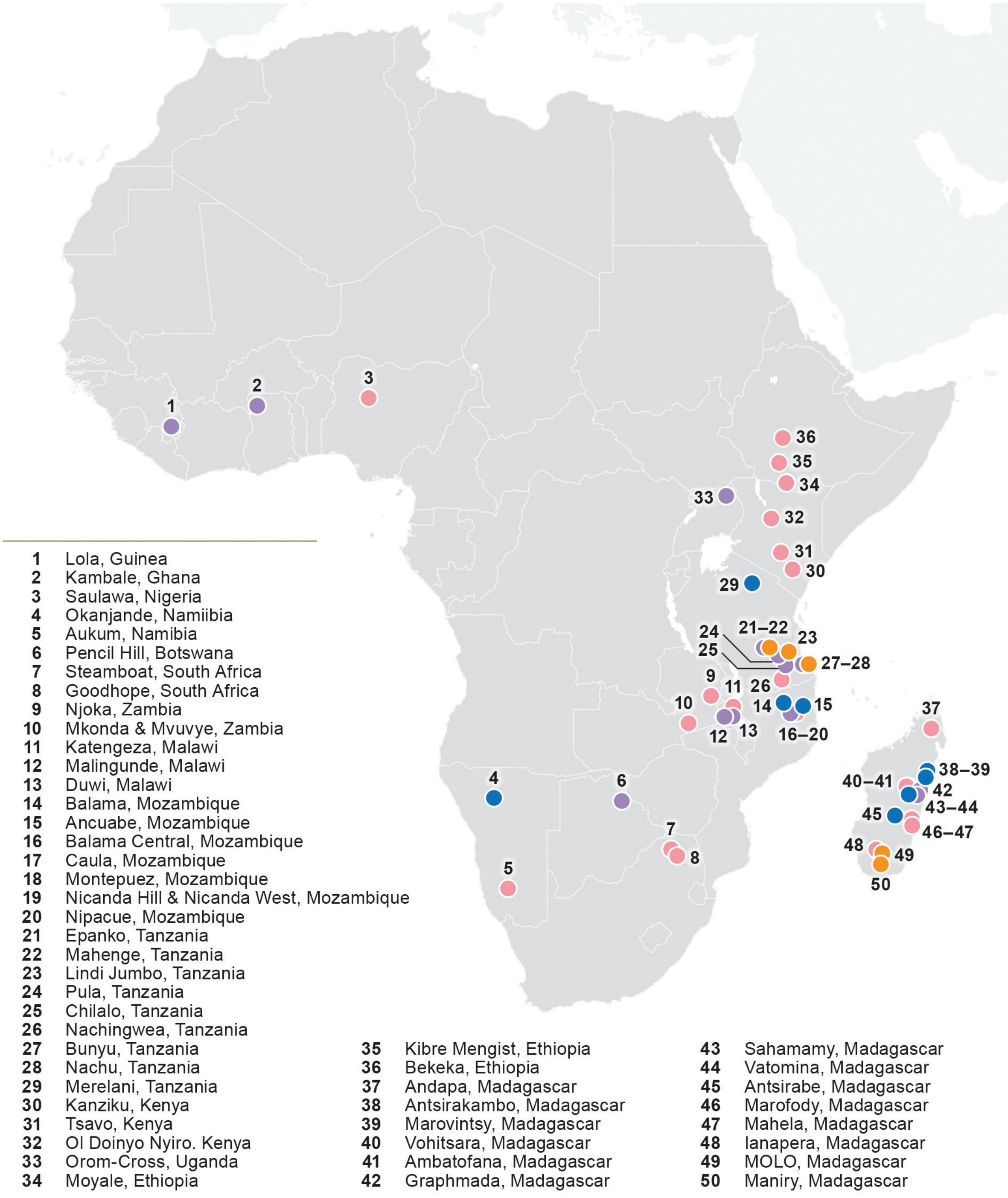

Figure 2. *Graphite exploration projects and operations in Africa (Mitchell and Deady, 2021). Basemap GLIM Lithological Map of the World ©CCGM-CGMW 2015.*

Cameroon, Egypt, Eswatini, Ethiopia, Kenya, Morocco, Nigeria, Somalia, South Africa, South Sudan, Sudan, Zambia and Zimbabwe (Figure 2). The colours of the dots indicate the development stage of each project as at 2021, details of which can be found in Appendix 1 of Mitchell & Deady 2021.

Examples of graphite advanced exploration projects and operations in eastern Africa include:

- **Madagascar**: Gallois flake graphite mine in Madagascar has a JORC-compliant indicated resource of 174.5 million tonnes at 6.7% graphite and plans to increase current production capacity to 140,000 tpy (Etablissements Gallois, 2021).
- **Malawi**: Malingunde flake graphite exploration project in Malawi has a JORC compliant resource of 65 million tonnes at 7.1% graphite and has a pre-feasibility plan to produce 52,000 tpy of flake graphite concentrate (Sovereign Metals Ltd, 2018).
- **Mozambique**: Balama flake graphite mine in Cabo Delgado Province, northern Mozambique, has a JORC-compliant resource of 1.4 billion tonnes at 10% graphite. The graphite operation has a production capacity of 350,000 tonnes per year (tpy) and a projected life span of 50 years. It is planned to export small flake graphite (75 - 150 microns) to Syrah Resources' battery anode plant currently under construction in Vidalia, Louisiana, USA. This will be the first major integrated producer of natural graphite HPSG and AAM outside China for electric vehicle batteries (Syrah Resources, 2021).
- **Tanzania**: Lindi Jumbo flake graphite exploration project in Tanzania (Plate 1) has a JORC compliant resource of 41.8 million tonnes at 10.8% graphite and is currently constructing a plant to produce 40,000 tpy of flake graphite concentrate (Walkabout Resources, 2022).

Other parts of Africa with geology favourable for graphite have similar Precambrian basement terranes to those of the Mozambique belt in eastern Africa. The following are currently the focus of active graphite mineral exploration and/ or development of mining operations:

- **Botswana**: Pencil Hill flake graphite exploration project in the Archean Motloutse Complex near Francistown in Botswana has a JORC compliant resource of 6.9 million tonnes at 8.82% graphite (Tonota Resources, 2022).
- **Ghana**: Kambale flake graphite exploration project in the Precambrian West African craton in northern Ghana has a JORC compliant resource of 14.4 million tonnes at 7.2% graphite (Castle Minerals, 2022).
- **Guinea**: Lola flake graphite exploration project in the Precambrian West African craton in south-east Guinea has a NI 43-101 compliant resource of 19.14 million tonnes at 4.37% graphite (Sama Resources, 2022).
- **Namibia**: Okanjande flake graphite project in the Namaqualand Metamorphic Complex in northern Namibia has a NI 43-101 compliant measured

Plate 1. *Lindi Jumbo graphite deposit, Tanzania (© Walkabout Resources).*

resource of 9.56 million tonnes at 6.25% graphite. Graphite production took place in 2017-18 and will resume in 2023 at a rate of 31,000 tpy of flake graphite concentrate (Northern Graphite Corporation, 2022).

- **Uganda**: Orom Cross flake graphite exploration project in the Neoproterozoic gneisses and schists in northern Uganda has a JORC compliant resource of 16.35 million tonnes at 6.01% graphite and has a pre feasibility plan to produce 101,000 tpy of flake graphite concentrate by 2025 (Blencowe Resources, 2022).

Those prospective areas in Africa with no current mineral exploration projects include the Neoproterozoic Arabian Nubian Shield in Egypt; the Mozambique belt in Ethiopia, Kenya, Zambia and Zimbabwe; the West African Craton in Nigeria; the Paleoproterozoic Beit Bridge Complex in South Africa; and ultramafic rocks in Morocco.

Constraints on graphite resource development in Africa

Graphite production is ongoing in Madagascar, Mozambique and Tanzania (Mitchell & Deady, 2021). Given the high level of exploration, production in these countries is likely to increase in the future. Currently graphite mining in Africa produces only graphite concentrates which are exported to China. There is no production in Africa of HPSG or AAM, although the scale of the known graphite resources would appear adequate to support such local value addition. There are encouraging initiatives to address this in Africa. In 2022, Zambia and the Democratic Republic of the Congo (DRC) signed a Cooperation Agreement on the “Establishment of a Value Chain in the Electric Vehicle and Clean Energy Sector” with the aim being to manufacture electric vehicle batteries using indigenous mineral resources (Nachalwe-Mbao, 2022). Factors that may contribute to the successful development of graphite mining operations in Africa include:

1. **High quality mineral deposits and geological information**: good quality, detailed, accessible geological information for mineral resources is a key requirement for mineral-rich countries looking to attract investment, particularly Foreign Direct Investment (FDI). Such data is often non-existent or hard to access.
2. **High standards of governance, legal framework and regulatory stability**: good governance of the mining industry is essential to attract investors and to ensure positive impacts for communities. A transparent, equitable and consistent legal context, and effective support and monitoring by well-organised government institutions are needed. There are a variety of different governance mechanisms across the relevant jurisdictions, which do not always meet good practice standards. The implementation of AMREC (African Mineral and Energy Resources Classification and Management System) may aid in improving and standardising the governance of mineral resources in Africa.
3. **Good infrastructure, mining services and supply chain**: mining investments require reliable infrastructure (roads, rail networks, ports, water supply and power generation). Mining services and a clear understanding of the supply chain are also needed. Graphite mineral processing is highly energy intensive and requires a reliable source of energy.
4. **Environmental regulations**: high standards of environmental regulation, and their continual monitoring and enforcement, are required in the vicinity of mine sites and processing plants. This is especially the case in areas where mining has not previously been carried out.
5. **Equitable taxation and use of revenues**: a competitive and well-structured fiscal regime and access to foreign exchange are important. FDI is an opportunity for governments to finance infrastructure development, sustainable economic growth to generate job creation, and involvement in exploration, extraction and processing.
6. **Skills and human resources**: a cadre of well-trained, highly skilled local staff will be essential for the development of a graphite mining industry in any African country. There is commonly a shortage of skills across the whole project lifecycle, from mineral exploration, environmental mitigation and downstream processing and manufacture. Capacity building and the use of standard international frameworks, such as the United Nations Framework Classification for Resources (UNFC) and the African Mineral and Energy Resources Classification and Management System (AMREC), may help to fill this gap.

Conclusions

The global graphite industry faces significant challenges in maintaining supply to meet the increasing demand for battery raw materials. Global graphite resources are abundant, particularly in eastern Africa, and could make a significant additional contribution to supply. The dramatic increase in exploration for, and production of, flake graphite in eastern Africa is encouraging. As are initiatives such as the Cooperation Agreement between Zambia and the DRC to manufacture electric vehicle batteries using indigenous mineral resources.

However, maintaining a sustainable, transparent and diversified graphite supply chain will be a considerable challenge. Meeting the conditions required to establish successful graphite mining operations in Africa will take many years. This will depend on long term commitments by governments and industry, underpinned by the support and trust of all stakeholder groups, especially local communities. The establishment of the capacity to produce HPSG and AAM is arguably the key challenge in ensuring the benefits of graphite resource development are retained in Africa.

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