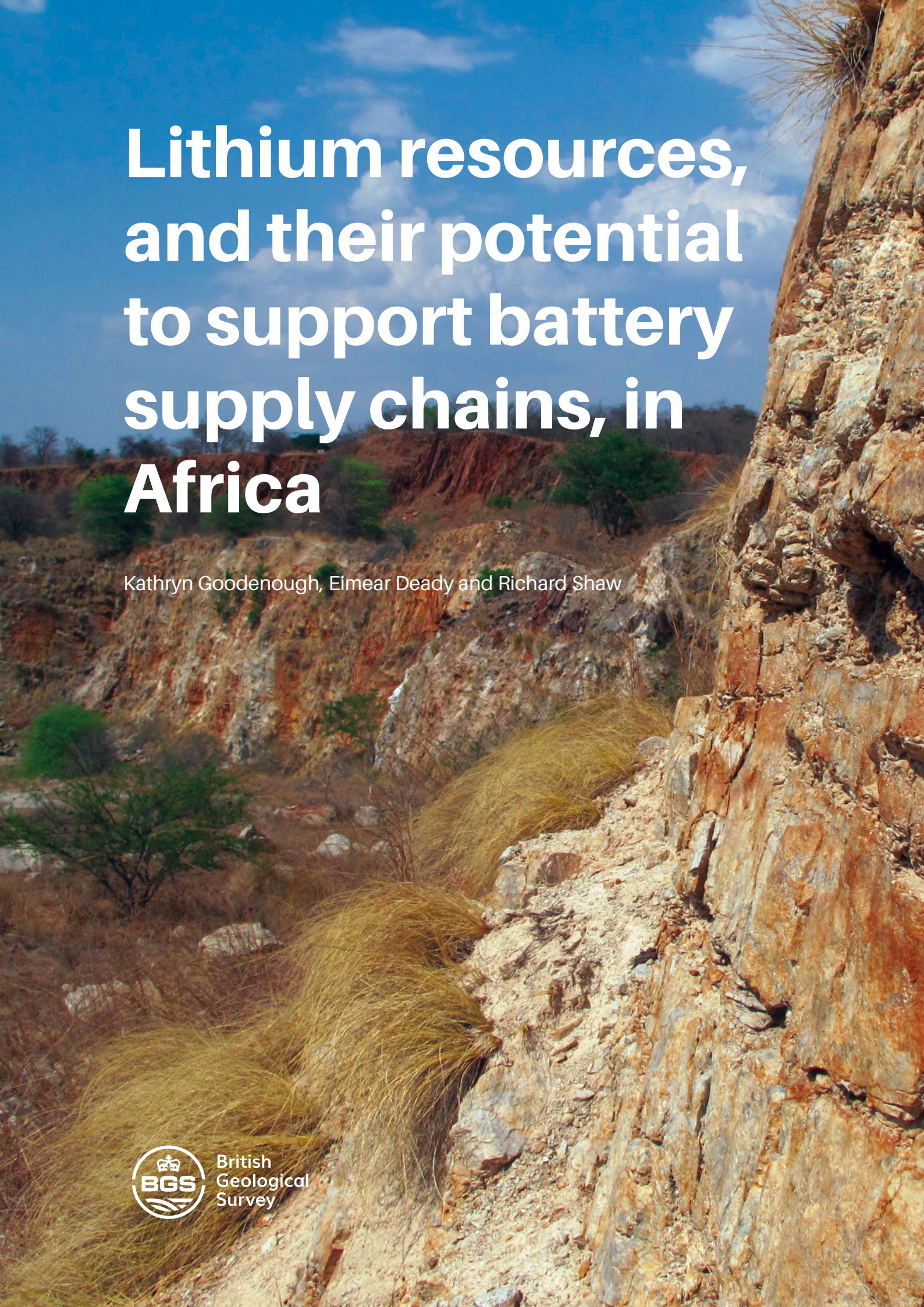

Lithium resources, and their potential to support battery supply chains, in Africa

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Cover photograph: The Kamativi lithium pegmatite, Zimbabwe.

Contents

Executive summary

Decarbonisation of energy and transport, to meet global net zero ambitions, will require significantly increased amounts of the raw materials used to manufacture batteries and other green technologies. This report focuses specifically on lithium, one of the major battery raw materials, for which demand is expected to grow rapidly in the coming decades. Lithium supply chains are complex and commonly global in their extent, with steps that include exploration, mining, processing, manufacturing, use and recycling.

The continent of Africa has significant natural lithium resources, which may provide an opportunity for many African countries to contribute to meeting increased demand whilst also supporting economic growth. This report reviews known resources of lithium, and engagement in the battery supply chain, across key African countries. Many African countries (most notably Zimbabwe, Namibia, Ghana, Democratic Republic of Congo and Mali) have lithium resources and the potential for lithium mines. However, there is much less engagement in critical stages further along the supply chain. Currently, Africa has very little capacity for lithium mineral processing, further refining of lithium chemicals, or manufacture of battery components. This leads to a typical situation where mineral concentrate is exported; value is added outside Africa; and products using lithium-ion batteries are then imported. There is clear potential for Africa's lithium resources to make an important economic contribution, but this should be placed in the context of the wider supply chain; in particular, the potential for regional cooperation on refining and production of lithium chemicals deserves further consideration.

There is currently limited data on the specific socio-economic and environmental impacts of lithium pegmatite mining. Development of new lithium mines across Africa will be most successful if good governance, human rights, and minimising environmental impacts are all considered as priorities.

Introduction

As tackling climate change becomes a global priority, countries worldwide are setting ambitious policy deadlines for decarbonisation of energy and transport. This is leading to significant growth in demand for electric vehicles and energy storage, particularly driven by Asia, Europe and the USA (IEA, 2020). The COVID-19 pandemic of 2020–21 has slowed, but not halted, this growth. Modern electric vehicles and energy storage applications dominantly use lithium-ion batteries, which require a range of battery raw materials, many labelled as critical, including lithium, cobalt, graphite, nickel and manganese. Demand for the first three of these, in particular, is expected to escalate rapidly over coming years, necessitating the development of new sources and supply chains (Ballinger et al., 2019; Hund et al., 2020). This report will focus specifically on lithium.

Global supply chains of lithium for batteries are currently dominated by sources in South America, Australia and China, with processing and manufacturing of the battery compounds and components focused in China, Japan and South Korea (Grant et al., 2020; Sun et al., 2019). This narrow geographical focus of key steps in the supply chain presents potential risks for security of supply, and many countries and regions have begun to consider how they can engage in lithium supply chains. However, despite the importance of lithium for global decarbonisation and the ongoing discussions regarding strong future demand, the diversification of supply from new jurisdictions is yet to be seen.

The anticipated growth in demand for battery raw materials has been recognised as offering a potential opportunity for resource-rich developing countries (Hund et al., 2020). Here, we focus on the continent of Africa, which currently has very limited engagement with lithium supply chains (Moreno-Brieva and Merino, 2020) despite having significant lithium mineral resources, and also importing substantial amounts of lithium batteries. In this report, we summarise the potential for developing an integrated lithium supply chain for batteries in Africa.

Types of lithium deposit

Lithium is a moderately abundant element in the Earth's crust, and is predominantly concentrated into three types of mineral deposit: pegmatites and granites; sedimentary deposits; and brines (Bowell et al., 2020). Current global lithium production is split between pegmatite deposits (particularly in Australia) and brine deposits (particularly in Chile and Argentina). Lithium-bearing pegmatites may also be important sources of other valuable co-product metals such as tantalum, caesium, and tin.

In Africa, lithium pegmatites represent the only significant deposit type known, and these occur in many countries across the continent (Von Knorring and Condliffe, 1987). These pegmatites are coarse-grained igneous intrusions that were originally formed by magma cooling at depths of a few kilometres below the Earth's surface, and now form tabular bodies of rock that may be tens to hundreds of metres thick, and extend laterally for hundreds of metres to kilometres. They commonly occur in stacks or swarms, so a single deposit may contain a number of individual pegmatite bodies. They are most commonly mined in open pits, but underground mining is also possible.

Lithium does not occur as a native element, but is bound up in a range of ore minerals within the pegmatite. Understanding the complex mineralogy of pegmatites is critically important for the supply chain (Linnen et al., 2012). The most important ore mineral for lithium batteries is spodumene, for which cracking and refining processes are well established. Other lithium ore minerals include

petalite, lepidolite and amblygonite. Other important minerals found in pegmatites include pollucite (mined for caesium), columbite-tantalite (tantalum) and cassiterite (tin). In several African countries, pegmatites are mined for tin and tantalum, but have not been explored for lithium in any detail. This is particularly the case in countries where tropical weathering has liberated the more resistant tin and tantalum minerals at the surface, but has contributed to breakdown of lithium minerals in the weathered zone, creating challenges for exploration.

The stages in the lithium supply chain for batteries

Knowledge that a lithium deposit exists is only the starting point of a complex supply chain. The lithium supply chain for batteries can be considered to include six stages:

1. Exploration stage: discovery and exploration of the mineral deposit, and progress to the point of opening the mine
2. Extraction stage: mining and concentration of the ore (minerals or brines)
3. Processing stage: processing and refining to produce the battery-grade chemicals lithium carbonate or lithium hydroxide
4. Manufacturing stage: manufacturing the components to make up the lithium-ion battery
5. Use stage: incorporation of the battery into a consumer product such as an electric vehicle, and use of that product
6. End-of-life stage: scrapping, reuse or recycling

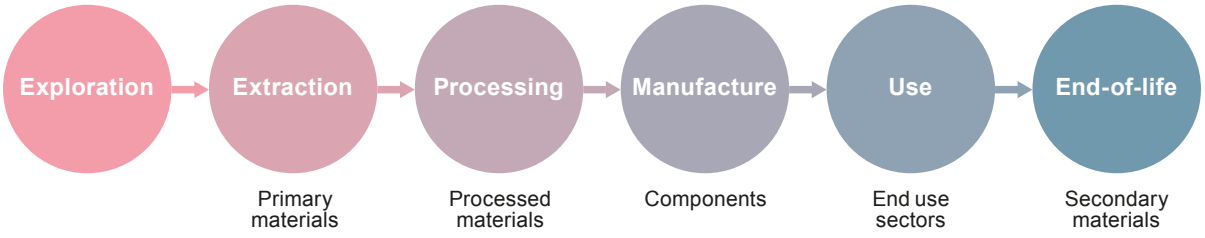

Figure 1 The stages in the lithium supply chain.

Stage 1: the exploration stage. This stage of the supply chain is essential for commodities like lithium where demand is expected to grow significantly in the coming years and so new deposits will need to be identified and developed. This stage includes initial discovery of a deposit, and then progresses through scoping and resource definition, pre-feasibility and definitive feasibility studies (DFS) as the deposit becomes better characterised (usually through drilling) and metallurgical flowsheets are

established through testwork. During this process the resource[1], and then the reserve[2], is gradually established with greater certainty (Wood and Hedenquist, 2019). These figures will typically have to comply with one of the globally-accepted mining codes, such as Australia's JORC code, Canada's NI 43-101, or South Africa's SAMREC. During exploration significant investment is required to enable characterisation of the deposit and assessment of its economic, environmental and social viability to become an operational mine. The exploration stage is often very lengthy, potentially taking more than 10 years to complete, and highly risky.

Stage 2: the extraction stage includes all the work that is done at a mine site, typically including production of ore and beneficiation to produce an exportable lithium mineral concentrate or intermediate product. For pegmatite deposits, beneficiation may use processes such as gravity separation, magnetic separation, and froth flotation to generate the lithium mineral concentrate, and also to separate out by-product minerals (Tadesse et al., 2019). For most African deposits, it is this lithium mineral concentrate that will be sold. In lithium brine deposits, this beneficiation may take the form of solar evaporation and precipitation of lithium minerals, or may use a range of direct lithium extraction (DLE) techniques (Liu et al., 2019).

Stage 3: the processing stage is a refining stage, in which lithium mineral concentrates are processed to produce battery-grade chemicals, typically lithium hydroxide or lithium carbonate, for use in cathode manufacturing (Weimer et al., 2019). For pegmatite deposits, this stage currently takes place exclusively in China (Grant et al., 2020) although refineries are being developed elsewhere in the world. For the brine deposits of South America, this refining is done prior to export. It is worth noting that there is no market price for elemental lithium; pricing is based on varied grades of lithium carbonate and hydroxide.

Stage 4: the manufacturing stage covers the manufacturing of cathode powders (which involves a number of steps to combine several elements (e.g. Ni, Mn, Co, Li) in appropriate concentrations); then manufacture of the components of the battery cell; and finally the complete lithium-ion battery.

Stage 5: the use stage comprises the incorporation of the battery into a consumer product, and its use.

Stage 6: the end-of-life stage comprises the scrapping, reuse or recycling of the lithium-ion battery after its primary use has ended.

In this report, we review the situation in key countries in Africa, and assess the potential for those countries to progress along the lithium supply chain. Several African countries are engaging in exploration (Stage 1 of the supply chain), but only Zimbabwe and Namibia have successfully attained Stage 2. The intermediate stages of the supply chain remain largely aspirational, although South Africa has some engagement in Stage 4. Stages 5 and 6 take place in many African countries, with import of products containing lithium-ion batteries and subsequent recycling or waste management. The major gap is at Stage 3, the processing stage, for which currently there are no facilities on the continent of Africa.

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[1] A resource is a concentration of naturally occurring material in or on the Earth's crust in such form that economic extraction of a commodity is regarded as feasible, either currently or at some future time. It can be divided (with decreasing levels of certainty) into measured, indicated, and inferred.

[2] A reserve is that portion of an identified resource from which a usable mineral or energy commodity can be economically and legally extracted at the time of determination. It can be divided into proven and probable.

Major countries in Africa's lithium supply chain

This section provides a brief overview of the activities in the lithium supply chain in each of the key countries. Exploration is the dominant stage, but where information is available on how a country is engaging in other stages, this is also reviewed. Details of exploration projects and mines, where available, are provided in Appendix 1.

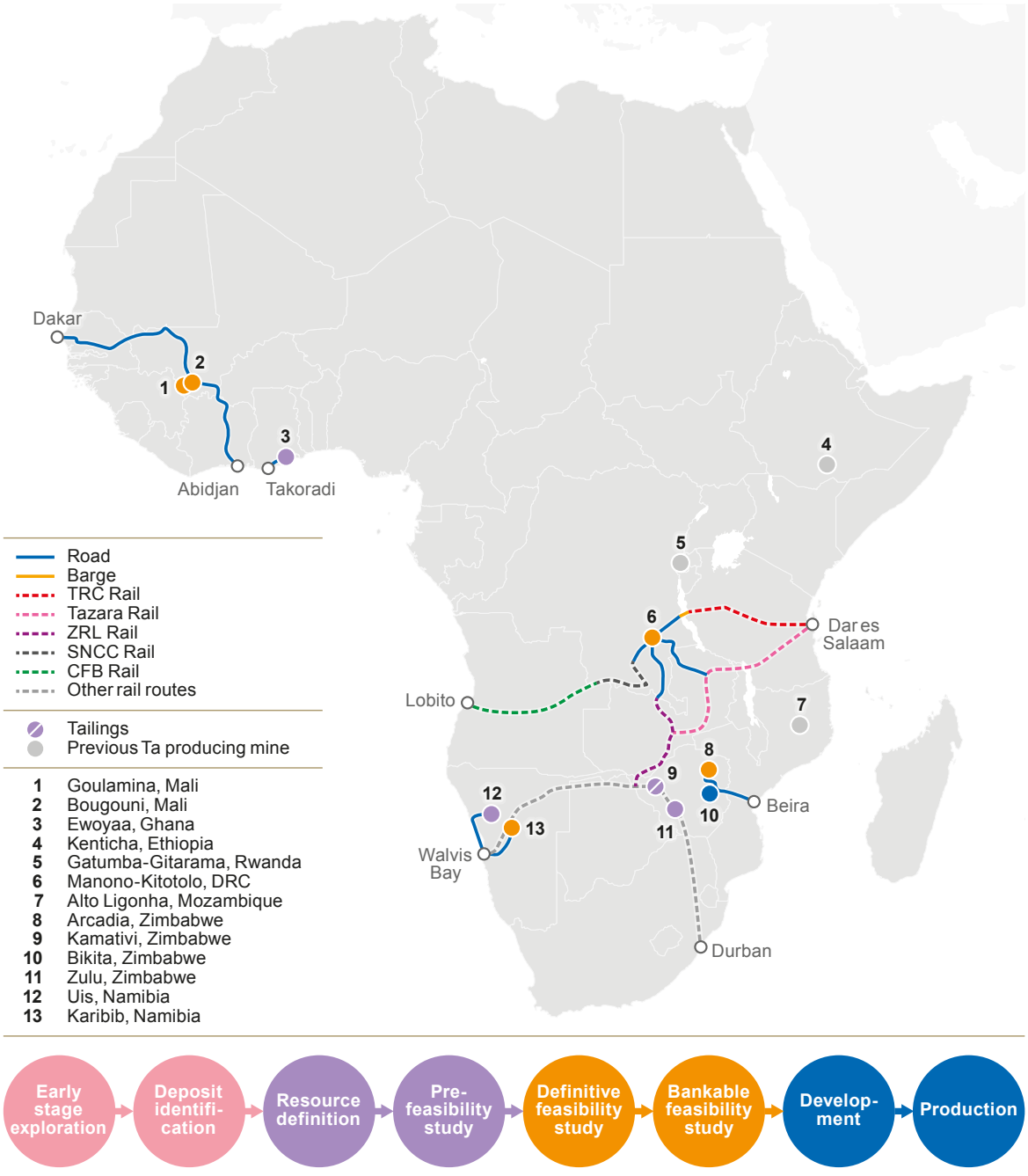

Figure 2 Map of Africa showing the main lithium resource localities discussed below and road, rail and port infrastructure that will be used in lithium supply chains. Circles indicating the localities are coloured by the lithium exploration phase that has been reached as per the timeline in the figure. Map outline © ESRI

Zimbabwe

Zimbabwe has a number of large lithium pegmatites, including Africa's only currently active lithium mine at Bikita (Dittrich et al., 2019) and historical mining (for tin) in the Kamativi pegmatite. Active exploration has taken place at several other localities in recent years. In 2019, the Zimbabwean Government issued a roadmap for the country's mining industry which noted the importance of lithium, but a challenging investment climate means that new developments are not progressing as rapidly as might be hoped. Zimbabwe currently has no significant engagement in the battery supply chain beyond the mining stage.

The **Bikita** pegmatite in SE Zimbabwe has been mined periodically since tin was discovered in 1910, and mining of petalite (for lithium) started in the 1940s. The main product currently exported by Bikita Minerals is a graded petalite concentrate which is produced on site at the mine and chiefly sold for glass and ceramics. Tantalite concentrates have also been produced at the mine. As of 2021, Bikita is the only mine in Africa producing lithium, and currently that lithium is not used in battery supply chains. However, the Bikita mine area does contain spodumene pegmatites, which may contribute to the battery supply chain in the future.

The **Arcadia** project, east of Harare, has been explored by Prospect Resources since 2016. It has Southern Africa's largest JORC-compliant Li reserve (Prospect, 2019). At the time of writing, it is transitioning from exploration to development, with a pilot plant completed in June 2021 and producing petalite concentrate at the mine site. It is expected that spodumene concentrate will also eventually be produced at Arcadia. The project is close to a tarmac highway, and petalite concentrate will be transported to the port of Beira in Mozambique (Figure 2).

The **Kamativi** pegmatite, in north-western Zimbabwe, was mined for tin from 1936 to 1994, but lithium minerals were never extracted. The tailings piles at Kamativi have been explored for lithium by Zimbabwe Lithium and the Zimbabwe Mining Development Corporation, and there is also potential for further exploration in the hard-rock extent of the pegmatite, beyond what has already been mined. The **Zulu** pegmatite, 80 km from Bulawayo, is under exploration by Premier African Minerals, which also owns a series of smaller lithium pegmatite prospects in eastern Zimbabwe.

Namibia

Namibia is the only other African country, after Zimbabwe, that has exported lithium mineral concentrate in recent years. It does not have further engagement in the battery supply chain until the use stage, although it does have a company offering electric vehicle conversions (E-car Namibia).

The most advanced lithium project in Namibia is at **Karibib**. Lepidico hold an 80% interest in this project in central Namibia, which is well-served by existing infrastructure. The project has a JORC-compliant ore reserve, announced in 2020. The Karibib project is unusual because the main product will be a lepidolite concentrate, which is planned to be exported via the deepwater port of Walvis Bay for refining in Abu Dhabi using Lepidico's proprietary technology. Export of a shipment of lepidolite concentrate from Karibib was achieved in 2018, meaning that Namibia is progressing well towards Stage 2 of the supply chain.

Afritin Mining currently own the **Uis** Tin Mine located in the Erongo region of Namibia. The deposit comprises a series of large mineralised pegmatites that are of primary interest for their tin resources, but at which lithium (in the form of petalite) is anticipated as a future by-product. Uis was once the

world's largest hard-rock, open-cast tin mine; it closed in 1990, but began producing tin again in 2020. Early-stage exploration has also taken place at a range of other pegmatites in Namibia.

Democratic Republic of Congo (DRC)

The DRC is only engaged in the exploration stage of the supply chain, but it does have some of Africa's largest lithium pegmatites and one of the most advanced projects. The **Manono-Kitotolo** pegmatites, in the DRC approximately 600 km north of Lubumbashi, were discovered in 1910 and mined for tin until 1982. The Manono mine project is now owned by AVZ Minerals Ltd (60%), La Congolese D'Exploitation Miniere SA (25%) and Dathomir Mining Resources SARL (15%). A DFS released in April 2020 reported a JORC-compliant ore reserve, and demonstrated that the main product of lithium mining would be spodumene concentrate. Tin will also be produced at the mine. Infrastructure around the mine project is currently limited, and the mineral concentrate will be transported significant distances by road to ports in Angola or Tanzania (Figure 2). Additionally, there are several other, less-well advanced exploration projects in the Manono-Kitotolo area.

Mali

Southern Mali has two well-advanced lithium exploration projects: **Goulamina** (Firefinch Ltd) and **Bougouni** (Kodal Minerals). In June 2021, Firefinch Ltd entered into a joint venture with Ganfeng Lithium to develop the Goulamina project. Both companies have JORC-compliant resource estimates (and, in the case of Goulamina, a reserve figure) and plan to produce spodumene concentrate at site and transport it by road to ports in Cote d'Ivoire or Senegal (Table 1, Figure 2). Mining licence applications for both projects have been submitted to the Malian government.

Ghana

The **Ewoyaa** project in southern Ghana, around 100 km from Accra, is being actively explored by Ironridge Resources, and a JORC-compliant mineral resource estimate has been presented (Table 1). The Ewoyaa deposit benefits from proximity to infrastructure, including a tarmac highway, power infrastructure, and a deep-water port (Takoradi) at a distance of around 110 km. Spodumene concentrate from the project will be trucked to Takoradi for export (Figure 2).

There has been some research into penetration of electric vehicles in Ghana (Ayetor et al., 2020). Some policy incentives have been put in place to encourage purchase of lower-emission vehicles, but there are several barriers to significant take-up; these include a lack of charging infrastructure, a skills gap in electric vehicle maintenance, and the purchase price of these vehicles. Access to electricity for charging is also likely to vary widely. Ghana has engagement in Stage 6 of the lithium supply chain, through the import of electronic waste for reuse or recycling, but this tends to be of an informal nature (Daum et al., 2017).

South Africa

South Africa has limited exploration for lithium, although some pegmatites are known, and no lithium extraction or mineral processing. A recent report has identified the refining and processing stage (Stage 3) as a key supply chain stage where South Africa could engage (TIPS, 2021). Projects are

underway to develop manufacturing of some battery chemicals (e.g. the Gilgamesh Cobalt Project) and there is potential for this to eventually expand to lithium chemicals.

South Africa does have nascent involvement in some of the stages further along the value chain, particularly Stage 5, manufacturing of battery cell components (Foli, 2020). The Energy Storage Innovation Laboratory at the University of the Western Cape has a pilot plant for battery production and works with a number of partners on development of battery technology. The Mega Million Energy Company has proposed to develop a Li-ion battery manufacturing plant in South Africa, and had committed to opening a pilot plant in 2020 (Foli, 2020) although there appears to have been little progress on this. There are also a number of companies that assemble Li-ion battery packs in South Africa (TIPS, 2021). Energy security is a critical issue for further development of the industry in South Africa.

Table 1 Publicly available code-compliant lithium resource data for major deposits in African countries.

Deposit	Company	Country	Code	Mineral resource	Tonnage (Mt)	Grade (% Li_2O)	Year
Arcadia	Prospect Resources	Zimbabwe	JORC	High Grade Resource estimate	43.2	1.41	2019
Kamativi	Zimbabwe Lithium & ZMDC	Zimbabwe	NI 43–101	Resource (Indicated)	26.32	0.58	2018
Zulu	Premier African Minerals	Zimbabwe	SAMREC	Resource (Inferred)	20.1	1.06	2020
Karibib	Lepidico	Namibia	JORC	Total Resource estimate	11.87	0.45	2021
Uis (V1V2)	Afritin Mining	Namibia	JORC	Total Resource estimate	71.54	0.63	2019
Manono	AVZ Minerals & others	DRC	JORC	Total Resource estimate	400	1.65	2020
Goulamina	Firefinch Ltd.	Mali	JORC	Total Resource estimate	108.4	1.45	2020
Bougouni	Kodal Minerals	Mali	JORC	Total Resource estimate	21.3	1.11	2020
Ewoyaa	Ironridge Resources	Ghana	JORC	Resource (Indicated + Inferred)	14.5	1.31	2021

Other countries

There are several other countries that have the potential for lithium resources, but where exploration is only at an early stage. Sn-Nb-Ta mineralisation is known from pegmatites in Burundi and Rwanda, where lithium minerals are also recorded (Romer and Lehmann, 1995; Dewaele et al., 2011; Hulsbosch and Muchez, 2020). Notably, Rwanda is also one of the African countries that is currently developing policies for electrification of transport (IGC, 2020). Mozambique also has a substantial number of lithium pegmatites (Von Knorring and Condliffe, 1987) but most mining and exploration has focused on tantalum, beryl and gemstones. In Ethiopia, the major Kenticha pegmatite has been mined for Ta since the 1990s by the Ethiopian Mineral Development Share Company, but may also have potential for lithium (Haile et al., 2020). Ethiopia also has some potential for Li in brines, in the Danakil Depression; characterisation work has shown that Li contents are elevated, but not to economic levels (Bekele and Schmerold, 2020). Lithium-bearing pegmatites in Nigeria, Uganda, Madagascar and Zambia have also been briefly described but not studied in detail (Von Knorring and Condliffe, 1987; Akoh et al., 2015; Garba, 2003). Bass Metals holds a Li prospect known as Millie's Reward in Madagascar. In Ivory Coast, Ironridge Resources holds licences for Li prospects that have not been described in detail.

Summary of Africa's participation in the lithium supply chain

Several African nations have extensive lithium resources, with many well-characterised hard-rock projects that represent potential lithium mines. However, the ability of some projects to supply material into the battery supply chain may depend upon exactly which ore minerals are present, and how easily they can be processed to produce battery-grade chemicals. Definitive feasibility studies have been completed at projects in Zimbabwe, Namibia, DRC, and Mali with significant progress in other countries including Ghana, and it is anticipated that lithium mining will grow in Africa over the coming years. In almost every case, the proposed plan is to produce a lithium mineral concentrate in-country and then ship that concentrate to a refinery elsewhere in the world. The only exception is the Manono Project (DRC) where primary lithium sulphate will be produced and exported. Thus, the supply chain will leave Africa at the end of Stage 2 or beginning of Stage 3. Most imports into Africa are at the use stage of the supply chain (Stage 5), either as battery cell components or as finished batteries, although a lithium-ion battery industry is beginning to grow, particularly in South Africa. Although Africa lacks formal recycling facilities for lithium-ion batteries (Stage 6), import of electronic waste for informal reuse or recycling takes place in some countries, and regulation tends to be limited (Ilankoon et al., 2018).

The critical missing steps in the supply chain in Africa are the processing stage (Stage 3) which is an essential stage in the battery supply chain, and currently only takes place outside Africa; and the manufacturing stage (Stage 4). Thus, the key stages where value is added do not occur in Africa.

Stage 3 of the supply chain is widely recognised as a bottleneck for global lithium supply chains (Olivetti et al., 2017). The major global producer of lithium from pegmatites is Australia, and until 2020 Australia's lithium was exported as mineral concentrates, such that processing took place elsewhere, largely in China. However, lithium processing plants are now being commissioned in Australia, with the aim of keeping Stage 3 of the supply chain in the country (Tabelin et al., 2021). The ramp-up of lithium processing in Australia has been delayed by the COVID-19 pandemic of 2020-21, which has

affected Li demand, but in the longer-term it is clearly seen as an opportunity by Australian policy-makers (Austrade, 2018).

Opportunities for Africa

Africa's primary contribution to lithium supply chains is likely to come via mining of its extensive resources. As many companies develop lithium exploration and mining projects across Africa, offtake agreements are being signed, chiefly for export of mineral concentrate to China. Global transportation of concentrate potentially represents a missed economic opportunity for the producing country, and is also likely to have significant environmental impacts. However, the relatively small scale of individual pegmatite mines means that no one mine would be able to support a lithium processing plant. If Africa is to engage in Stages 3 and 4 of the lithium supply chain, there will be a need for regional cooperation to ensure that the supply chain is sustainable.

This section highlights some of the main issues that may affect decision-making on involvement in lithium supply chains across Africa.

1. Economic considerations. Whilst global Li demand is expected to grow rapidly as the switch to electric vehicles gathers pace, this is not always matched by prices; in recent years oversupply has led to falls in Li prices that have impacted many parts of the Li industry (Tabelin et al., 2021). Understanding of lithium supply, demand and markets is essential for development of the Li supply chain in Africa.

2. Energy security. Lithium mineral processing is highly energy intensive, and so secure energy supplies are essential for industrial engagement in the lithium supply chain. Many African countries already have energy demand that is greater than available supply, leading to concerns over energy security (Alemzero et al., 2021).

3. Environmental impacts. Life-cycle assessment (LCA) shows that the mineral processing stage (Stage 3) typically has a much more significant environmental impact (in terms of greenhouse gas emissions) than mining and transport of high-grade resources (Jiang et al., 2020). This is largely due to the energy required for the process itself, and the intense use of chemicals. Use of renewable energy, rather than fossil fuels, can have a significant impact on the overall LCA. It is also to be expected that concerns will be raised about more local environmental impacts around mine sites and processing plants. There is limited data available for such environmental impacts around lithium pegmatite mines (Agusdinata et al., 2018; Chaves et al., 2021) and so good environmental assessment will be a critical part of any new developments.

4. Human rights and good governance. Good governance of mining and mineral processing is essential to attract companies to invest in a country, and to ensure that mining supports positive impacts for communities. This is particularly true in conflict-affected and high-risk countries, for which clear guidance is available (OECD, 2016).

5. Skills and human resources. A cadre of well-trained, highly skilled local staff will be essential for a lithium industry to develop in any African country.

Conclusions

As of June 2021, very few African countries have any engagement in supply chains of lithium for batteries. This is despite the fact that several countries across Africa have well-known lithium resources. In the coming years, as global demand for lithium for batteries grows, it is highly likely that some current exploration projects will develop into mines. However, these mines will likely produce mineral concentrates that will then be exported outside Africa for further refining. The major value-adding stages in the supply chain (refining, manufacturing) will occur elsewhere in the world, with finished batteries or consumer products containing batteries then imported back into the African continent. There are significant opportunities for African countries to engage more widely in stages of the lithium supply chain, but these will require regional cooperation and strong environmental, social and governance principles alongside development of infrastructure, people and skills.

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Appendix 1

This appendix provides a more comprehensive summary of the current situation at lithium exploration projects and mines in Africa, as of June 2021, based on publicly available information.

Zimbabwe

Mining has taken place on the **Bikita** pegmatite in SE Zimbabwe since tin was discovered in 1910, and mining of petalite started in the 1940s. Petalite has been the main commodity mined at Bikita since then, but pollucite and tantalite have also been mined in certain zones of the pegmatite. The mining claim is now owned by Bikita Minerals. It includes several pegmatites, with several open pits exploiting a large pegmatite that trends roughly north-north-east and dipping around 30° towards the east. A separate pegmatite to the west has been explored, and is rich in spodumene. A resource of 13 Mt @ >1.6% Li_2O has been identified in this western spodumene pegmatite, and NI 43-101 reporting was in development in 2020. The main product currently exported at Bikita is a graded petalite concentrate which is produced on site at the mine and chiefly sold for glass and ceramics. Tantalite concentrates have also been produced at the mine, with tantalite occurring in lepidolite-rich zones of the pegmatite. It is anticipated that, when mining begins on the western pegmatite, spodumene concentrate will be produced at the mine and exported for Li-carbonate production.

The **Arcadia** project, east of Harare, has been explored by Prospect Resources since 2016. This project has Southern Africa's largest JORC-compliant Li reserve (37.4 Mt @ 1.22% Li_2O). Approximately 28 000 m of exploration drilling was carried out during 2016–2018, underpinning a DFS that was updated in 2019 (Prospect, 2019). The 3D resource model for the project illustrates

a series of parallel, flat-lying stacked pegmatites, which contain petalite and spodumene as the main ore minerals. Extensive metallurgical test work has led to the development of a beneficiation flowsheet, and Prospect Resources is now working to develop Arcadia as a mine. A pilot plant, completed in June 2021, will allow production of petalite concentrate at the mine site. Initial production of low-Fe petalite concentrate (4% Li_2O), to be sold for glass and ceramics, is expected to be followed by production of spodumene concentrate (6% Li_2O) to be sold to the battery chemical market (Prospect, 2019). In 2020, Prospect Resources signed an offtake agreement with Belgium-based Sibelco N.V for their low-Fe petalite concentrate, building on an earlier offtake agreement with Sinomine Ltd. The Arcadia Project is relatively close to existing infrastructure, and petalite concentrate will be trucked for export to the port of Beira in Mozambique.

The **Kamativi** pegmatite, in north-western Zimbabwe, was mined for tin from 1936 to 1994, but lithium minerals were never extracted. The tailings piles at Kamativi have been explored for lithium by Zimbabwe Lithium and the Zimbabwe Mining Development Corporation, who have declared an NI 43–101-compliant indicated resource of 26.32 Mt @ 0.58% Li_2O (Cronwright and Derbyshire, 2018). There is also potential for further exploration in the hard-rock extent of the pegmatite, beyond what has already been mined.

The **Zulu** pegmatite, 80 km from Bulawayo, is under exploration by Premier African Minerals, which completed a scoping study in 2017, publishing a SAMREC-compliant inferred resource estimate of 20.1 Mt @ 1.06% Li_2O. In 2020, Premier African Minerals also acquired a series of smaller lithium pegmatite prospects in eastern Zimbabwe.

Namibia

The most significant lithium pegmatites in Namibia are those at **Karibib**. Lepidico hold an 80% interest in the Karibib Project, which covers a fully permitted mining licence area of 68 km^2 in central Namibia, some 180 km south-east of Windhoek. The Karibib Project is well-serviced by existing infrastructure, including power, water and road networks. The project includes historically important lepidolite deposits hosted in the Rubicon and Helikon pegmatites. In 2020 Lepidico announced a JORC-compliant ore reserve for the Rubicon and Helikon 1 pegmatites of 6.72 Mt @ 0.46% Li_2O, and a broader JORC-compliant global resource estimate of 11.24 Mt @ 0.43% Li_2O for the Rubicon and Helikon (1–5) pegmatites, based on 81 drill holes and more than 5 km of diamond drilling (https://www.lepidico.com/projects/karibib/). An upgraded JORC-compliant global mineral resource estimate from March 2021, of 11.87 Mt @ 0.45% Li_2O, includes the tailings and stockpiles on site. A DFS was completed in May 2020. The predominant ore mineral in the Rubicon and Helicon pegmatites is lepidolite, with lesser amounts of petalite and amblygonite. The company plan to send lepidolite concentrate (c. 4% Li_2O) to Abu Dhabi for processing using their proprietary L-Max and LOH-Max leaching technologies, to produce about 5 000 tonnes of lithium hydroxide per annum, with the potential to produce a range of by-products including Rb and Cs chemicals. Export of 30 000 tonnes of lepidolite concentrate from Karibib was achieved by previous owners Desert Lion Energy in 2018.

Afritin Mining currently own the **Uis** Tin Mine located in the Erongo region of Namibia. The deposit comprises a series of large mineralised pegmatites that were historically mined for tin, and recommenced production of tin concentrate in 2020. In 2021, production is running at approximately 60 tonnes of tin concentrate per month. The company has focussed on re-evaluating the mineral resource contained in the V1 and V2 pegmatites, which form part of a much larger swarm of 16 mineralised pegmatites. In 2019 the company released a JORC-compliant measured, indicated and

inferred resource estimate of 71.54 Mt @ 0.134 % Sn and 0.63 % Li_2O (Afritin, 2019). The lithium at Uis is predominantly hosted by petalite. Work is currently underway to expand the current processing infrastructure to produce by-product petalite concentrate containing 4 % Li_2O. The Uis Project is serviced by a well-established power supply and transport network, and is located less than 300 km from the deep-water port at Walvis Bay. The company is also fully permitted for water abstraction from local boreholes, which is used to run the processing plant.

In southern Namibia, small-scale mining of tantalum takes place in the Orange River pegmatite belt, at the Tantalite Valley Mine, operated by Kazera Global PLC. Active assessment of lithium resources in the licence area is underway. Early-stage exploration has also been carried out on other pegmatites in the belt, by companies including Walkabout Resources and Namibia Critical Metals Inc.

Democratic Republic of Congo (DRC)

The Manono-Kitotolo pegmatites, in the Tanganyika Province of the DRC approximately 600 km north of Lubumbashi, were discovered in 1910. The historic Manono mine was exploited for its tin content from 1919 to 1982, and consists of numerous open pit mines that extend over an area about 800 m wide by 15 km long (Dewaele et al., 2016). The Manono mine project, and a large licence extension in the surrounding area, are now owned by AVZ Minerals Ltd (60%), La Congolese D'Exploitation Miniere SA (25%) and Dathomir Mining Resources SARL (15%). A Definitive Feasibility Study for the Manono Lithium and Tin Project, published in April 2020, reported a JORC-compliant ore reserve comprising 44.6 Mt @ 1.62% Li_2O (proved) and 48.5 Mt @ 1.54% Li_2O (probable). The permitting and approvals process is under way in 2021. The DFS base case expects a 4.5 Mtpa operation producing 700 000 tpa of spodumene concentrate at 6% Li_2O over a 20-year mine life, together with 45 375 tpa of primary lithium sulfate (AVZ, 2020). Tin will also be produced. The products would be transported by road and rail to either Dar es Salaam in Tanzania or Lobito in Angola for export. AVZ have signed offtake agreements with Gangfeng Lithium (late 2020) and Yibin Tianyi Lithium Industry Co (early 2021) for their spodumene concentrate. A Memorandum of Understanding (MoU) was signed in January 2020 with the DRC government for refurbishment of a nearby hydroelectric power station to provide power. The use of renewable energy will significantly reduce the carbon footprint of the mine.

Lithium mineralisation in pegmatites has also been confirmed to exist in extensions to the NE and SW of Manono. Other exploration projects in the area include the Bucknell Li-Sn-Ta project near Manono, the licence for which is owned by Tantalex Resources Corporation in a joint venture with Cominière SA, and the Kitotolo project to the SW of Manono.

Mali

The **Goulamina** lithium project is in southern Mali, 150 km from the capital Bamako. The licence area covers an area of approximately 100 km^2 and was acquired by Mali Lithium Ltd in 2016. Mali Lithium Ltd subsequently adopted a new identity as Firefinch Ltd in November 2020. In June 2021, Firefinch Ltd established a 50:50 joint venture with Ganfeng Lithium to develop the project. Exploration drilling has identified several sub-parallel spodumene-bearing pegmatites at Goulamina (Wilde et al., 2021). A 2018 pre-feasibility study was followed by a Definitive Feasibility Study in October 2020, giving JORC-compliant proven and probable reserves of 52 Mt @ 1.51% Li_2O. The total resource estimate is 108.4 @ 1.45% Li_2O. Metallurgical test work has led to the development of a beneficiation flowsheet that includes crushing and grinding, dense media separation, desliming and froth flotation, which

will be carried out on-site. The company plans to transport spodumene concentrate (6% Li_2O) by road to ports at Abidjan and Dakar, both of which have bulk-loading facilities. The company received its environmental permit in March 2019 and submitted its exploitation permit (mining licence) application during the same month; the company is currently focussed on getting approval to mine from the National Directorate of Geology and Mines.

The **Bougouni** project, also in southern Mali, is held by Kodal Minerals. A Feasibility Study was published in 2020 and includes a JORC-compliant resource estimate of 21.3 Mt @ 1.11% Li_2O. A flowsheet has been developed and, similarly to Goulamina, there is a plan to produce spodumene concentrate (6% Li_2O) on site, then transport it by road to San Pedro Port in Côte d'Ivoire. The mining licence application for Bougouni was submitted in 2020.

Ghana

The **Ewoyaa** project in southern Ghana, around 100 km from Accra, is being actively explored by Ironridge Resources. Drilling at Ewoyaa has defined several individual spodumene pegmatites up to a few tens of metres thick, and a JORC-compliant mineral resource estimate of 14.5 Mt @1.31% Li_2O (Inferred and Indicated). The whole area licenced by Ironridge Resources is >680 km^2. There is also potential interest at the nearby historical mine site of Egyasimanku Hill. A scoping study for the Ewoyaa project, released in January 2021, proposes a contract mining operation, mobile contract crushing facility and fixed conventional DMS (dense media separation) processing facility, capable of treating 2.0 Mt of ore per annum over an initial 8-year mine life. The Ewoyaa deposit benefits from proximity to infrastructure, including a deep-water port (Takoradi) at a distance of around 110 km. The tarmac highway from Accra to Takoradi passes close to the project, as does national power infrastructure. Spodumene concentrate (6% Li_2O) from the mine will be trucked to Takoradi for export.

South Africa

South Africa has lithium pegmatites in the **Orange River** pegmatite belt on the Namibian border, which have been mined on a small scale in the past (Ballouard et al., 2020). Spodumene-bearing pegmatites are also known to occur in the Highbury area of southern **Natal**, where Thomas et al. (1994) report SQI (spodumene-quartz-intergrowth) zones that in places account for 70% of the rock. Despite research interest in the South African pegmatites, active exploration is limited. South Africa this has no lithium extraction (Stage 2) or mineral processing (Stage 3) although a recent report has identified Stage 3 as a key supply chain stage where South Africa could engage (TIPS, 2021).

Rwanda

The **Gatumba–Gitarama** pegmatite field in NW Rwanda, approximately 50 km west of the capital Kigali, contains extensive pegmatites that are largely known for their Sn-Nb-Ta mineralisation, but do also contain Li minerals (Dewaele et al., 2011; Hulsbosch and Muchez, 2020). Until 2014, Gatumba Mining Concessions (a joint venture between the Rwandan Government and a consortium of private companies) exploited mines in this area for tantalum and tin. Most tin and tantalum production in this area is from artisanal and small-scale mines, typically in the upper parts of pegmatites (Schütte and Näher, 2020) where Li minerals are likely to have been broken down by weathering. Exploration for Sn and Ta at the Musha and Ntunga mines, by Piran Resources, has led to the recognition of

high-grade Li intercepts at deeper levels in the pegmatites. It is likely that Rwanda has potential for Li resources that could be recognised with further exploration.

Other countries

Sn-Nb-Ta mineralisation is known from pegmatites in **Burundi**, where lithium minerals are also recorded (Romer and Lehmann, 1995). As in Rwanda, most mining of Sn and Ta is artisanal and small-scale, and there is no Li extraction.

The **Alto Ligonha** pegmatite field in Mozambique contains a substantial number of lithium pegmatites (Von Knorring and Condliffe, 1987) but most mining and exploration has focused on tantalum, beryl and gemstones. The Marropino mine has operated intermittently for Ta, most recently being minded between 2010 and 2012 by Noventa Ltd. The Muiane Ta mine was owned by Pacific Wildcat Resources until 2015, when it was damaged by rioters. As with other countries, Mozambique has potential for Li, but has seen little exploration.

In Ethiopia, the major **Kenticha** pegmatite (>2 km long) and other associated pegmatites show Li-Cs-Ta enrichment (Küster et al., 2009). Kenticha has been mined for Ta since the 1990s by the Ethiopian Mineral Development Share Company, with around 150 tons of tantalite concentrate produced annually (Haile et al., 2020). As in other Ta-mining areas, much of the focus has been on the upper weathered parts of the pegmatite, where columbite-tantalite minerals are relatively enriched, but lithium minerals are likely to have been broken down (Mohammedyasin, 2017). Ethiopia has some potential for Li in brines, in the Danakil Depression; characterisation work has shown that Li contents are elevated, but not to economic levels (Bekele and Schmerold, 2020).

Rare-metal pegmatites with Sn-Ta mineralisation are known in many parts of **Nigeria** (Matheis, 1987) but there has been little detailed investigation. Some Nigerian pegmatites have been recorded as containing Li minerals including spodumene, petalite and lepidolite (Akoh et al., 2015; Garba, 2003)

Lithium-bearing pegmatites in Uganda, Madagascar and Zambia have also been briefly described but not studied in detail (Von Knorring and Condliffe, 1987). Bass Metals holds a Li prospect known as Millie's Reward in Madagascar. In Ivory Coast, Ironridge Resources holds licences for Li prospects at the Touvre project centred on 'Colline de Spodumene'.