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# Country profiles of artisanal and small-scale ECRM mine production and processing dev

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**Summary**

Selected country profiles shall be prepared for those African countries that have an artisanal and small-scale mining sector related to significant ECRM production. To the extent possible, the country profiles shall include reported or estimated artisanal and small-scale production or export data for relevant ECRM, combined with context information that is required to assess the plausibility of these data. Where possible, supply chain information shall be added as well. The profiles shall further provide information on the amenability of relevant national mineral deposit types with regards to artisanal exploitation and processing techniques.

Approval

| Date | By |
|---|---|
| 2023-09-25 21:35:55 | Dr. Daniel OLIVEIRA (LNEG) |
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Horizon Europe Framework Programme (HORIZON)

# D1.4 – Country profiles of artisanal and small-scale ECRM mine production and processing developments

## WP1 – Task 1.3

September 2023

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## Table of Contents

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## List of Figures



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## List of Tables



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# Abbreviations and Acronyms

| Acronym | Description |
|---|---|
| 3Ts | Tin, tantalum and tungsten (mineral concentrates) |
| ASM | Artisanal and small-scale mining |
| BCMM | Bureau du Cadastre Minier de Madagascar |
| CADETAF | Centrale d'achat et de développement de la région minière du Tafilalt et de Figuig (Morocco) |
| CAPAM | Cadre d'Appui de la Promotion de l'Artisanat Minier (Cameroon) |
| Coltan | Informal trade name for columbite group minerals (including tantalite) |
| DRC | Democratic Republic of the Congo |
| ECC | Environmental Clearance Certificate (Namibia) |
| ECRM | Extended critical raw materials |
| INAMI | Instituto Nacional de Minas (Mozambique) |
| iTSCi | ITRI Tin Supply Chain Initiative (original use until ITRI changed its name to the ITA); currently unclear if it is still an acronym or simply a brand name |
| LSM | Large-scale mining |
| OECD | Organization for Economic Cooperation and Development |
| PGM | Platinum group metals |
| REE | Rare earth elements |
| SMDN | Société Minière du Niger (Niger) |
| SODEMI | Société pour le Développement Minier en Côte d’Ivoire (Côte d’Ivoire) |
| SOMIRWA | Société Minière du Rwanda (Rwanda) |
| SOREMI | Société de Recherche et d’Exploitation Minière (Congo Brazzaville) |

| | |
|---|---|
| SSM | Small-scale mining |
| UN | United Nations |
| USGS | United States Geological Survey |
| ZEA | Zone d'Exploitation Artisanale (DRC) |

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# Executive Summary

The present deliverable provides an overview on the ore deposits and production parameters of critical raw materials currently recovered by artisanal and small-scale mining in Africa. A total of 18 countries were identified with active or recent artisanal production of such raw materials. The report demonstrates the importance of artisanal mining for a range of commodities (including but not limited to copper, cobalt, tantalum, niobium, tin, tungsten, and lithium) and serves as an illustration for which countries to engage to potentially increase critical mineral supply from the artisanal mining sector. The report provides geological and economic information that is relevant to consider when planning any engagement at a technical level, for instance regarding mineral exploration, processing, trading or mine investment in the ASM sector. The report may further be a useful technical contribution to discussions regarding developing support projects and driving formalization in the artisanal mining sector.

The report was compiled by the Federal Institute for Geosciences and Natural Resources (BGR) as a desktop study based on public and internal information, supplemented by targeted field research activities for selected countries. The report forms part of AfricaMaVal work package 1 which aims at presenting Africa's supply potential for critical raw materials. The report complements other AfricaMaVal project work on artisanal and small-scale mining in work packages 4 and 7 which provide information regarding environmental, social and governance parameters and recommendations for engaging the African artisanal and small-scale mining sector.

# Keywords

Artisanal and small-scale mining, critical raw materials, economic geology, mineral supply, Africa

# 1 Objective, Authorship and Report Organization

This report was compiled by the German Federal Institute for Geosciences and Natural Resources (BGR) as a contribution to AfricaMaVal's work package 1 on the Extended Critical Raw Materials (ECRM) supply potential, led by Portugal's National Laboratory for Energy and Geology (LNEG). This work package includes a task on developing an inventory of existing ECRM ore processing and refining capacities in Africa. While, for certain commodities, artisanal and small-scale mining (ASM) activities contribute significantly to Africa's ECRM production, there is commonly a lack of easily accessible information regarding the ASM sector. This lack of information often precludes presenting detailed project- or deposit-specific information related to ASM operations. For this reason, it was decided to present ASM-related information at the level of country profiles instead. Each country's chapter follows the same content structure.

The objective of this report is to present information related to the economic geology of ore deposit, mining and mineral processing procedures, as well as production and trade developments related to African ASM production as far as ECRM are concerned. This information is a relevant parameter to consider when discussing investment opportunities in the ASM sector from a technical and economic perspective. The report does not include any information on ASM-related risks, environmental or social impacts, or on governance developments or donor engagement. These other factors are equally important parameters to consider for any ASM-related investment planning, but they are presented in complementary work packages and tasks of the AfricaMaVal project, for instance in the ASM sector profiles developed as part of AfricaMaVal work package 7 (responsible investment opportunities) or in documents related to the work package 4 (ESG improvements for raw material value chains).

The 'ECRM' mineral commodities discussed in the present report are based on the consensus definition applied throughout the AfricaMaVal project. They refer to the mineral commodities on the EU critical raw materials list published in 2020, except for natural rubber and coking coal, and additionally include copper, manganese, nickel and tin. Gold and precious stones, two common ASM commodities, are outside of the scope of this report.

The report is organized in chapters for each country which, at the time of writing, the editors considered as relevant ASM producer countries of ECRM in Africa and where sufficient relevant information were available. The individual country chapters were written by the authors shown in the following table. Citations referring to the content of a given country chapter should reference the author(s) of that country chapter, as part of the overall report volume.

The editors note that the African ECRM ASM producer countries presented in this report were based on information available to the editors at the time of task implementation in early to mid-2023, without claiming that the list of countries is necessarily exhaustive. There may be additional

African countries where, based on geological features, ASM production of ECRM might seem possible, but the editors did not find sufficient relevant information about the associated ore deposits and ASM production or processing characteristics in recent years to confirm this or provide any details. This refers, for example, to Sierra Leone and Somalia where small, somewhat erratic tantalum (coltan) exports may be observed through the years.

| Country | Author(s) |
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| Burundi | Jürgen Vasters |
| Cameroon | Jürgen Vasters |
| Congo (Brazzaville) | Philip Schütte |
| Côte d'Ivoire | Philip Schütte |
| Democratic Republic of the Congo | Philip Schütte |
| Ethiopia | Jürgen Vasters |
| Liberia | Philip Schütte |
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| Morocco | Jürgen Vasters |
| Mozambique | Malte Drobe |
| Namibia | Mary Barton, Zach Kauraisa (Odikwa Geoservices) |
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| Rwanda | Jürgen Vasters |
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| Zambia | Philip Schütte |
| Zimbabwe | Jürgen Vasters |

**Table 1. List of presented countries and associated authors contributing to this study.**

The references used for compiling information on individual countries are cited in a country-specific reference list at the end of each chapter, rather than compiling a single large reference list for the whole report. The authors believe this organization is in the interest of the readers.

In addition, for many countries, import and export data for different mineral commodities were extracted from the United Nations (UN) Comtrade database (United Nations 2023). This general reference is given below this introductory chapter to avoid duplication in the different country chapters. Later on, data from this database is simply referenced as "UN Comtrade database" in the text. Similarly the S&P Global market intelligence platform was accessed to evaluate context information for several countries and is referenced as such in the text (S&P Global 2023). This general reference is included below as well and subsequently not shown as a reference for each individual country chapter.

## 1.1 Bibliography

S&P Global (2023): S&P Capital IQ Metals and Mining Database. https://www.capitaliq.spglobal.com/ (last accessed: 11.9.2023)

United Nations (2023): Comtrade International Trade Statistics Database. https://comtradeplus.un.org/ (last accessed: 11.9.2023)

# 2 Burundi

## 2.1 Background

The Ministère de l'Energie et des Mines is responsible for the development of the mining sector in Burundi. Its main tasks in this regard are defined in Decree No. 100/107 of 17 November 2005. Support to mining, and ASM specifically, falls under the purview of the Direction des Mines et Carrières. The new Mining Code (Code minier du Burundi [Mining Code of Burundi], Loi No. 1/ 21 du 15 Octobre 2013) covers all operations of prospecting, research, and industrial and artisanal mining exploitation, as well as the conversion, use, transport, trade, and closure of mines. "Artisanal exploitation" is defined as any non-permanent operation carried out on the surface and up to 30 meters depth, utilizing tools, methods, and non-industrial mechanical processes to extract and concentrate mineral substances with the aim of marketing them. According to the law, only mining cooperatives formed under the auspices of private and public companies may obtain a license for artisanal mining. Cooperatives can only sell their production at approved comptoirs (World Bank Group 2016).

## 2.2 Overview of the national ASM sector

The ASM sector has three forms of labor organization in Burundi (World Bank Group 2016):

(a) Cooperatives: A cooperative is a formal structure responsible for acquiring and managing a mining site and ensuring the equitable distribution of the proceeds from the mine. Membership of cooperatives is restricted to small groups of individuals which may include the land owner, financiers, mineral buyers and others who create a financial and management structure. In most cases, individuals work for the cooperative on a paid basis without being members of the cooperative. Miners are organized into teams with a leader who collects and records the production on a daily basis. The World Bank Group estimated in 2016 that about 10 % of the ASM sector is organized in cooperatives. Cooperatives can only sell their production at approved comptoirs. In 2014, there were five comptoirs (or traders) licensed for the trade in tin, tantalum and tungsten (3Ts) concentrates. The comptoirs realize the final upgrading of the pre-concentrates from the mining sites, by using for example magnetic separation equipment.

(b) Unstructured operations: In 2015, 45% of ASM has been formal and 55 % informal. The informal operations take two main forms. Some are family organized operations in which the resulting gains are usually retained and managed by the head of the family. The other form is group operations in which the mine site is considered to belong to the group as a whole, and production is shared out between the members of the group each evening in accordance with their established rules.

(c) Small-scale operations: Only one private company, TAMINCO, is involved in the extraction of the 3Ts in the northern region of Burundi (Kabarore-Kayanza and Busoni-Kirundo). This company purchases production from artisanal miners working on the company's concession. These miners are paid by the kilogram of concentrate produced.

Burundi has a wide range of mineral deposits of which tin, tantalum and tungsten ores, along with gold, are its primary mineral exports. Burundi's geological endowment also includes nickel (partly associated with platinum group metals), rare earths (REE), phosphate, vanadium, and construction materials. The majority of mineral extraction is carried out by ASM which is officially structured through cooperatives. Tin, tantalum, tungsten (from the minerals cassiterite, tantalite and wolframite and often referred to as the '3Ts') and gold are the primary minerals mined and exported (World Bank Group 2016).

Artisanal mining is an important rural livelihood for up to 34,000 people. Some 6,000–7,000 men and women are working in mines producing the 3Ts. Of these, around 75% are miners with the other quarter engaged in mineral washing, transporting and other tasks. It is estimated that there are a further 14,000–27,000 artisanal gold miners (World Bank Group 2016). The University of British Columbia (UBC 2014) estimated the total number of artisanal miners in Burundi to about 90,000.

Of the total exported mine production averaged for the period 2018-2020, including the pilot production of rare earth concentrates, gold accounts for the largest proportion (85%) of the minerals mined and exported by value. Coltan holds the second place in export value with about 10 % and tungsten accounts for about 5 % of recorded export value of about US$ 186 million for the considered time span. Tin has only a minor share of about 1% of the commodity exports, Fig. 1. The exported rare earth concentrate comes from a pilot plant that is operated under a large-scale mining license. The share of mineral commodities in the total export earnings of Burundi is about 36 %. The 3T production in Burundi consists of 'mixed' minerals which are produced in the mines. These mixed minerals are only separated at export level. At the export level, in 2018-2020, coltan accounted for approximately 2/3 of the mixed minerals by weight, wolframite accounted for less than 30 % and cassiterite for about 4 %.

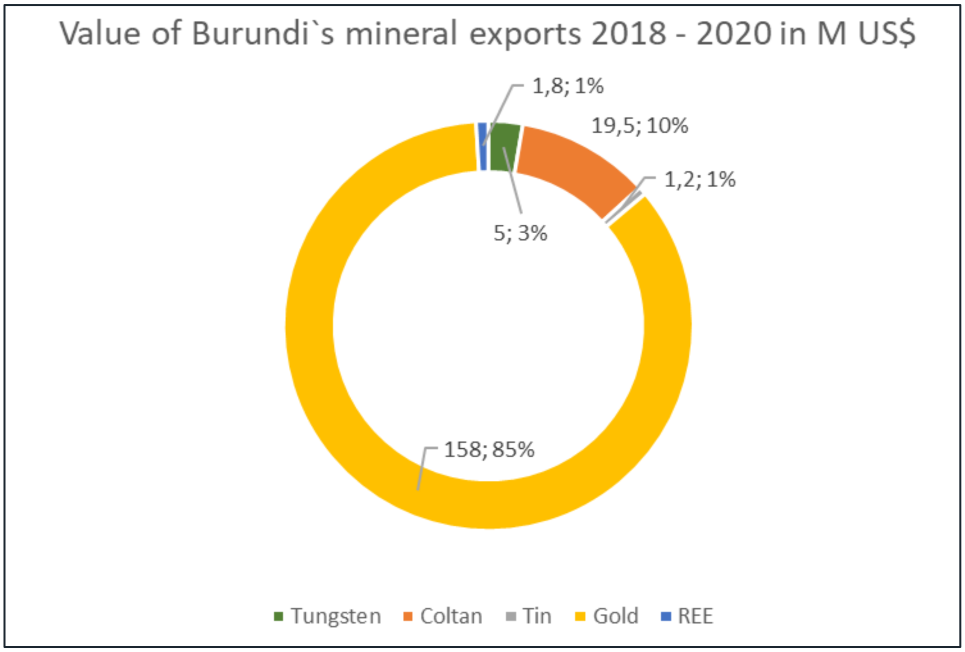


**Figure 1. Share of mineral exports of Burundi, aggregated for the period 2018 – 2020 (UN Comtrade).**

## 2.3 ECRM deposits amenable to ASM exploitation

The Mesoproterozoic Kibaran Belt that is well known for the economic potential for tin, tungsten and tantalum goes through five countries, namely the Democratic Republic of Congo, Burundi, Rwanda, Uganda, and a small part in Tanzania. It is made of two different segments, which are separated by a northwest-trending "Rusizi Ubende belt" basement (Ntirampeba 2020).

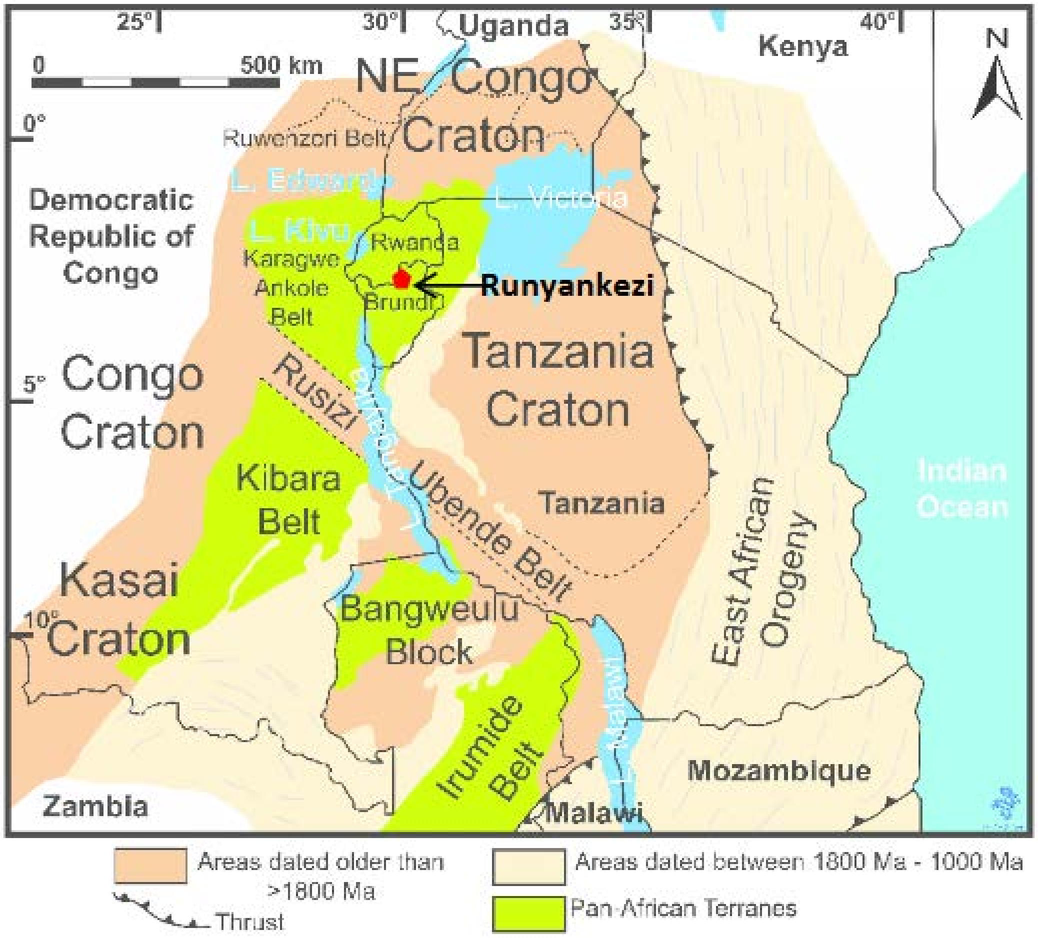


**Figure 2. Geological overview map of the central African tin region, including the Runyankezi tin deposit (Ntirampeba 2020).**

The two parts that are composed of metasedimentary rocks have been intruded by various generations of granitoid massifs and subordinate mafic bodies. The intrusions related to the amalgamation of Rodinia are considered as fertile granites, also called “Tin-Granites”, that have been emplaced around 986 million years and are associated with rare-metal pegmatites and Sn-W mineralized quartz veins (Ntirampeba 2020). The small-scale mining operations can be grouped according to the principal minerals mined in 4 zones. These are in the north-west of Burundi the gold zone around the city of Cibitoke, in the north-central part the coltan-tin zone in the provinces Kayanza and Gitega, the wolframite zone south of lake Rweru and the gold zone in the north-east of Burundi close to the city of Muyinga.

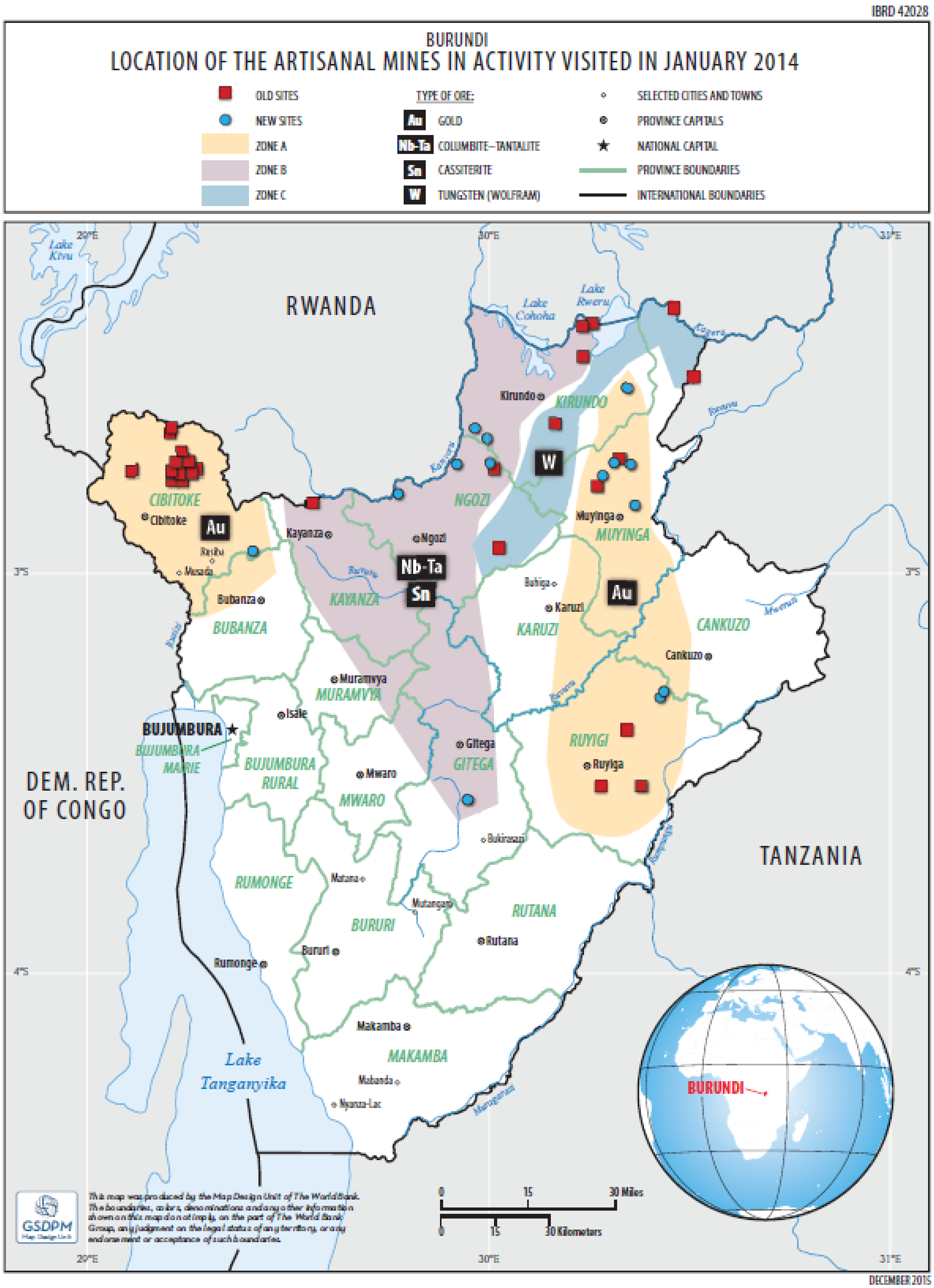


**Figure 3. Location of ASM mining districts in Burundi in 2014 (World Bank Group 2016).**

Mining activities began in Burundi in the 1920s and focused primarily on the extraction of tin, coltan, and alluvial and eluvial gold in northwestern Burundi. One of the many centers of mining activity was at Muhokore and Mulehe for cassiterite ores. From the 1940s and 1950s, the establishment of small-scale mining in the Kirundo regions took place. The first documents from the Mulehe mine date back to 1948, when the Corem Company began the exploitation of eluvial cassiterite. During this early phase, primary mineral extraction was also undertaken, and the company also owned the Nemba mine in Rwanda. It was located immediately north of Mulehe in Kirundo Province. From the late 1960s until 1978, the Belgian company Sobumines, which had taken over the Mulehe concession, mainly exploited the vein mineralization and undertook extensive underground mining for this purpose.

Wolframite has been mined at Nyabisaka since the 1950s. There are several small-scale mining operations here, in which primary ore has been excavated from vein outcrops and secondary ore from slope debris. Documents from the 1950s indicate the existence of a small washing plant near the Nibenga River. The ore from the Nyabisaka was pre-concentrated by manual sorting and dry sieving and then processed into final concentrate at the Mulehe mine.

Alongside these mechanized operations, artisanal cassiterite was also mined in many small, mineralized occurrences in northern Burundi; these activities were concentrated in the mountainous region of northwestern Burundi, which produced about 80% of the total gold and 60% of the total tin production at that time, mainly from alluvial deposits (Ntirampeba 2020).

## 2.4 Artisanal ECRM mining and processing

Mining is usually realized manually by using hammer, chisel and pick in underground mines and open pits. Open pit dimensions, for example can have a size up to 300 m x 300 m and a depth of 20 m (e.g., Kivuvu open pit) that is currently mined by artisanal miners for 3Ts; the 3T underground mine at Murehe is accessed at the outcropping Nicaise vein by an inclined shaft of 100 m length, (the cross-section is 4.5 m width by 2.5 m height) and at the Maria vein by a vertical shaft of 24 m depth (Nukurunziza 2013). These dimensions can be considered as typical for the ASM sector of 3Ts in Burundi. The ventilation method employed is usually natural ventilation. In some occasions the stopes are ventilated by small blowing fans. Support is only used occasionally when an immediate risk of rock fall exists.

The run of mine ore is crushed and washed to remove the less dense minerals. In some cases ground sluicing is also used to liberate and concentrate minerals of value. The heavy mineral sand from the ground sluice is further upgraded to a pre-concentrate by panning. The pre-concentrates are collected and sold to the comptoirs where further magnetic separation or other processing of the minerals is carried out to achieve saleable qualities of wolframite, cassiterite and coltan concentrates that are exported.

## 2.5 Production and trade patterns

The following subchapter evaluates Burundi's cumulative historical mineral production, starting from old data and then looking at the more recent data. According to the Ministry of Public Works, Energy and Mines (Ntirampeba 2020), the total accumulated production of Burundi until 1984 was: 3,000 t of cassiterite, 150 t of Wolframite, 56 t Colombo-tantalite, and 6 t of gold, as shown in the following table.

| Nature of the ore | Period | Cumulative production in kg | Average per year in kg |
|---|---|---|---|
| Gold | 1933-1961<br>1962-1965<br>1966-1979 | 5,324<br>0.5<br>66.4 | 183.6<br>0.125<br>4.7 |
| Cassiterite | 1934-1961<br>1962-1965<br>1966-1979 | 2,465.700<br>106,000<br>985,000 | 88,060<br>26,500<br>75,770 |
| Columbite-tantalite | 1935-1961<br>1962-1975<br><br>1976-1979 | 82,500<br>Statistics not available<br>11,700 | 3,056<br>Statistics not available<br>2,930 |
| Tungsten | 1974-1977 | 8,430 | 2,108 |

**Table 2. ASM production of mineral commodities in Burundi from 1933 to 1979 according to the statistics of the Ministry of Public Works, Energy and Mines (Ntirampeba 2020).**

After the withdrawal of Belgian mining companies, the organized artisanal mining activity stopped to give way to the uncontrolled exploitation carried out by artisanal miners, without technical supervision and inadequate mining equipment. After 1979, the Government of Burundi decided to stop the artisanal mining activity for a geological exploration campaign. This campaign started in the early 1980s with German cooperation. The artisanal mining activity resumed during the year 1988 with the establishment of the company COMEBU (Ntirampeba 2020). The following figure shows the evolution of estimated artisanal mining production or exports for the 3T minerals from 1988 to 2020.

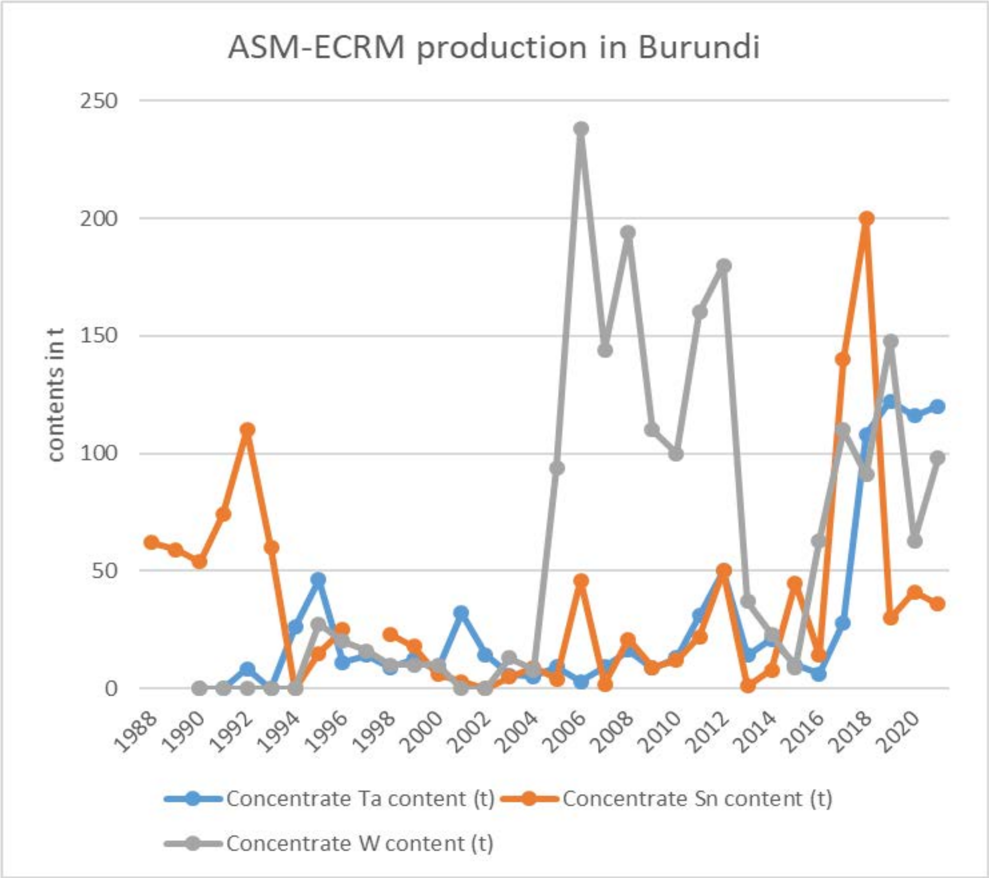


**Figure 4. Evolution of the estimated ASM ECRM production (or exports) in Burundi according to the Burundian Office of Mines and Quarries (1988 – 1990), USGS (1991 – 2018), UN Comtrade (2019 – 2021).**

When combining the historical statistical data set and the recent data covering together a period of 85 years the total mining production in Burundi of ECRM by ASM can be estimated to about 3100 t of tin content, about 1000 t of tantalum content and 2000t of tungsten content. Considering the production statistics for the recent period 2016 - 2021, it could perhaps be concluded that the tantalum production is rising, tungsten is stable but tin is declining. However, the validity of the statistics is limited since in the past there has been some smuggling of coltan and other minerals to Rwanda, at least until the 'iTSCi' (formerly the ITRI Tin Supply Chain Initiative, current acronym somewhat unclear) scheme became active there, creating an official international sales channel for 3T minerals. It is also possible that Congolese 3Ts were smuggled into Burundi.

## 2.6 Potential future ASM ECRM production opportunities

The facts that Burundi, with a surface area of 27,834 km$^2$, is a relatively small African country, its economic geology is well known and explored and, despite the high price level for 3T minerals, the mine production of 3Ts in Burundi has remained relatively stagnant, might indicate that the

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Burundian ASM sector can only play a subordinate role for the supply of 3T ores to Europe. On the other hand, European companies obtain currently critical raw materials like tungsten from Burundi, even though the tonnages are not large. The 3Ts hosting pegmatites in general are well known to contain lithium-rich minerals. This potential for Burundi has not yet been investigated and evaluated in detail.

Caused by the mature degree of the ASM sector in Burundi, it can be expected that the framework conditions of mining are worsening in the course of the time (e.g., higher waste to ore ratios in open pits and deeper underground mines) and that, in the future, the production of 3Ts in Burundi will decline, if there is no investment in a technological upscaling of the ASM sector.

Considering the long historical production of 3Ts it seems possible that there is a huge potential for the reprocessing of washing tailings and the processing of mine wastes. The historic Kivuvu mine that is currently mined by artisanal miners contains about 4 Mt of mine waste (Nkurunziza 2013).

A feasibility study contracted by BGR in 1986 for the investigation of the cassiterite deposits Mulehe and Nyamugali in Burundi reported for the waste dumps of Mulehe a volume of about 70,000 t @ 0.1 % $SnO_2$ (BGR 1986). Because of the collapse of the international tin price cartel in 1985 and the corresponding decline of the tin price, the processing of the mine waste was not feasible at that time. With the current price level of tin, the economic outcome of the project would probably be more positive.

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# 3 Cameroon

## 3.1 Background

The present Mining Code in Cameroon dates from 2016 and introduced definitions for categories of mining permits, from small to large, artisanal mining and semi-mechanized artisanal mining authorizations, small mine and industrial mine extraction permits. At the same time, terms allowing foreign partnerships in artisanal and small-scale mining were introduced: foreign partners can have up to 49% ownership of semi-mechanized artisanal mining operations, and the permitted plot size is up to 21 hectares. In 2003, in a bid to provide tools for artisanal miners to institutionalize the formalization process while taxing and regulating production, Cameroon created the Small-Scale Miners Promotion Unit, known by its French acronym Cadre d'Appui de la Promotion de l'Artisanat Minier (CAPAM). The support provided by CAPAM includes technical supervision of operators, provision of production equipment, training sessions, and channeling production into formal pathways. Within the management scheme of CAPAM, Common Initiative Groups for Artisanal Miners were created. CAPAM organizes independent miners into groups of fifty individuals to help them transition to a more industrialized production model and provide them with access to formal market channels and funding. The CAPAM supervised the collection of the total mining tax from artisanal semi-mechanized mining of precious and semi-precious substances. This mining tax is 25% of each site's gross production. It includes the share of the State (17.8%) in production, the Ad Valorem Tax on precious and semi-precious substances (5%) and the monthly instalment of corporate tax (2.2 %). The companies keep 75% of the production, the distribution of the share of the State and the Ad valorem tax will be described within the framework of the decree of application during preparation.

## 3.2 Overview of the national ASM sector

The production of mineral commodities represents only a minor part of the economy of Cameroon (International Monetary Fund 2020). The only metals that are currently produced in Cameroon are aluminum and gold. The latter metal is produced principally in the ASM sector. For the production of aluminum exists a primary smelter with an annual capacity of about 100,000 t of aluminum (USGS 2019). In Cameroon there are major exploration projects with regard to bauxite, iron ore, nickel and cobalt, and rutile in the project pipeline.

In Cameroon, ASM has existed at least since the first half of the 20$^{th}$ Century. Most artisanal miners are currently engaged in the extraction of gold but there are also significant numbers of people exploiting alluvial diamonds and other gemstones. Alluvial gold extraction in Southeast Cameroon began in 1934. The diamond mining carried out by artisanal miners in this part of the country began in Mobilong in the 1930s (Weng 2022). An estimated 79% of the 44,000 small-scale miners estimated to be working in Cameroon in 2014 were engaged in the extraction of gold (Weng 2022). The trade value of the gold exports from Cameroon in 2021 was about US$ 312 million; this corresponds to a calculated production of 6.4 t of gold. A relatively new trend is that Chinese companies import machinery for use at mines and share gold production with the artisanal miners from whom they lease permits (Weng 2022). In the past, the only ECRM commodities in Cameroon mined by ASM were rutile, tin and tantalite. Under the supervision of CAPAM, artisanal miners were able to produce approximately 0.5 t of rutile from 2011 to 2016 in the central region of Cameroon; a continuous exploitation of tin was observed in the locality of Mayo-Darlé.

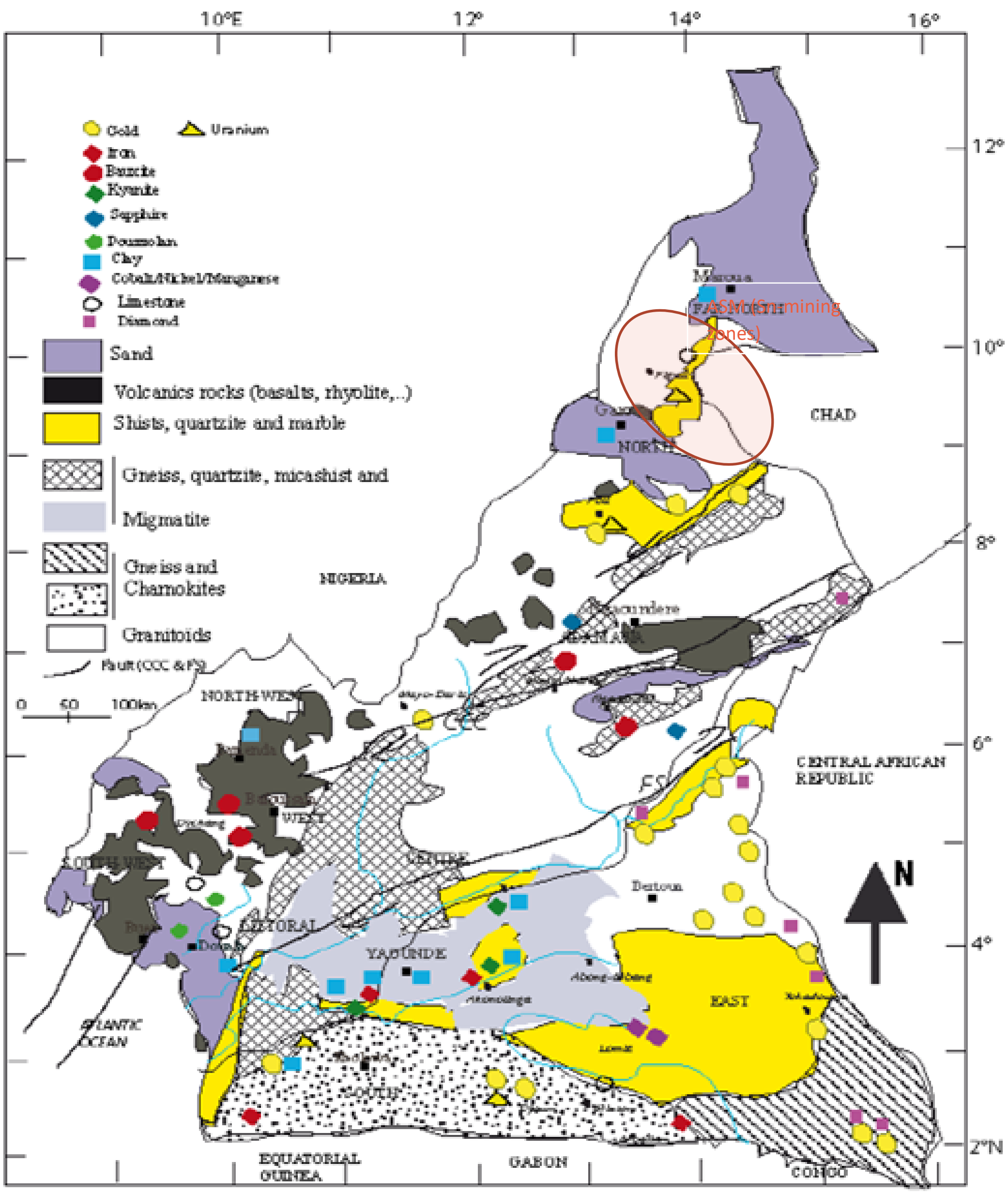


**Figure 5. Mineral deposit map of Cameroon (Lemougna 2023).**

## 3.3 ECRM deposits amenable to ASM exploitation

Rutile was mined by ASM in Cameroon between 1935 and 1957 when a total of 15,000 tons of rutile were extracted from alluvial deposits. Rutile has been known to occur in Cameroon since 1908 and was very actively exploited in the area around Yaounde (Agyingi 2020). Besides the Yaounde area, some trade in rutile was also reported in Tali close to Mamfe during the Second World War. All deposits in these areas are alluvial and mining has been artisanal. In that time period, Cameroon ranked third in global rutile production after Australia and the United States of America. With the recently renewed interest in the rutile mining sector in the country, there is active exploration and research in the area around Yaounde with the goal of discovering new deposits that could warrant industrial mining (Lemougna 2023).

The French Bureau de Recherches Géologiques et Minières conducted a drilling program in Cameroon in the 1980s which identified 2.6 million tons of rutile in discontinuous occurrences, with concentrations of about 1% rutile. Most of the occurrences are located in small- to medium-sized riverbeds with a thickness of 1.5 - 4.5 m. In 2019 the French company Eramet secured an exploration license in Akonolinga. This rutile mineral sands exploration and development project is focused on a rutile block, situated about 135 km east of Cameroon's capital city of Yaoundé. The Akonolinga area is home to an estimated potential 500,000 t of rutile, out of about three million tons countrywide – the second largest rutile resource globally after Sierra Leone. There are more other rutiliferous areas in Cameroon in East, South and Littoral regions.

Columbo-tantalite (coltan) and cassiterite occurrences have been historically identified in Mayo Darle ́ (Adamawa Region, North Cameroon) and Garga-Sarali (East Cameroon; Bidzang 2021). In the Mayo-Darlé deposit, the alluvium and eluvium were the subject of ancient artisanal mining with 6,500 tons of cassiterite extracted from 1933 to 1968. The mining engineers and geologists of the time (1940s - 1950s) described this deposit as very rich, and its primary deposit source remains to be defined (Lemougna 2023).

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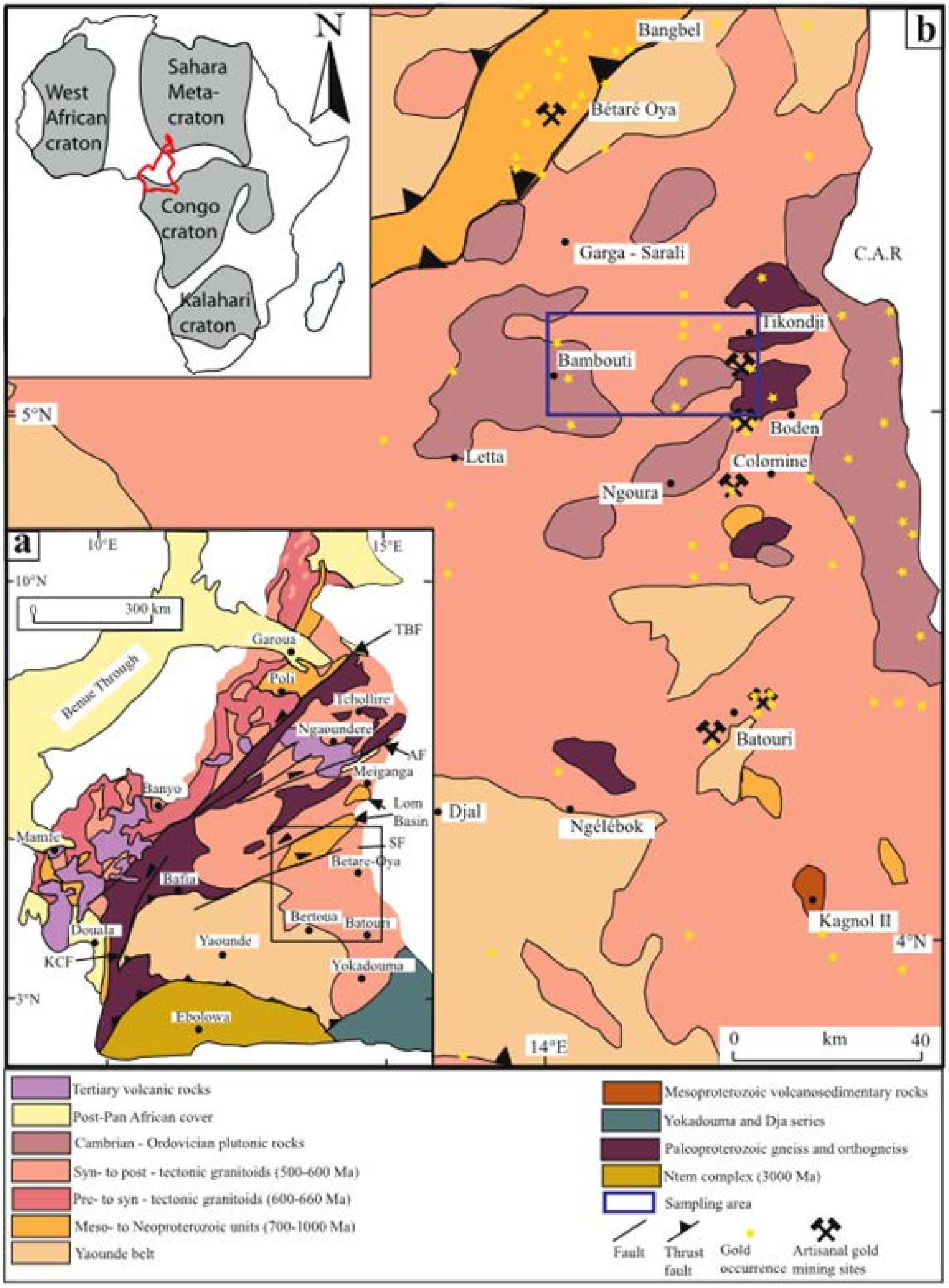


**Figure 6. Geological map of Cameroon and inset of regional geological map of southeastern Cameroon, showing artisanal gold mining sites; the blue rectangles show the study area of Ta-Nb minerals (Bidzang 2021).**

## 3.4 Artisanal ECRM mining and processing

Information about current tin and tantalum mining and processing are unknown to the author. However, it can be supposed that simple, manual mining methods and hand panning are employed.

## 3.5 Production and trade patterns

There are no recent records of tin, tantalum and rutile production in Cameroon. However, there is anecdotal evidence that tantalum concentrate is produced and exported or informally traded, perhaps under false declaration, to Nigeria, where a vivid mining and processing sector, including for tin and tantalum, exists. The relatively high value of rutile suggests that there is a current ASM production of rutile and that small batches of rutile are also exported. In the business directory of Douala there are several trading companies listed that claim to trade in rutile sand and coltan.

## 3.6 Potential future ASM ECRM production opportunities

In the case that the Eramet rutile project in Akonolinga will not be developed, it can be evaluated if high-grade rutile pockets in the explored area can possibly be mined by ASM. It is not probable that tin and tantalum can play a major role in the supply of European clients since major placer or hard rock deposits are unknown until now in Cameroon. However, with the advent of mechanized gold mining equipment for placer gold mining, it could be examined whether tin and tantalum could be produced as by-product of the gold extraction in the occasion that gold placer deposits contain also tin and tantalum. The possibility that heavy mineral pre-concentrate of the gravitational gold plant contains besides of gold also contains additional value elements has to be evaluated for each individual case.

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# 4 Republic of Congo (Brazzaville)

## 4.1 Background

While Congo Brazzaville is known for its petroleum industry, it seeks to diversify its economy from oil, including through growth of the national mining sector. The country's mining code of 2005 allows for the national mining authority to issue artisanal exploitation permits to Congolese citizens. Membership in cooperatives is not a pre-requisite to obtain a permit. Furthermore, the country has a law, published in 2010, targeting artisanal activities in general, including but not limited to mining. In practice, illegal or controversial activities are prominent in the Congolese ASM sector. This refers to both gold mining – for example in Sangha department in the north of the country, where ASM activities overseen by Chinese-owned companies create significant environmental problems – and copper-lead-zinc mining in southwestern Congo, where artisanal miners illegally entered the premises of the formal mining title holder at Mfouati. In January 2023, the escalating situation at Mfouati led the government to enforce a suspension of all illegal artisanal mining and trading activities in the copper-lead-zinc sector, although emphasizing that formally licensed artisanal activities would be encouraged.

## 4.2 Overview of the national ASM sector

Congo Brazzaville's ASM sector focuses mostly on gold and diamond production. According to the national action plan on artisanal gold mining elaborated in conformance with the Minamata Convention, the country hosts more than 5,000 (alternative sources mention 10,000) artisanal gold miners, active on at least 221 sites. ASM activities in the ECRM sector refer to coltan (tantalum-niobium) as well as copper-lead-zinc production. Coltan production takes place at alluvial deposits in the Mayoko region (Niari department), in the southwestern part of the country, close to the border with Gabon (Figure 7). Economically probably more important, albeit illegal, is the country's artisanal copper-lead-zinc production which focuses on the Bouenza department, between Boko-Songho and Mindouli. This area is located about halfway between Brazzaville and Pointe-Noire on the coast.

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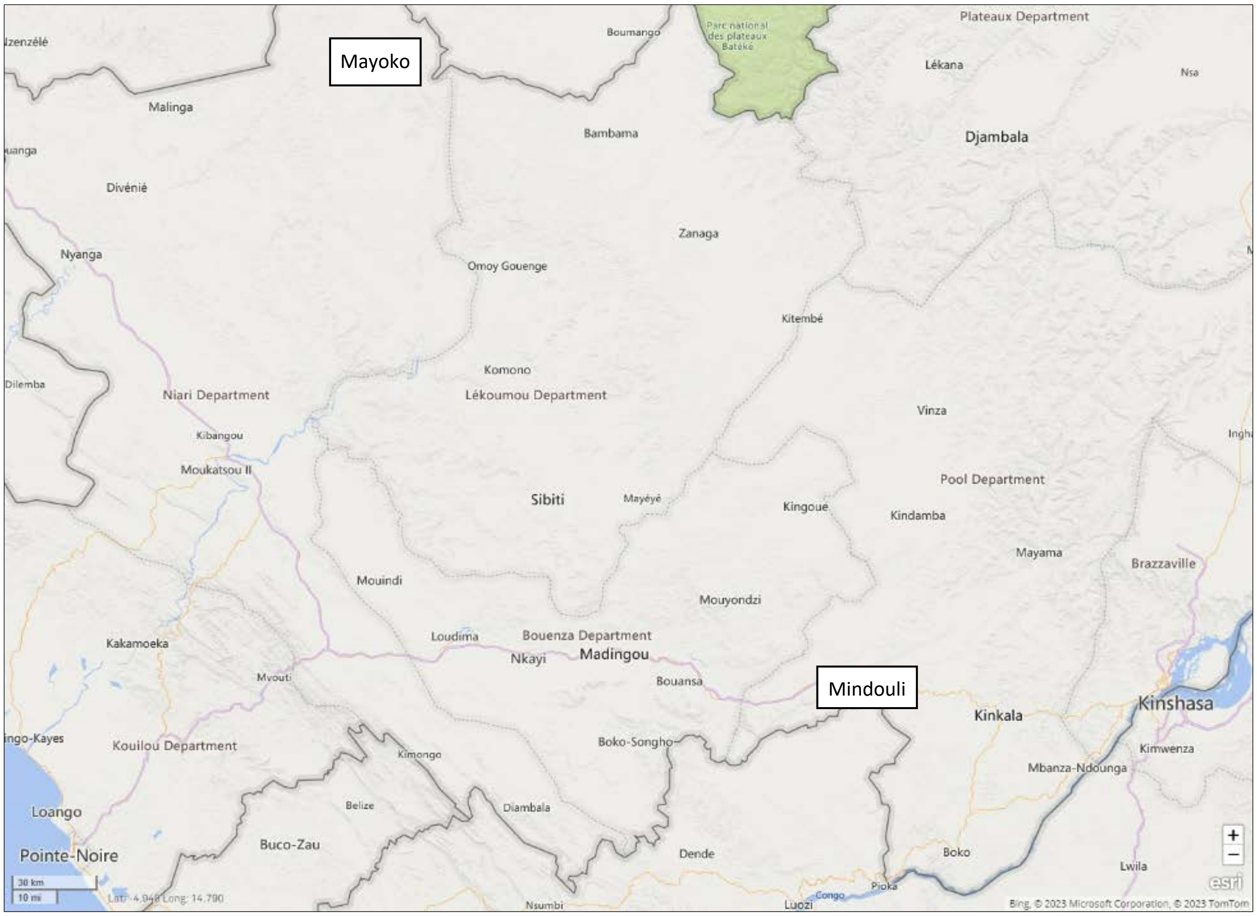


**Figure 7. Map of the southwestern part of Congo-Brazzaville, the country's center for ECRM-related ASM activities. Map data is based on Bing as presented by S&P Global (2023).**

## 4.3 ECRM deposits amenable to ASM exploitation

The Mayoko deposit hosts coltan as well as gold in alluvial gravel layers in active streambeds, mainly consisting of quartz pebbles. The streams in the Mayoko area cut into a meta-volcanic belt which comprises basaltic rocks, iron stone, schists and meta-sedimentary rocks; the belt is hosted by deeply weathered granitoid basement, the Chaillu Massif. The hard, cherty ironstone forms ledges in the streambeds where alluvium, including coltan, tends to accumulate (Girard 2013). The alluvial coltan mostly consists of tantalite(-columbite) with minor microlite (-pyrochlore). The tantalum content of coltan grains, analyzed by portable X-ray fluorescence, shows a bimodal distribution pattern peaking at Ta/(Ta+Nb) ratios of 0.35 and 0.55. The primary source of the alluvial coltan mineralization has not been identified yet. It is possibly related to local pegmatites, as Girard (2013) identified several pegmatite outcrops in the area, but he could not verify whether these were mineralized.

Based on field observations and sampling activities conducted via hand panning, Girard (2013) provides a conceptual estimate on the size of the Mayoko coltan deposit but emphasizes that this does not correspond to a formal resource estimate. Accordingly, mineralized gravel layers vary in thickness from 0.5-1 meters. Typical streambeds are 10 meters wide, and the various branches have a minimal length of 1 kilometer each. Girard (2013) estimates 5-10 m³ of gravel per meter of stream and, based on the stream density in the rea, infers a total ore volume of 100,000-200,000 m³ over an area of 20 km². Considering the coltan concentrations of panned down concentrate, the gravel beds yield approximately 2 kg coltan per m³. As a rough, conservative estimate, Girard (2013) notes the area may contain >100 tons of coltan.

Base metal mineralization in the Bouenza area, comprising copper, lead and zinc in variable proportions as well as accessory silver and other metals (sometimes including cobalt), is hosted by different deposits located in the Niari basin. These deposits include, from west to east, Boko-Songo, Djenguilé, Hapilo, Mfouati, Yanga-Koubenza, M'Passa, Nzala-Diangala, Nzala Minbodi, Tchikoumba, Moubiri, and Mindouli. Some deposits (Hapilo, Mfouati, Nzala-Dinagala) are poor in copper while others (Nzala Minbodi, Mindouli) are poor in lead-zinc. Ore grades vary considerably, with typical historical copper grades of 2-4%. The silver grade at Mindouli is around 100 g/t while Djenguilé ore shows 0.2-0.6% cobalt. In massive ore zones, lead and zinc grades are in the range of 10-30% each (Meloux et al. 1983).

Several deposits occur near the faulted contact between Neoproterozoic limestone and younger pink sandstone. The area was subject to karst development as well as dolomitization and silicification, followed by a hydrothermal mineralization event which formed the ore deposits. The associated hydrothermal fluids precipitated massive lenses of Fe-Cu-Pb-Zn sulfides (e.g., chalcopyrite, chalcocite, galena, sphalerite) as well as sulfide-cemented breccias (De Putter & Nikis 2016). Several deposits show variably strong supergene overprint of primary sulfide mineralization, leading to the formation of secondary ore minerals; the latter comprise both silicates (e.g., dioptase) and carbonates (e.g., malachite, chrysocolla). Ore body size at the different deposits varies and typically contains a few 100,000 tons of ore. Smaller deposits show tonnages of several 10,000 tons of ore; Mindouli, as a large deposit, hosts different ore zones with a total tonnage of 1.6 million tons. Fracture-hosted massive ore clusters are several meters in lateral dimension. A high-grade cluster at M'Passa is described as 0.2-0.8 m thick and up to few hundred meters long while an ore zone at Djenguilé has a dimension of 90 m x 95 m and a thickness varying from 6-44 m (Meloux et al. 1983). In the past, these deposits have been exploited by small-, medium- and sometimes large-scale industrial operations but their high ore grades make them amenable to ASM activities as well.

Even though the author did not identify any descriptions of present-day artisanal tin mining activities, it should be noted that Congo Brazzaville hosts few cassiterite deposits with small historic production and generally amenable to ASM extraction. These are alluvial cassiterite deposits with associated minor wolframite, in the areas of Mayombé and Bississi (Meloux et al. 1983).

## 4.4 Artisanal ECRM mining and processing

The area of Mayoko shows alluvial gold and coltan occurring in the streambed of active creeks. Meloux et al. (1983) note that coltan was extracted from auriferous alluvial gravels from 1945-1955, with a cumulative production of 22 tons. The area hosts a small-scale historic gold production site. Gold was discovered in 1956 and a small gold mine was in production from 1963 to 1966. Following the departure of the gold mining company, artisanal miners have operated in the area and, at least until 2011, focused on gold while often discarding coltan along with other heavy minerals concentrated during panning (Girard 2013). However, we cannot discard the fact that small amounts of coltan concentrate might have been recovered. Tantalex Resources acquired the license covering the area in 2011, signed a coltan offtake agreement with a tantalum refiner, contracted the then Better Sourcing Program (now called 'Better Mining') to perform supply chain due diligence services, and might have had plans for (semi-) mechanized coltan mining and/or processing operations. In 2016, the company apparently lost interest in the Mayoko project (Tantalex Resources Corporation 2016). Hence, any ASM activities and possible coltan concentrate production in the Mayoko area are probably based on manual panning methods.

The historical Cu-Zn-Pb mining operations and the polymetallic deposits in Bouenza department are currently covered by an active industrial mining license held by SOREMI (Société de Recherche et d'Exploitation Minière), a Chinese majority-owned company (with a 10% share held by the government and 30% by a US company). SOREMI installed a copper, zinc and lead processing plant at Mfouati that started operating in late 2016. The plant produces copper cathodes and has an annual processing capacity of 20,000 tons of copper and 28,000 tons of zinc (Ambassade du Congo 2019). Since 2019, artisanal miners, comprising both citizens of Congo Brazzaville as well as migrants from the DR Congo and West Africa, have illegally entered SOREMI's concession. These artisanal miners might directly engage in mining in certain permit areas while they also steal ore from the stockpiles of SOREMI. Descriptions of these ASM activities appear somewhat speculative, though, and further details on the employed ASM techniques are not provided. The situation escalated in early 2023 when artisanal miners started looting company premises and attacking on-site security personnel, prompting the company to ask the government to intervene (ADIAC 2023). The mined or stolen material is sold to a local trader. It is unclear whether these artisanal (illegally produced) ores or concentrates are subject to any further in-country processing. Historical artisanal copper mine workings, dating back to the 13-14$^{th}$ century, comprised open trenches, pits or galleries, with associated smelting activities in the vicinity of the deposits (Nikis & De Putter 2016).

## 4.5 Production and trade patterns

At Mayoko, the initial permit holder, Société Avoine, apparently left a coltan concentrate stockpile of about 20 tons when abandoning the project in 1966. Tantalex Resources, the permit holder from 2011 onwards, expected significant production of coltan concentrate, as indicated by an offtake agreement with a tantalum refiner foreseeing the delivery of 24-98 tons of contained tantalum pentoxide per year (the wording in Tantalex' documents is slightly ambiguous; if this really referred to contained tantalum pentoxide, rather than concentrate, this would correspond to an annual coltan concentrate tonnage of perhaps 60-400 tons, depending on the concentrate grade). However, the company only shipped about 3 tons of contained tantalum pentoxide (or concentrate?) in 2015. This, together with the above-mentioned conceptual estimate of the deposit's potential resources, might indicate a rather low tantalum (-niobium) production potential, but more exploration efforts would be required to evaluate this.

The rather low coltan production capacity of Congo Brazzaville stands in stark contrast to the declared international imports of coltan concentrate (trade category 261590, that is, tantalum, niobium and vanadium ores and concentrates) identifying Congo Brazzaville as the origin. Significant coltan concentrate tonnages from Congo Brazzaville, on the order of 100-1000 tons per year (which is a significant amount for the small tantalum market), have been regularly reported as imports by Thailand from 2014-2022. It is almost certain that these imports have been erroneously labeled as originating from Congo Brazzaville while they in fact, originate from the DR Congo instead (Schütte 2019). The same challenge applies to the declared imports of tin ores and concentrates from Congo Brazzaville. Other tantalum refining countries, such as China or the United States report minor coltan imports from Congo Brazzaville, on the order of <10 up to 60 tons of concentrate in some years. While it is still possible that some of these imports have originated in the DR Congo as well (again reflecting labelling inaccuracies), these lower tonnages appear generally reconcilable with the minor coltan production capacities of Congo Brazzaville.

In modern times, the mining and processing of copper, lead and zinc ores in Congo Brazzaville started in 1900, moving to new deposits once the attractive ore zones in each mine had been depleted. The ASM production capacity for copper (-zinc-lead), related to illegal operations on SOREMI's concession within the historical mining area is unclear. During a visit by a government delegation to the area in early 2023, an estimated 100 tons (or more) of allegedly stolen or illegally mined ore, stored in bags, were observed (ADIAC 2023). It may further be noted that the Niari basin in present-day Congo Brazzaville was a center for ancient copper extraction and smelting activities that started in the 13-14$^{th}$ century (Nikis & De Putter 2016). Through long-distance trading networks, production from the region supplied different African kingdoms with copper. This attests to the area's potential for copper extraction by ASM methods.

Congo Brazzaville's total exports of copper ores and concentrates, inferred from imports declared by trading partners (mainly China), reached 15,000 tons in 2022, up from earlier years when annual exports were below 4000 tons. Since SOREMI produces and exports copper cathodes, these ores and concentrates might be partly related to ASM activities, or reflect production by the country's other copper producer, Lulu de Mines. It is noteworthy that major imports of copper metal from Congo Brazzaville are declared by a range of countries, including the United Arab Emirates, Italy, Vietnam, Greece and others. Cumulatively, these countries declare annual copper metal imports at a scale of 400,000 tons per year, worth US$1.5-3 billion. This is surprising since the country's largest – and only – copper refining facility, SOREMI's Mfouati plant, has a nameplate capacity of 20,000 tons of copper per year (Ambassade du Congo 2019). Speculatively, a significant share of the copper imports declared to originate from Congo Brazzaville might originate from the DR Congo, due to the same reporting inaccuracies noted for coltan concentrate.

## 4.6 Potential future ASM ECRM production opportunities

When confronted with the escalating conflict at Mfouati in early 2023, the government noted that artisanal miners were not authorized to work on SOREMI's permit but explicitly stressed that local youths should have the opportunity to work legally as artisanal miners. The minister tasked the governmental departments in charge of mining and geology to verify whether there are any prospective areas for copper-zinc-lead ores available to be potentially claimed by ASM stakeholders in the departments of Pool, Bouenza, Niari or Leoumou (Nganga 2023). This underlines the common challenge and general need for identifying suitable ASM zones as observed in other countries. Related exploration activities and other forms of support to ASM zone development might thus present a potential entry point to strengthen the artisanal supply potential of copper (-zinc-lead) from Congo Brazzaville.

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# 5 Côte d'Ivoire

## 5.1 Background

Illegal artisanal gold and diamond mining characterized the period of conflict and civil war in Côte d'Ivoire until 2011. Since then, the government established a new mining law (in 2014) and has undertaken certain measures to start formalizing the ASM sector. The mining law is reported to favor industrial mining, although it does provide permit types for artisanal and semi-industrial mining, requiring such activities to be conducted by Ivorian citizens or by companies with Ivorian majority owners. There is further some form of cooperation between a parastatal mining company (SODEMI, Société pour le Développement Minier en Côte d'Ivoire) and ASM groups in the diamond sector. Significant parts of the national artisanal gold mining and trading sector remain informal though, with frequent smuggling links to Burkina Faso and Mali (PAC 2017). Compared to gold and diamonds, ASM activities related to coltan, the only ECRM of note in Côte d'Ivoire, are of minor importance at best, without any major controversies reported.

## 5.2 Overview of the national ASM sector

Côte d'Ivoire has a prominent artisanal gold sector, comprising more than half a million miners, including many migrants from neighboring countries, Mali and Burkina Faso. In recent years, these miners annually produced an estimated 17 tons of gold, making the country one of the larger artisanal gold producers in Africa (UNEP 2023). Artisanal gold mining takes place in 24 out of 31 regions of the country (IMPACT 2017). From 2014-2016, the government implemented a program to map and improve control in the gold sector, identifying 429 gold mining sites in total. The ASM sector further includes diamond mining activities, especially in the Bobi-Séguéla and Tortiya areas. Since the lifting of an export ban related to UN sanctions in 2014, Côte d'Ivoire has been able to officially export diamonds under the Kimberley Process.

As far as ECRM are concerned, tantalum-niobium (coltan) is the only commodity found to be associated with the Ivorian ASM sector, even though exports in recent years have been low (see subchapter on production and trade). The historic center of coltan mining in the country focuses on Issia (Figure 8) where the parastatal SODEMI used to be active as well. Export development suggests that some ASM operations may be targeting tin as well, though the author could not identify any actual descriptions of this activity.

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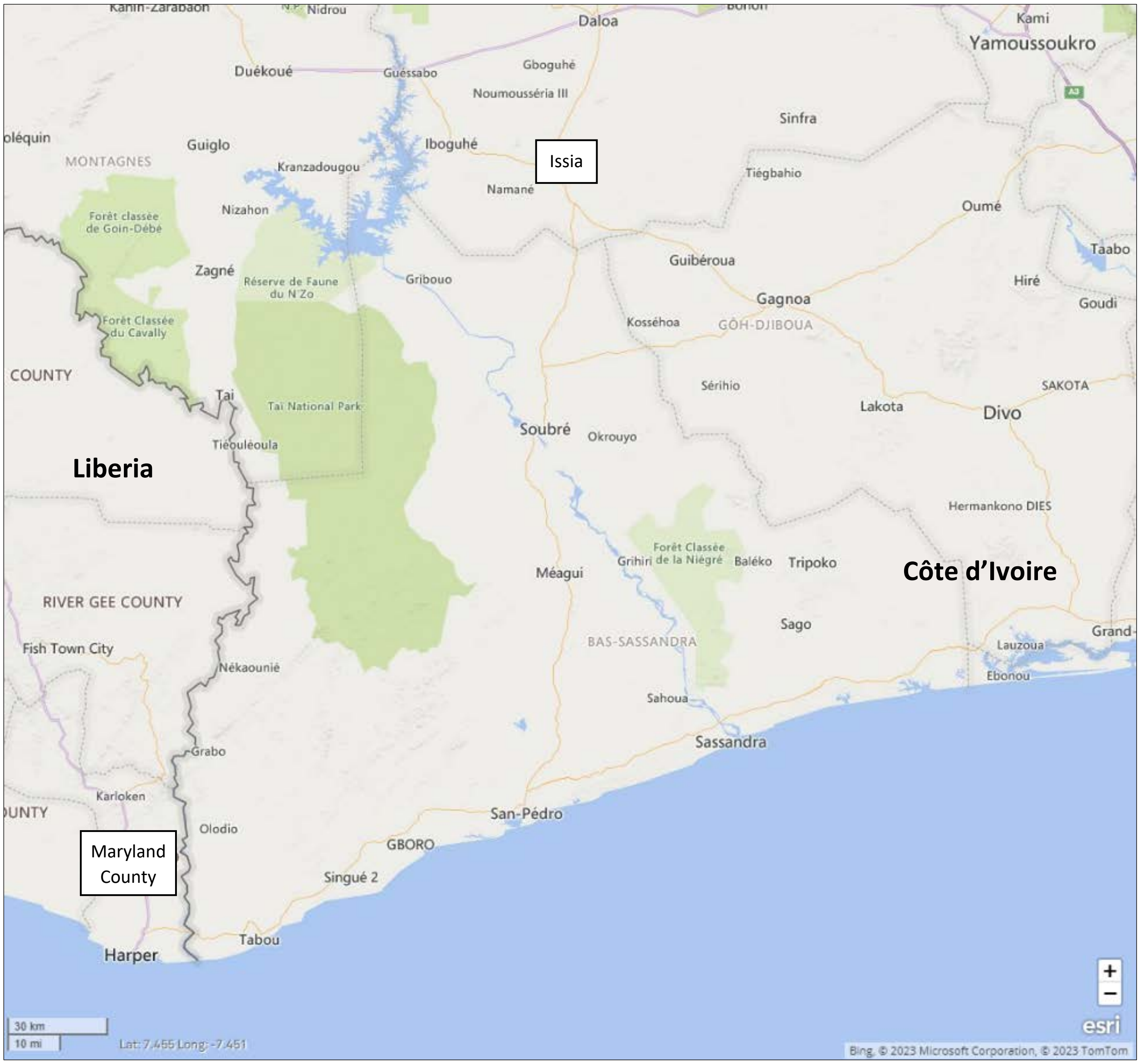


**Figure 8. Map of the southwestern part of Côte d'Ivoire and eastern Liberia where artisanal coltan mining activities center on Issia as well as on Maryland County. Map data is based on Bing as presented in S&P Global (2023).**

## 5.3 ECRM deposits amenable to ASM exploitation

The historic coltan deposits in Côte d'Ivoire, discovered as early as 1963, are pegmatite-related alluvial placers and eluvial deposits formed by in-situ weathering and colluvial processes. Allou (2005) describes zoned pegmatites with thickness up to 15 m, genetically related to the Issia granite system and associated contact metamorphism. Main ore minerals are tantalite (both Mn- and Fe-rich phases) as well as tapiolite, suggesting the mineralization is relatively rich in tantalum (vs. niobium). The pegmatites are classified as Be-Ta-Nb type and additionally contain significant lithium in the form of lithium-bearing mica as well as spodumene (Allou 2005).

The alluvial ore deposit at Bémadi corresponds to mineralized gravels covering an area of 0.8 km times 0.4 km. Their thickness inferred from illustrative cross sections varies from 0.25 to 1.1 m. The total coltan content (supposedly referring to the mineral concentrate rather than tantalum pentoxide) varies from 40-140 g/m³ as a function of gravel layer grades and thickness, with an average coltan grade of 49 g/m³. Aside from coltan, the mineralized gravels contain beryl as well as minor gold.

In the same area, in-situ pegmatite weathering and laterite development at Etienne-Méguhé gave rise to a slightly higher-grade eluvial deposit. Coltan content across this eluvial and colluvial zone rises up to 275 g/m³ at an overall average of 63 g/m³ (Allou 2005). Allou (2005) does not describe any cassiterite in these deposits and did not analyze the tin content of the genetically related Issia granite. It is hence unclear whether tin forms part of the alluvial or eluvial mineralization as it is often the case elsewhere, for instance in Central Africa.

An alluvial (and likely eluvial) total resource of 1.5 million tons at a grade of 0.006% $Ta_2O_5$ has been cited for the older works of SODEMI in the Issia region (Roskill 2020).

## 5.4 Artisanal ECRM mining and processing

Cabinet Alica (2020) conducted an environmental impact assessment in the Issia area for a coltan semi-industrial mining permit application by BRI-COLTAN, a local company run by former employees of the parastatal SODEMI. Based on this document, the company planned using excavators and trucks to extract and transport the ore to a washing site (sluicing; unclear if other steps of gravimetric concentration were planned). The company planned open pit mining down to 30 m depth, in accordance with legal requirements. It is unclear, though, whether the thickness of the mineralized alluvial layer(s) or eluvial zones would imply the need for exploiting the pit down to full depth. The resulting coltan concentrate was supposed to be transported to Abidjan from where it can be exported to international customers. Based on techniques applied in other countries, the author notes that less-mechanized manual sluicing and panning might be possible alternatives for other local coltan mining operations. Coltan concentrates recovered from local operations might be regarded as high-grade, as suggested by Roskill's (2020) impression that former SODEMI mining operations produced a 63-64% $Ta_2O_5$ concentrate. The latter would imply that the niobium content of the ore was relatively low.

## 5.5 Production and trade patterns

Since 2015, there have been few Ivorian exports of coltan concentrate, at irregular frequency, registered in the UN Comtrade database under the trade category for tantalum, niobium and vanadium ores and concentrates. The concentrate was exported to China and North Macedonia, with highest exports of 4.6 tons registered in 2020 whereas, in other years, exports were in the range of few 100 kg. In each of these cases, the reported value of the exported concentrate was significantly lower than the common trade value expected for commercial-grade tantalum concentrate. It is therefore possible that these exports were lower-grade material, for instance samples for geochemical assays. In any case, these patterns suggest that there has been very limited coltan production in the country in recent years. This is corroborated by Roskill (2020) who also noted reduced production in recent years while citing older production estimates by SODEMI with an annual production of 12 tons of coltan concentrate.

There have been allegations that small amounts of coltan concentrate mined in eastern Liberia are smuggled across the border to Côte d'Ivoire. This informal trade, possibly caused by logistical factors, might hence influence Ivorian export patterns as well.

In contrast to coltan, Côte d'Ivoire has exported significant quantities of tin concentrate from 2016-2020, in the range of 72-274 tons in several years. These exports were destined for Malaysia, suggesting that they represented actual tin concentrates (for smelting by MSC), rather than mislabeled coltan concentrates. While the authors did not find any descriptions of ASM activities related to tin in Côte d'Ivoire, the country's geological environment with highly fractionated granite systems and associated pegmatites as well as supergene enrichment, is generally compatible with primary and secondary tin mineralization.

## 5.6 Potential future ASM ECRM production opportunities

It might be of interest to explore the lithium potential of Ivorian pegmatites. In fact, Allou (2005) notes that earlier geological studies overlooked the occurrence of spodumene in local pegmatites at Issia, and, in 2023, a gold exploration company reported finding lithium-bearing pegmatites on one of their concessions. It is important to note that potential lithium mineralization would not necessarily be directly encountered in the historic coltan mining sites because spodumene or lithium-bearing mica would not be expected to be concentrated in alluvial deposits in the same way as coltan.

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# 6 Democratic Republic of the Congo (DRC)

## 6.1 Background

The DRC is probably the largest ASM producer of ECRM commodities in Africa. ASM activities have expanded since the 1990s in a context of failure of state-owned mining enterprises, war and conflict. Risks for conflict financing in association with illegal ASM activities have coined the term 'conflict minerals' for some of the DRC's artisanal mineral commodities (tin, tantalum, tungsten and gold), bringing about significant international attention, regular monitoring activities by an expert group of the United Nations, industry initiatives as well as supply chain due diligence regulations, initially in the United States (2010) and, later on and at a global scale for conflict-affected and high-risk areas, in the EU (2017). These regulations require downstream companies importing (EU) or using 'conflict minerals' in their products (US) to demonstrate management of their supply chain risks such as conflict financing and child labor as defined in a Due Diligence Guidance published by the Organization for Economic Cooperation and Development (OECD). The regulations have a significant impact on the international trade in these commodities originating from the DRC as well as from neighboring countries such as Rwanda.

Provisions for legal ASM mining and trade by Congolese citizens were made in the DRC's mining laws of 2002 and 2018. In the 2018 mining law, the state foresees artisanal mining activities to take place in designated artisanal mining areas ('ZEA' in French). While several ZEAs have been established, these are rarely accepted by artisanal miners as they tend to be located in remote areas, have relatively poor mineralization or their mineral potential is unknown. Therefore, many ASM activities, especially in the copper-cobalt sector, take place within large- and small-scale mining and exploration license areas that are often situated closer to major roads and show well-known mineralization (BGR 2019, BGR 2021). In addition, according to the latest (2018) national mining code and its associated regulations, artisanal miners are not allowed to work underground in the DRC, but in practice ASM production originates from both open pit and underground operations. Despite their formal illegality due to the above and other reasons, local authorities tolerate many ASM activities, provided that they are performed by cooperatives that have an agreement with the license holder, and if the activities fulfill certain minimum criteria such as the absence of armed groups (in the gold, tin and tantalum subsectors) or child labor (for all commodities and especially relevant in the cobalt subsector).

## 6.2 Overview of the national ASM sector

The currently commercialized Congolese ECRM commodities provided by the ASM sector comprise cobalt, copper, rare earth elements (REE), tantalum (and associated niobium; unpaid), tin and tungsten, as well as additional non-ECRM commodities, mainly gold, diamonds and tourmaline. In few areas, there is a possibility for platinum group metals (PGM) recoverable by

ASM means, though no official sales take place. Most of the ASM activities, except for diamond mining, are concentrated in the eastern and south-eastern part of the country, with a north-south extension covering more than 1500 km.

Gold constitutes the largest ASM subsector with more than 230,000 artisanal miners working at >1500 sites, creating an annual production value of >US$ 500 million, most of which is smuggled out of the country (Neumann et al. 2019). Recent (2022) local developments comprise the creation of a gold refinery in Bukavu as well as the creation of a gold exporter with a special (reduced) export tax. Both measures aim to reduce ASM gold smuggling incentives and increase legal ASM gold exports.

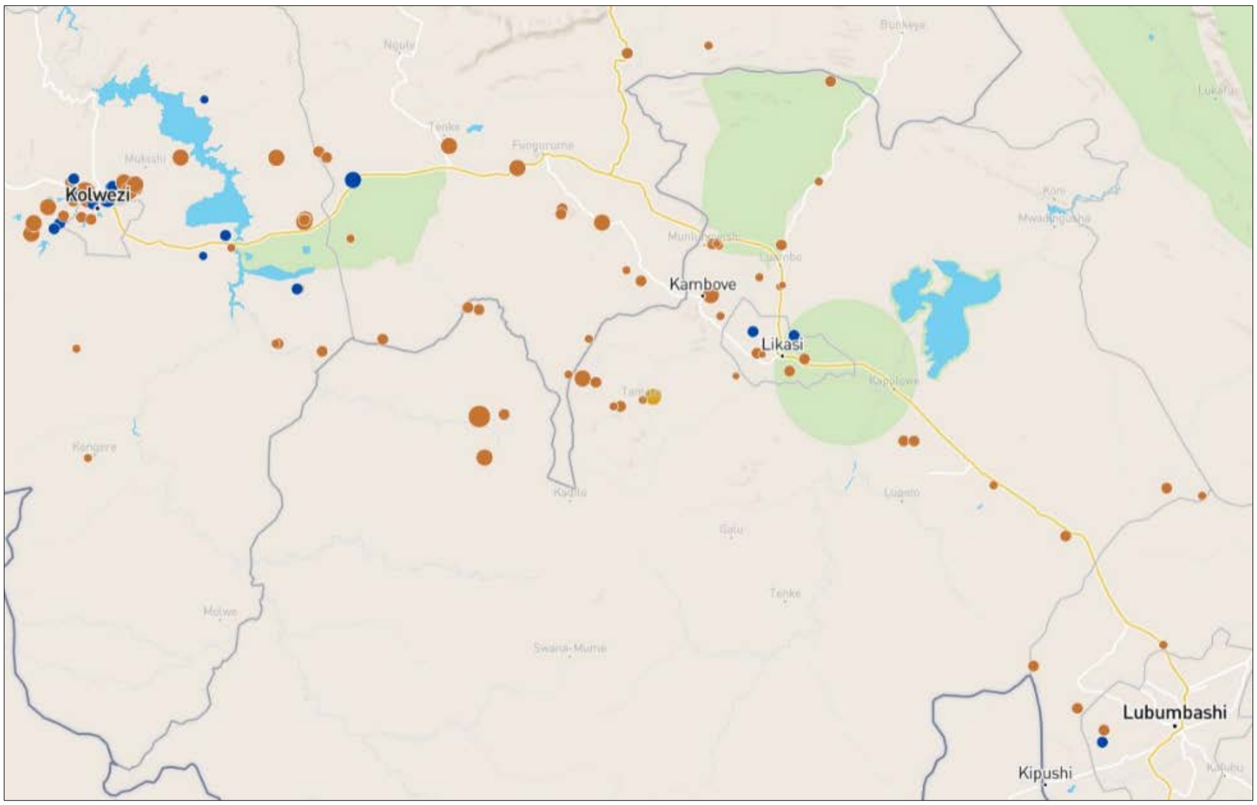


**Figure 9. Location of copper (brown) and cobalt (dark blue) artisanal mine sites in the DRC's Copperbelt as mapped by the BGR in 2019-2020 (IPIS 2023).**

The scale of artisanal copper-cobalt mining activities in the Copperbelt (mainly in the provinces of Lualaba and Haut-Katanga, covering a belt of 350 km by 50 km) is highly variable through time. In recent years, the subsector variably employed 50,000-200,000 artisanal miners in response to commodity price fluctuations as well as different measures taken by DRC authorities (e.g., the eviction of cobalt miners from certain industrial concessions conducted by DRC armed forces). These artisanal copper-cobalt miners work at about 60-100 sites, some of which are very large and employ thousands of miners (BGR 2019, 2021). In addition, parts of the local population engage in handpicking of high-grade cobalt ore from stockpiles or industrial open pits at night, a practice considered as theft by industrial mine operators. The provinces of Maniema, Tanganyika and (probably) Thsopo host very small artisanal copper (without cobalt) production as well. The following figure[1] shows an overview on artisanal copper-cobalt mining sites in the Copperbelt area.

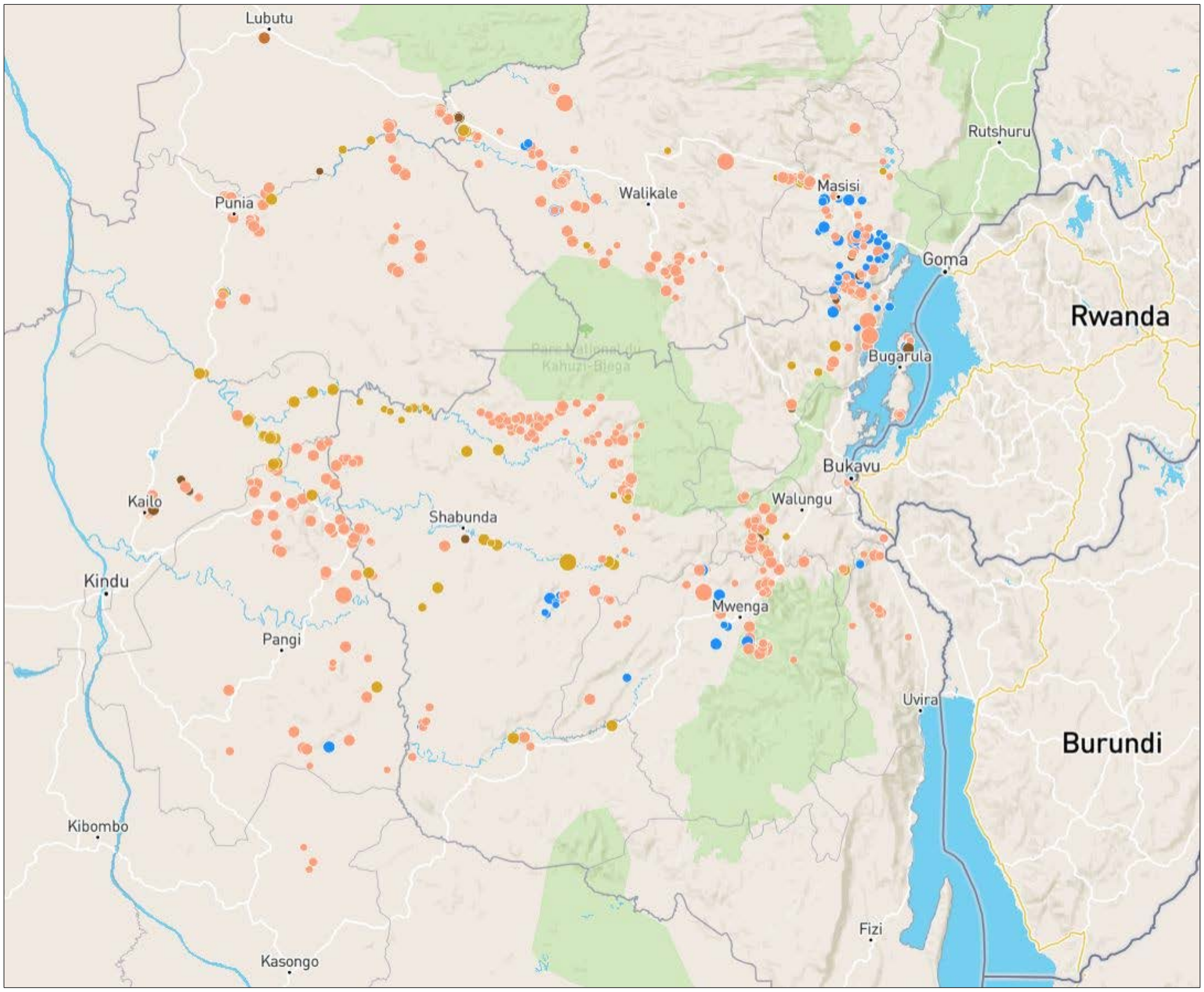


**Figure 10. Location of artisanal mine sites producing, as main product, tin (pink), tantalum (blue), tungsten (dark brown) and gold (light brown) concentrates in the eastern DRC (provinces of North and South Kivu, Maniema; IPIS 2023).**

Based on semi-continuous artisanal mine monitoring data (IPIS 2023), the mining of “3T” (tin, tantalum and tungsten) minerals in recent years has taken place on several hundred sites with approximately 30,000-60,000 miners in total. Tin and tantalum are the major 3T commodities

[1] Note that only mine sites visited by IPIS in the 2016-2023 period are displayed. The map does not show all existing artisanal gold mining sites but only those producing tin (cassiterite) or tantalum (coltan) as by-products, typically from alluvial deposits.

whereas tungsten mining is of subordinate importance in the DRC. Tantalum mineralization is usually associated with niobium; both metals are recovered in the same ore concentrate although only the tantalum content is paid. Artisanal production of REE concentrates from old tin mining concessions has started recently, focusing on an operation in North Kivu province.

## 6.3 ECRM deposits amenable to ASM exploitation

Tantalum and tin ore extracted by artisanal miners in the DRC is hosted by hundreds of pegmatite bodies of variable dimensions, which were emplaced in older meta-sedimentary rocks. Individual pegmatite deposits comprise dikes of variable thickness (up to several meters, rarely >10 m) and length (up to several hundred meters, rarely >2 km; Schütte & Näher 2020). Typical grades range from 100-500 g/t tantalum for tantalum-rich pegmatites. Tin-rich pegmatites may show grades up to several thousand g/t tin with lower tantalum grades (< 100 g/t). Strong weathering of these pegmatites is common, giving rise to eluvial (in-situ weathering) and alluvial (placer) deposits. Aside from pegmatites, tin is also hosted by quartz vein systems. The same applies to tungsten. Mineralogically, tin and tungsten occur as cassiterite and wolframite/ferberite, respectively. Tantalum, along with niobium, is hosted by a range of ore minerals with columbite and tantalite representing the most important ones. Other relevant tantalum ore minerals of lesser importance include tapiolite, wodginite and microlite (Melcher et al. 2017). Collectively, all these minerals are locally referred to as ‘coltan’.

Pegmatites and the associated tailings additionally contain lithium, usually in the minerals lepidolite or spodumene, which may be strongly weathered. To the knowledge of the authors, this lithium ore is currently not recovered by artisanal means in the DRC, though there are indications that this occasionally happens in neighboring Rwanda and other African countries. It might therefore start in the DRC as well, at some point, if supported by attractive lithium prices.

The DRC has geological REE potential related to both carbonatites (e.g., at Lueshe, Bingo and Kirumba) and pegmatites. Weathering may give rise to alluvial or eluvial REE deposits, for instance at Kabengelwa, Mashabuto, and Obaye (Kasay et al. 2022). Tailings associated with ASM and former (semi-) industrial mine workings in mineralized pegmatites and quartz veins hold REE potential as well. At Obaye, in former tin mining concessions at Walikali, North Kivu province, tailings and alluvial material were confirmed to contain light REE of commercial interest, hosted in the ore mineral monazite. The mineralization is very shallow and spatially extensive over a few square kilometers. Monazite concentrates obtained from rudimentary artisanal processing show total REE oxide grades of about 30 % (Groupe RD Consultants 2020). Assuming a concentration factor of ten and ignoring (for simplicity) recovery rates, this suggests typical ore grades of at least 3 % REE oxides in the tailings, but the material is very heterogeneous, such that strong grade variations may be expected. It is noteworthy that these tailings still contain significant cassiterite as well, underlining the potential for artisanal reprocessing of tailings.

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Copper and cobalt mineralization in the Copperbelt of the DRC and neighboring Zambia is hosted by (meta-)sedimentary rocks. Copper-cobalt ratios in these deposits are variable and tend to increase towards the southern part of the Copperbelt. Average deposit grades reported for resources and reserves of industrial mine operators are in the range of 1-6% copper and 0.1-1% cobalt. Weathering caused supergene enrichment in the upper portions of the ore bodies. Artisanal miners selectively mine high-grade ore zones close to the surface (down to about 80 m depth) typically containing 1.5-5% cobalt. In addition, artisanal miners process old copper mine tailings which may have residual cobalt contents in the range of 0.2-2% (Schütte 2021). Depending on the individual deposit and the prevailing copper vs. cobalt price levels, artisanal miners may focus on copper-rich ore zones instead. In that case, they will sell their production as copper rather than cobalt concentrate. Artisanal copper ore grades are typically at least as high as cobalt grades, and may be higher. The copper-cobalt mineralization occurs as disseminated grains or veins (including fracture fillings), though may show massive lenses in places. Copper and cobalt ore minerals include sulfides (copper: chalcocite, bornite and chalcopyrite; cobalt: carrollite) as well as secondary oxides, hydroxides and carbonates formed during weathering (copper: malachite, chrysocolla; cobalt: heterogenite). Artisanal miners mostly mine oxide, hydroxide and carbonate minerals found in high-grade ore zones close to the surface. They only encounter sulfide minerals when engaging in handpicking of industrially mined ore from pit floors and stockpiles.

PGM mineralization is associated with at least three areas in the DRC. Historic copper-cobalt mining in the Copperbelt from 1930-1958 produced about 1.6 tons of refined platinum and palladium at a ratio of 1:4 (Mertie 1969). It is therefore possible that some of the copper-cobalt ores obtained by artisanal miners working in the area contain PGM, though the authors are not aware of the existence or feasibility of dedicated artisanal PGM concentration processes; the platinum or palladium content is not analyzed when artisanal miners sell copper-cobalt ore. Alluvial platinum occurrences, associated with gold, were described around Lubero, North Kivu province, and official production and sales were recorded before 1940 (Jedwab 1992). Since local artisanal miners may recover gold from alluvial placers, it is likely that some of their gold concentrates contain PGM as well, albeit in unknown quantities. It is not known to the authors whether the PGM content of these concentrates is analyzed and paid for, but it seems unlikely. Finally, mafic rocks in the Kasai Province may hold PGM potential as well (along with nickel), though this material would only be accessible to artisanal miners if secondary alluvial or eluvial deposits (e.g., placers) developed.

## 6.4 Artisanal ECRM mining and processing

Pegmatite deposits hosting tantalum and tin ore in the DRC are often pervasively weathered so that large volumes of unconsolidated ore may be mined by manual methods (Schütte & Näher 2020). Manual crushing takes place if artisanal miners mine hard rock deposits. This rarely applies to pegmatites but is often required for quartz vein-hosted tin and tungsten mineralization. Unconsolidated ore is typically processed by ground sluicing, whereby a water stream is directed downhill across ore stockpiles and artisanal miners shovel ore against the direction of the water current. This leads to residual enrichment of heavy ore mineral particles while the lighter gangue material gets carried downhill. This technique is associated with strong erosion along hill flanks. Alternatively, or additionally, manual gravity concentration is performed in constructed sluice basins and by means of washing pans. Standardized mine site processing and ore size classification are missing. Consequently, the obtained mineral concentrates show variable grades depending on ore grades, mineralogical features, and recovery rates of 3T minerals. Recovery rates are typically estimated at 50% or less, especially in cases of very fine-grained tantalum ore minerals, though strong variations in recovery rates may occur from one deposit to the next (Heizmann & Liebetrau 2017, Schütte & Näher 2020). In some artisanal mines, the lack of particle liberalization during local processing may lead to a loss of coarse-grained ore minerals as well. Artisanal processing of tin mine tailings in North Kivu applies similar methods as used for the 3Ts in order to obtain REE concentrates with average total REE oxide contents (mostly cerium, with some neodymium, samarium and lanthanum) in the range of 30 %, with strong grade variations (Groupe RD Consultants 2020).

Aside from these manual mining and processing methods, semi-mechanized processes may be in place at certain 3T mine sites as well as processing centers. At the mine level, this mainly refers to the use of excavators to clear overburden and basic mine site processing plants. The use of such semi-mechanized equipment usually involves cooperation between a (semi-) industrial mining license holder, who oversees equipment use, and a mining cooperative. A second step of concentrate processing may take place prior to export. Processing facilities may include shaking tables and magnetic separators. Overall, 3T mineral processing in the DRC is less standardized than in neighboring Rwanda (Schütte & Näher 2020). Grade control is sometimes, but not always applied when the concentrate is sold to local traders or exporters. All of the DRC's 3T minerals are currently exported as concentrate. Typical export grades are 20-30% tantalum and 50-60% tin or tungsten content. Presently, tin smelting or hydrometallurgical processing (tantalum-niobium or tungsten) are not established in the country, though tin smelting did take place historically and a new tin smelter is currently (2023) being commissioned in Lubumbashi.

Copper and cobalt ore mined by artisanal miners usually corresponds to the oxidized upper part of the ore deposits. This ore type is easier to process than the deeper-seated sulfide ore or mixed sulfide-oxide ore. At the mine site, the ore variably undergoes washing, manual crushing and screening before being sold as ore or pre-concentrate to local traders and processors. In 2018, the mean metal content of sold ASM pre-concentrate was estimated at 14% copper and 4.2% cobalt for copper and cobalt, respectively (BGR 2019). At that time, local traders rarely accepted ASM material with grades <1% cobalt or <3% copper; with the recent positive copper price

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development, lower copper cutoff grades may apply by now. The traders and processors (‘depots’) receiving these pre-concentrates directly from mining cooperatives or through intermediaries perform particle size classification and milling, with the aim of reducing grain size sufficiently to allow for subsequent leaching at local hydrometallurgical processors. Artisanal oxide ore is sometimes blended with mixed sulfide-oxide ore from other mines, as this may allow for cheaper processing (avoiding the use of expensive oxidation agents that must be added otherwise). In-country hydrometallurgical processing comprises leaching, solvent extraction and electro-winning to obtain crude cobalt hydroxide and copper cathodes. While the law prohibits exporting unprocessed products, ores and concentrates are sometimes exported as well. In addition, some producers export a pyrometallurgical concentrate (‘alliage blanc’) which represents a copper-cobalt alloy.

## 6.5 Production and trade patterns

Congolese ECRM are variably produced by ASM as well as through industrial mining. While some artisanal tantalum mines are run by operators who registered industrial small-scale or even large-scale concessions and variably mechanized their mining operations, the DRC’s tantalum production can essentially be attributed to the ASM sector. The Bibatama mine site (SMB, former MHI) in North-Kivu represents one of the most advanced tantalum mining operations in terms of mechanization, though a dispute, partly escalating into a conflict, exists between the mine operator and a local mining cooperative. This is accompanied by increasing risks of tantalum concentrate theft from the mine and neighboring concessions. Kisengo in Tanganyika province is another example of an advanced artisanal tantalum mine site in the DRC. These mine sites may be classified as semi-industrial.

Tin mining is by means of artisanal production, except for industrial production at Alphamines’ Bisie mine (and very minor contributions from few other location), where industrial production started in May 2019 and has expanded since then. Formerly, Bisie was a hotspot of artisanal cassiterite production, but these ASM activities were officially banned to allow developing the industrial mine. In 2021, ASM operators contributed one third to the Congolese tin concentrate exports while the Bisie mine (and very small amounts from other concessions) made up the remaining fraction. Located in the border region between the provinces of Haut-Lomami and Tanganyika, the Kanuka mine site may be considered as a semi-industrial producer of mixed tin and tantalum concentrates. Artisanal REE mining through re-processing of tin mine tailings and alluvial material is taking place on the concession of state-owned SAKIMA in North Kivu province, which is registered as an industrial mining concession.

Mining in the Copperbelt is mostly by industrial means, with artisanal cobalt miners variably contributing up to about a quarter of national cobalt production in some years. From 2017-2021, the authors estimate an average national cobalt ASM production share of 17%. Gulley (2023) estimates a slightly lower average national cobalt ASM share of 15% for the period from 2017-2020. While artisanal miners do locally sell copper concentrates as well, their relative share in the total Congolese copper exports is very low, due to the large tonnages supplied from industrial copper production. In 2018, the BGR estimated a total artisanal copper production of about 16,000 tons (copper content; BGR 2019). This corresponded to about 1% of the DRC's copper exports of that year. Based on on-the-ground observations and pending evaluations, the authors assume that artisanal copper production has increased significantly since then. In its provisional release of mining statistics for the year 2022 (January-October), distributed at Mining Indaba in February 2023, the DRC Ministry of Mines released production figures for artisanal copper and cobalt ore (for ore metal grades, see above). These figures show 384,315 tons of artisanal cobalt ore and about 1.1 million tons of artisanal copper ore. The following table[2] provides an overview of the ASM ECRM exports of the DRC.

| Commodity | 2021 | 2017-2021 (average) |
|---|---|---|
| Tantalum concentrate; contains significant niobium | 1,848 t | 1,824 t |
| Tin concentrate | 10,302 t | 12,145 t |
| Tungsten concentrate | 761 t | 412 t |
| Cobalt (content), exported as hydroxide or ore/ concentrate; rounded estimate | ~ 15,000 t | ~ 17,500 t |
| Copper, exported as various intermediate or refined products | n/a | n/a (~ 16,000 t in 2018, likely higher nowadays) |
| REE concentrate | From 04-09/2022: 720 t | n/a |

**Table 3. ECRM ASM commodity exports from the DRC.**

## 6.6 Potential future ASM ECRM production opportunities

The DRC's artisanal tin and tantalum (+/- tungsten) subsector may represent a straightforward investment target to increase the country's artisanal ECRM production. Several mine sites appear to have sufficient production potential to warrant undergoing semi-mechanization. Note, however, that there are a number of geological and economic uncertainties and risks to consider

[2] Data shown in the table are based on export statistics by the DRC Ministry of Mines, except for REE concentrate (company information) and copper (BGR 2019). For cobalt, BGR estimated ASM production considering national exports, site-specific production reported by service providers such as CRU, as well as BGR-internal information to verify local artisanal mineral supply. Gulley (2023) provides an alternative ASM cobalt dataset for the period until 2020, based on peer-reviewed methods, which shows overall similar (slightly lower) artisanal cobalt production estimates. Note that, based on permit types, the Ministry of Mines classifies part of the national tantalum production as 'industrial' but all national tantalum production is reported here as ASM; part of it is semi-mechanized. For tin, the production from Bisie mine (and minor contributions from others) is treated as industrial and excluded from the table while the remaining national tin concentrate production is assigned to the ASM sector and shown in the table.

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for such investments. In the absence of actual exploration data, the size of the ore body, the grade distribution and the remaining mineral resources are poorly known, and resource depletion at any given site will occur eventually. In implementing mechanization programs, mining companies and investors might further create conflict and tensions with local cooperatives or informal artisanal mining groups. These stakeholders often resist mine mechanization efforts as this may result in job losses for unqualified workers. This has happened at the Bibatama mine site (SMB) in North Kivu, for instance, the country's largest coltan producer for many years. Another economic risk for investment in the artisanal 3T sector refers to the impact of the Primera joint venture, set up between the DRC and a company based in the United Arab Emirates in December 2022, and to its influence on artisanal mineral exports. While Primera Gold's role in controlling the artisanal gold exports in the eastern DRC has become well known since then, the joint venture additionally includes provisions for Primera Metals DRC to develop a technical business plan regarding exporting and setting up a smelter for 3T minerals. As part of the joint venture agreement, the DRC government commits to authorizing an exclusive export tax rate of 3.5% for 3T minerals. For tin (cassiterite) and tungsten (wolframite), this rate is the same as the general export royalty rate in place for base metals. For tantalum (coltan), however, this exclusive rate awarded to Primera Metals DRC would be substantially lower than the current export royalty rate in place for other companies, set at 10% due to coltan being classified as a 'strategic substance' by the DRC government.

The lithium content of artisanal pegmatite mine sites (producing tin and tantalum) and associated tailings is of potential market interest at certain lithium price levels if operators were to introduce lepidolite and/or spodumene processing circuits that would allow separation and recovery of lithium concentrates for export. Currently, most lithium minerals contained in 3T pegmatite ore report to the tailings fraction. The efficiency of recovering lithium concentrates also depends on the degree of weathering of the lithium minerals, among others, and would hence require conducting metallurgical processing studies. Also, artisanal mine site operators rarely engage in systematic ore stockpiling and tailings storage, which may complicate lithium recovery through re-processing. In any case, it is possible that basic handpicking of high-grade lithium pegmatite ore would be economically viable for individual artisanal miners at the current (03/2023) lithium price level if local traders offered to buy such material. Similar considerations apply to REE concentrates obtained from re-processing of tin mine tailings, though monazite is more resistant to weathering (and, in fact, enriched in placers) than lithium minerals. There is a small potential to increase the value potential in artisanal gold supply chains in the Lubero area if gold concentrates were analyzed for their PGM content.

At the time of writing (04/2023), despite its major commercial significance, the artisanal copper and cobalt sector represents perhaps the most challenging subsector to engage in terms of structured national ECRM production growth, due to the associated legal uncertainties and pending decisions by the DRC government. Unless the DRC mining authorities enforce a clear framework on enabling factors such as artisanal copper and cobalt trade and the associated roles of parastatal companies such as the Entreprise Générale de Cobalt, it is likely that the subsector's output will mainly be driven by external commodity price developments. In any case, it is important to underline the economic importance of the country's artisanal copper production, in addition to artisanal cobalt production.

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# 7 Ethiopia

## 7.1 Background

In Ethiopia, the Mining Operations Proclamation governs all mining and related activities in the country. It underlines that mineral resources of the country are the property of the state and the people. The government, custodian of mineral resources, acts through the licensing authority to control and administer mineral resources. Mining activities are open for private investment and the mining law distinguishes between large-scale, small-scale and artisanal mining. According to the Proclamation (No. 816/2013), the Licensing Authority can issue four types of mining licenses as per the following table (EITI 2016).

| Types of Mineral License | Duration | Remark |
|---|---|---|
| 1. Artisan Mining | up to 2 years initial – Non renewable | Exclusive; Reserved for nationals; Regional States provide license |
| 2. Special small-scale mining | Up to 10 years + renewable for 5 years | Exclusive |
| 3. Small-scale mining | Up to 10 years initial + renewed for 5 yrs unlimitedly | Exclusive |
| 4. Large-scale mining | up to 20 yrs initial + unlimited renewals of 10 years each | MoM Provides a large scale exclusive mining license |

**Table 4. Types of mining licenses in Ethiopia.**

## 7.2 Overview of the national ASM sector

Ethiopia is a nation endowed with various mineral resources. According to the Ethiopian Geological Survey the resources discovered in different regions of the country are mainly gold, tantalum, phosphorus, iron, salt, potash, soda ash, gemstones, coal, geothermal and natural gas. Other mineral resources of importance are platinum, niobium, copper, nickel, manganese and molybdenum. However, only the high-value commodities gold and tantalum are currently produced in relevant amounts. In 2019, the country's industrial operations produced about 3.5 t of gold and 163 t of tantalite concentrate that contained about 70 t of tantalum and 7 t of niobium (USGS 2019). The exported volume of tantalum containing concentrate in 2019, according to the UN Comtrade statistics, was however only about 76 t of tantalite concentrate, with a trade value of US$ 5.7 million.

Apart from the industrial gold mining, the ASM sector in Ethiopia is also a significant gold producer. For the ASM gold mining sector in Ethiopia, the USGS estimated 2019 a production of

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about 9 t Au. Likewise, for the production of tantalum and niobium concentrates, the USGS sees a significant share coming from ASM operations. USGS estimates the annual production capacity of the ASM sector at 25 t tantalum and 14 t niobium (corresponding to about 60 t of tantalite concentrate). The ASM production of gold did not appear in the past in the official gold export statistics of Ethiopia. However, the Ethiopian National Bank is buying currently gold from the ASM sector paying a premium of up to 35 % on the global market price of gold to encourage the artisanal suppliers and obtain the desired foreign currency. Thus, in 2022 the National Bank reported an increase in earnings of about USD 1.2 billion from gold in the period from August 2021 to June 2022. Gold has been the second highest among Ethiopia's export items next to coffee exports. However, the smuggling of gold from illegal mining is still a big issue in Ethiopia.

Since 2004 according to the USGS, platinum has been produced in Ethiopia as well, resulting from the metallurgical test work carried out at the Yubdo platinum deposit. The maximum production rate of PGMs that was achieved in the period 2006 – 2012 was about 10 kg PGM contents/a. After the withdrawal of various junior companies that explored the different Pt-prospective zones of the Yubdo deposit, it seems that artisanal miners are now working on the deposit and other locations. According to the USGS, the ASM platinum miners can maintain the production capacities of PGMs at about 10 kg/yr (USGS 2019).

Estimations of the size of the ASM sector in Ethiopia vary significantly, ranging from 450,000 to 1.25 million artisanal miners. Most artisanal miners work in the gold mining sector, but the production of gemstones (opal) and tantalite is also of significance. Only 6% of the ASM sector is formally organized and licensed (DELVE 2022).

All the gemstone production in Ethiopia results from ASM operations. In 2019, about 4.6 t were produced (export value about US$ 5 million). This was a significant decline after the peak production of about 75 t in 2015 that had an export value of about US$ 157 million.

## 7.3 ECRM deposits amenable to ASM exploitation

In Ethiopia there are various types of ECRM deposits amenable to ASM exploitation. Historically, platinum was mined by ASM panning activities exploiting both alluvial and eluvial ores. Additionally, tantalite concentrates have been produced in ASM operations working in pegmatite or placer deposits.

Platinum was first produced in Ethiopia by Europeans in 1925, but platinum is known to have been purchased long before that date by itinerant traders, who probably smuggled it through the Sudan into Egypt. From 1927 to 1940, Ethiopia was a rather important producer of the platinum metals, but until the 1960s the output has greatly diminished. It was estimated that the total output from 1926 to 1959 was about 2.8 t of PGMs, with a maximum production of 255 kg in 1940 (Mertie 1969).

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Platinum was produced in the early years from two general districts, in the valleys of the Didessa and Birbir rivers. The declining or low production indicates that no new discoveries have been made and these districts remain the only two districts with known platinum occurrences. The productive area in the Birbir district is near Yubdo, which is on the west side of the Birbir River, on a plateau incised by the river. This plateau consists of two well-defined ridges, the Yubdo ridge trending north and the Sodo Ridge trending northwest (Mertie 1969).

The Yubdo and Sodo ridges consist mainly of dunite bordered by pyroxenite, which in turn is bounded discontinuously by gabbroic rocks. In some places where dunite forms the crests of these two ridges, there occurs a well-indurated brownish quartzite, which was formed by the silicification of dunite. This rock, which contains about 9 % $Fe_2O_3$ and 1 % $Cr_2O_3$, is called "birbirite". This weathered rock extends below the surface is enriched in PGMs to a depth of 3 - 5 m. Much of the platinum in this field, however, is recovered from deposits of red clay that mantle the tops and slopes of the hills over an area of about 100 square miles. This represents residual and eluvial material derived from the weathering of the ultrabasic and basic rocks. Another part of the platinum is recovered from gold-platinum placers in the valleys of the Birbir and Didessa Rivers and their tributaries (Mertie 1969).

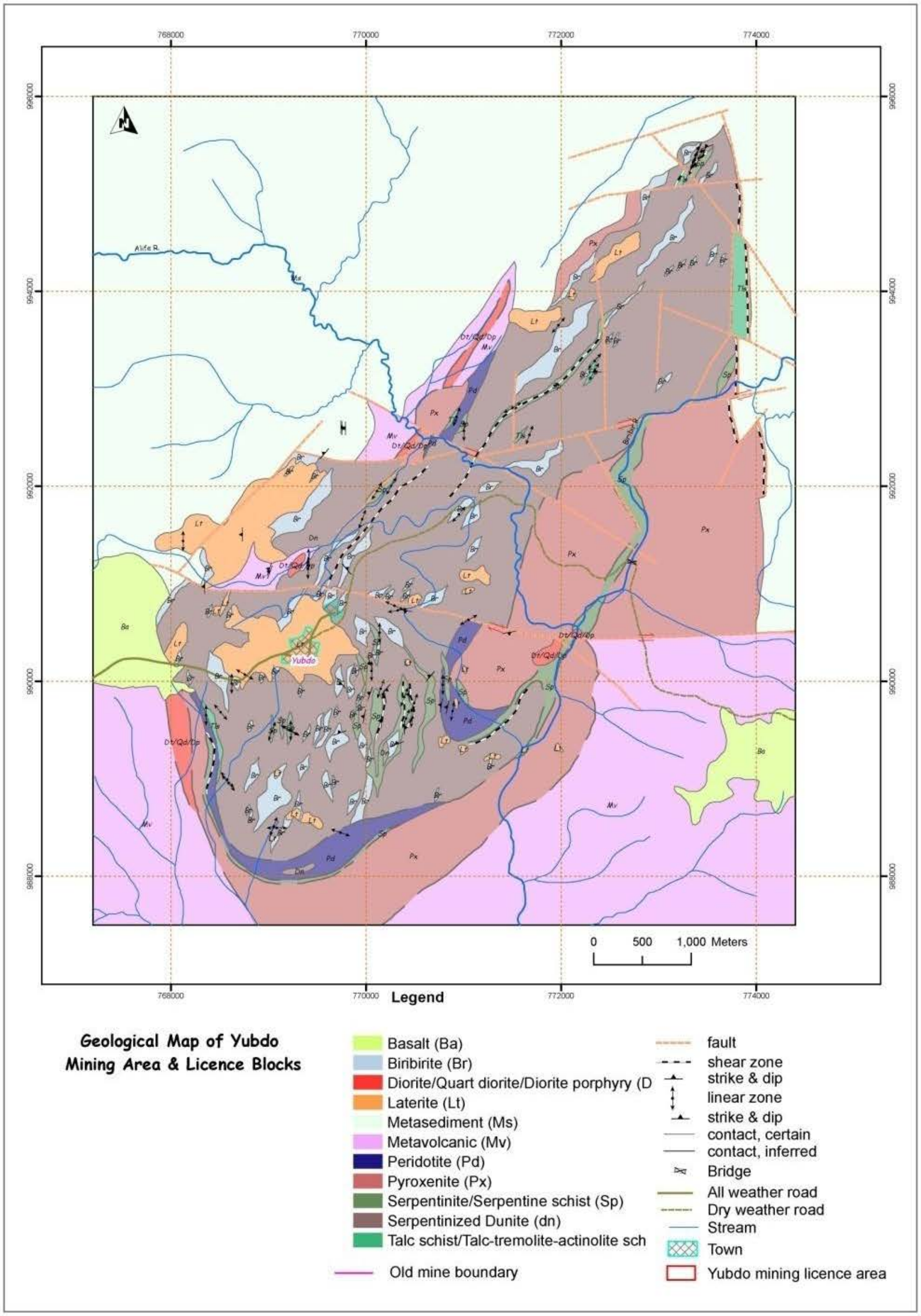


**Figure 11. Geological map of the Yubdo mafic-ultramafic complex, the main prospective area for PGMs in Ethiopia (Alemu & Hailu 2013).**

The historic mining zone at Yubdo consists of surface workings extending over an area of 200 hectares. There is one known shaft. The ore mined is composed of sperrylite, magnetite and chromite with waste material consisting primarily of serpentine, magnesite and hematite. In strike direction the ore body extends over 6,000 meter, the width is 2,000 meters, and the thickness 10 meters. The total contained resources of PGMs are estimated at about 12 tons of metal content, with an average ore grade of 0.34 g/t. In 2006, the mining company Minerva conducted an exploration pitting program at a ridge that comprised at that time a small-scale mining area. Platinum grades ranging up to 1.8 g Pt/t were located (S&P Global market intelligence platform). Minerva had been considering the potential to expand the small-scale platinum production at Yubdo to a full-scale mine with a capacity of 1.6 t PGM/yr. For conducting metallurgical test work, a gravity processing plant at pilot scale was installed with a capacity of about 10 kg PGM/a. Under changing ownerships, the production records, according to the USGS, indicate that the pilot plant was in operation until 2012. Then, the large scale mining (LSM) concession was relinquished and ASM took over again. The ASM capacity for platinum is estimated by the USGS at 10 kg annually. However, it is unknown if the ASM platinum production is derived only from Yubdo or from other placer deposits in the Western Wellega Region as well.

The interest in tantalum in Ethiopia started in the 1980s when a Russian geologist discovered the rare-metal pegmatite deposit of Kenticha near Borena in the Oromia Region of Southern Ethiopia. Because the tantalite-columbite deposits at Kenticha have higher tantalum concentrations than niobium (Ta:Nb is up to 3:1), the ore is referred to as tantalite. Tantalite ore is produced at Kenticha from a deeply weathered pegmatite regolith and from adjacent eluvial deposits. At a thickness of 40-100 m, the pegmatite at Kenticha is unusually thick (Küster 2009). Mining at Kenticha is usually industrial, but artisanal miners have illegally entered the concession repeatedly. In 2012 mining cooperatives of artisanal miners also started to produce columbite-tantalite from pegmatites in other regions of the Oromia Regional State. The USGS estimates these produced a concentrate containing 25 t of tantalum and 14 t of niobium per year.

## 7.4 Artisanal ECRM mining and processing

The digging for platinum and tantalum ores is realized in surface operations using manual tools like picks, shovels and hoes. The PGM contents of the ore is enhanced by handpicking and the processing of the ore is realized by simple washing in sluice boxes and by hand panning. Frequently gold and platinum are produced at the same time during processing.

The tantalite containing ore can occur in alluvial or eluvial deposits or is mined from hard rock pegmatites. The mining can be realized totally manually or can be supported by earth moving machinery when this equipment is available for ASM. Alluvial and eluvial ore can be concentrated directly by washing and panning, and pegmatite material requires crushing before the concentration by gravity means can be carried out. In this desktop study the locations of ASM processing plants could not be identified.

## 7.5 Production and trade patterns

As shown in the following figure, the total recent ASM production of PGMs can be estimated to at least 25 kg and that of tantalite concentrates to at least to 500 t (estimated ASM production by the USGS in the period considered in the diagram) while industrial mining at Kenticha produced about 3200 t of tantalite concentrates.

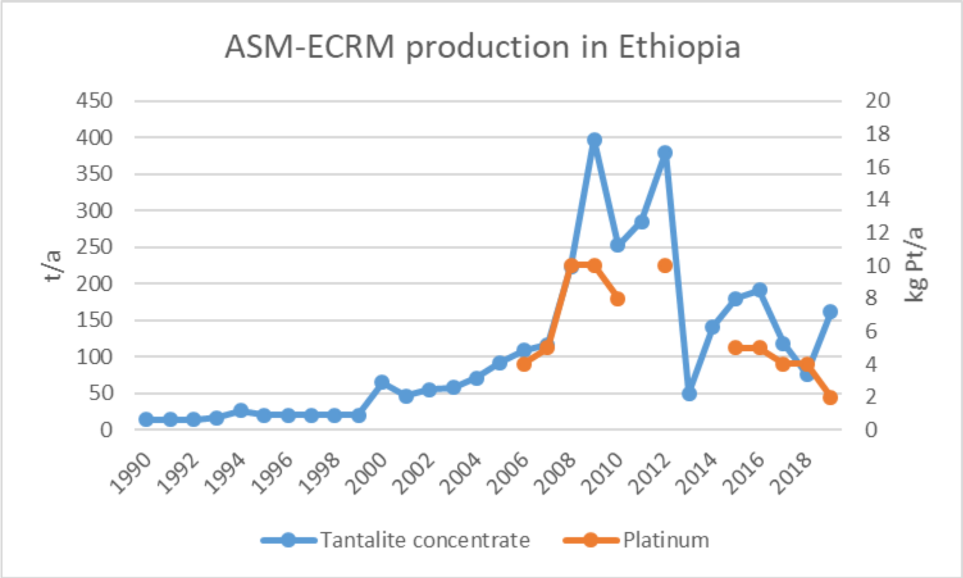


**Figure 12. Production statistics for tantalite concentrate and platinum in Ethiopia; since 2012 a part of the tantalite production and since 2015 the complete platinum production is derived from ASM activities (USGS statistic for Ethiopia 1996 – 2019).**

In the beginning of the 1990s a small industrial mining operation with an open pit and a gravity processing plant was constructed at Kenticha by the Ethiopian Mineral Resources Development Enterprise (EMRDE) that produced annually about 20 t of tantalite concentrate (also containing niobium) in the first years of operation.

The Kenticha mine capacity expanded under the regime of the Ethiopian Mineral Development Share Company (EMDSC) to over 100 t of $Ta_2O_5$ per year and Ethiopia was among the large tantalum producer countries and accounted for 6% of the world production in the year 2007 (Schulz et al. 2017). The industrial Kenticha mine suspended its operations in December 2017 (Abyssinian Metals 2022). Kenticha was closed both due to declining prices and the high cost of managing by-product radioactive mineral compounds (Bekele 2018a), (Carvalho 2021). In addition, problems with the undersized tailings pond occurred in 2017. The initial focus at Kenticha was the production of tantalite concentrates. The aggregated historical production for

27 consecutive years of operation from 1990-2017 was about 3200 t of tantalum concentrate containing over 50% tantalum pentoxide (the total extraction of run-of-mine ore until to date is about 5.3 Mt) (Abyssinian Metals 2022). As shown in the following figure, after the suspension of the industrial operation, ASM had the opportunity to work at the Kenticha deposit for a period of several years (Bekele 2018b). After the closure of the industrial Kenticha mine the government of Ethiopia tried to find foreign investors for the Kenticha project. Following a formal bid the private company Abyssinian Metals was awarded the Kenticha project in 2020. In addition to tantalum lithium is now also in the project focus. It is currently not known if there are production arrangements between artisanal miners and Abyssian Metals or whether all artisanal activities will be prohibited by the company on its concession.

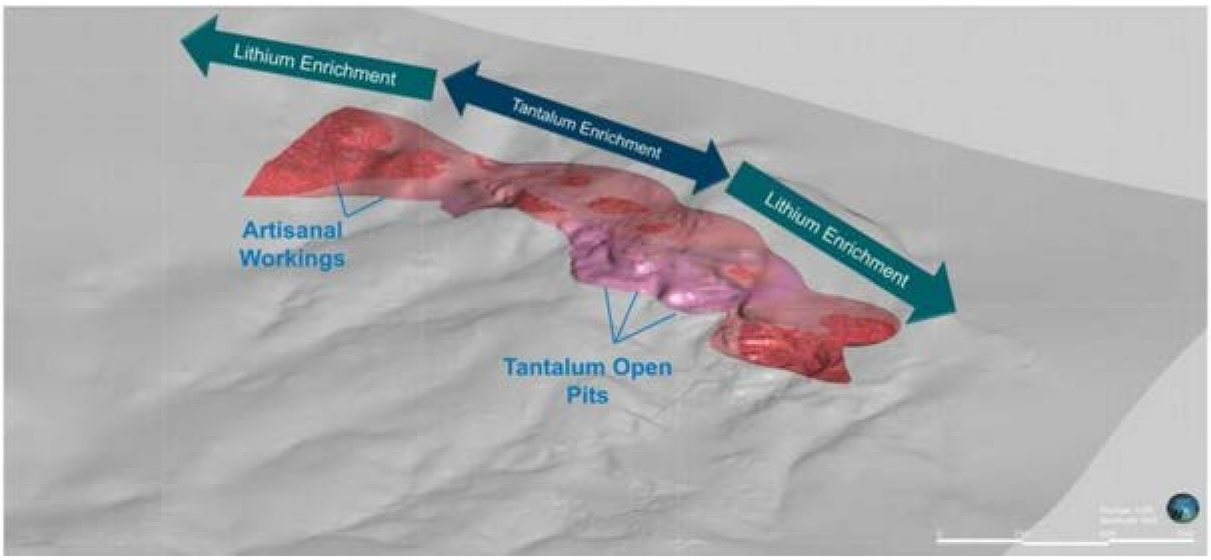


**Figure 13. Mining zones at the Kenticha pegmatite deposit (Abyssinian Metals 2022).**

## 7.6 Potential future ASM ECRM production opportunities

No systematic exploration has been carried out in Ethiopia for finding further rare-metal pegmatites, apart from Kenticha. However, in the surrounding of Kenticha a large number of small showings of coltan were found, many of which have been mined by small-scale miners. These are only surface deposits and the extension of these deposits to the depth is unknown. However, geological information from the company that is currently carrying out pre-mining and mining activities at the Kenticha pegmatite indicate that the shear zone hosting the Kenticha rare-metal pegmatite can be followed for more than a hundred kilometers towards the north, containing a number of columbite and tantalite showings. Reports of columbite minerals in placer deposits further north, towards the border to Somaliland, and the presence of coltan mineralization across the border near Hergiesa substantiate the assumption that there is a vast potential for finding further commercial tantalum deposits in Ethiopia that are suitable to small scale mining. Since the pegmatites in many cases also contain Li-bearing mica, an ASM production of lithium containing mineral concentrates seems possible. However, in this case the transport costs to an export harbor would be a hindrance for the profitability of marketing the otherwise relatively low-cost concentrate.

A significant increase of the platinum production from ASM does not seem probable since the geological resources are limited and the average grades for platinum in the vast Jubdo deposit are too low to be exploited artisanally. An upscaling of the currently existing ASM technology would not be appropriate since the high-grading focus of the artisanal miners would be lost and, consequently, the production would not be economically feasible.

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# 8 Liberia

## 8.1 Background

Liberia’s ASM sector is mostly focused on gold and diamonds, comprising an estimated 500,000 artisanal miners (locally termed ‘diggers’) who are employed by another 100,000 ‘miners’ (who may hold the license but might also mine themselves). As far as ECRM are concerned, the country hosts minor ASM activities related to coltan, although their scale is currently negligible compared to gold and diamonds. Liberia’s Minerals and Mining Law of 2000 defines license types applicable in the ASM sector. These comprise a Class C mining license for artisanal prospection of alluvial deposits on 25-acre plots, exclusively available to Liberian citizens, as well as a Class B mining license for small-scale production on a somewhat larger area (100 acres). The government recently banned the use of heavy equipment for Class C licenses. There are abundant illicit artisanal mining activities in the country, especially in the gold sector. Compared to the latter, the local diamond supply chain is more formalized (Bazillier et al. 2023). The small coltan mining sector features both legal and illegal operations.

## 8.2 Overview of the national ASM sector

Artisanal diamond mining activities, which take place mostly in the northern half of Liberia, were interrupted during the period of civil war, conflict and associated UN sanctions, but have been formally re-established since 2007 when Liberia became a member country of the Kimberley Certification Process. Artisanal gold mining takes place across Liberia. The country hosts at least 600 known gold occurrences, some of which were already worked during colonial times. Artisanal gold mining activities have intensified with the increasing gold price since 2008. About 90% of the Liberian ASM gold production are allegedly smuggled out of the country, mainly to Guinea (Kalokoh & Kochtcheeva 2022). Coltan is mined in few ASM operations in the easternmost region of Liberia, in Maryland County, close to the border with Côte d’Ivoire where part of Liberia’s coltan may be sold informally (see map in the country profile of Côte d’Ivoire). Aside from coltan, the author could not identify other ECRM mined by ASM in Liberia.

## 8.3 ECRM deposits amenable to ASM exploitation

Coltan mineralization occurs in alluvial placers or eluvial zones associated with pegmatites in the eastern part of the country, though coltan also occurs in western Liberia (Gunn et al. 2018). Due to their thin and discontinuous nature, the distribution of pegmatite bodies is poorly documented on national geological maps. The authors could not identify any detailed geological descriptions of coltan deposits.

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## 8.4 Artisanal ECRM mining and processing

A small-scale mining operation in Maryland County, southeastern Liberia, recovers high-grade coltan concentrate (45% $Ta_2O_5$) from placers. Coltan ore is processed using a 10-meter sluice covered with a sluice carpet to recover the heavy mineral fraction. The final concentrate is panned down and dried. The operator closely monitors concentrate yield and quality, including through use of an on-site portable X-ray diffractometer; based on their observations, they note that significant amounts of fine-grained tantalite currently report to the tailings and plan optimizing the sluicing process (Bruder et al. 2022). The processing techniques employed at neighboring coltan mining sites are not described, but it may be expected that these are somewhat less sophisticated.

## 8.5 Production and trade patterns

The small-scale mine in Maryland County planned to produce 0.5-1 ton of coltan concentrate per month but did not achieve this output level due to different reasons, such as artisanal workers selling their concentrates to competing local traders (Bruder et al. 2022). The operator expects that coltan mining operations in the area as a whole may have an annual concentrate production output of 24-60 tons, and they are currently considering setting up a buying scheme, since they also hold a formal mineral dealer's license. Meanwhile, the operator has only been able to export a single coltan concentrate shipment of 436 kg so far, which was shipped in February 2022, and is anticipating following up with a second shipment soon.

The UN Comtrade database does not show any tantalum (or tin) ores and concentrate shipments exported from Liberia in the 2016-2021 period. China declared minor tantalum concentrate imports from Liberia, in the order of 1-2 tons per year. Bruder et al. (2022) note the possibility that some Liberian coltan is sold informally across the border in Côte d'Ivoire but the latter country did not show any major coltan exports neither in the same period.

## 8.6 Potential future ASM ECRM production opportunities

Considering the small size of alluvial coltan deposits described so far, there seems to be a somewhat limited ASM coltan production potential in Liberia. Current industrial exploration activities in Liberia target multiple ECRM commodities, including lithium as a pegmatite-related metal. Data from these activities might be useful in the ASM environment as well in case a given area's mineralization eventually does not warrant developing an industrial large-scale mine.

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# 9 Madagascar

## 9.1 Background

In Madagascar, the Office of the Mining Cadastre (Bureau du Cadastre Minier de Madagascar, BCMM) is the governmental agency that manages all types of mining licenses. According to the mining law there exist four types of mining authorization and licenses in Madagascar: research permit (PR = permit de recherche), mining permit (PE = permit d'exploitation), permit reserved for small scale mining (PRE = Permis réservés aux petits exploitants) and the "Exclusive Authorization for Area Reservation". Of these, only the small-scale mining license PRE is of relevance for the ASM sector in Madagascar. This mining permit grants the holder the rights for prospection and mining activities. The PRE is exclusively used by Malagasy individuals and small scale mining groups organized in cooperatives. The concession holder of a PRE is allowed to explore and exploit the deposit at the same time. The extracted minerals can be sold to private business units. The maximum concession size per holder is 256 squares (1 square = 0.345 $km^2$). The validity is for 8 years and can be renewed for 4 years upon each renewal.

The relatively high administrative hurdles set for acquiring the PRE (for example, besides of PRE mining plan, the permit form, the environmental engagement plan, the code of conduct, the form for the engagement for the environmental impact study have to be submitted) make it in reality difficult for smaller, self-funded groups of miners to comply with all governmental obligations in order to receive the mining rights.

For this reason, the government has set a special mining regime for small scale miners, called "zone d'encadrement", that permits a learning phase of 6 - 12 months for the small scale mining groups or cooperatives aiming to fulfil the requirements of mining law in this period and finally to be granted with the PRE. During this time, ASM activities can be carried out. The participation in this zone shall be supported technically by the municipality where the mining takes place and by the regional office of the mining ministry.

Until now, 1468 PRE licenses have been granted, however a third part of the PREs is currently waiting for the cancelation decision that should be issued by the mining ministry upon reception of the necessary documents for the cancelation procedure by BCMM. Another 60 % of the PREs is in the progress of liberation – i.e., the releasing process that has been signed by the ministry, but yet has to be officially issued – or in the movement process of the permit area. This means that the area will be officially available for a new tender upon reception of the official document issued by the mining ministry. Only 10 % of the PREs are currently in the process of permit granting waiting for the final decision of the ministry of mines. The typical causes for the expiration of the mining permits are the negligence of fee and royalty payments or inability to pay due to lack of markets (ban on export, Covid crisis, suspension of activities). There are currently only 17 PRE permits that can be considered as regular small-scale mining licenses. This overall image of the PRE situation leads to the conclusion that most of the current ASM production obtained in Madagascar is more or less irregular and informal. The possibility to get assistance in the frame of "zone d'encadrement" is taken by about 205 miner groups and cooperatives and has resulted in an increase of ASM productivity in 2023 (pers. comm., Lova Mahefa, BCMM, July 26 2023).

## 9.2 Overview of the national ASM sector

Madagascar has a long-established history of precious mineral extraction with extensive mineral deposits throughout the island nation. Large-scale mining activities have expanded since the early 2000s with industrial production of chromium, cobalt, ilmenite and nickel. Artisanal and small-scale mining remains a largely informal activity in Madagascar, but it is believed to be the second largest job provider in Madagascar behind agriculture, with gold, colored gemstones and mica being key commodities, however, not being considered as ECRMs. To a lesser extent, currently the ECRMs columbite-tantalite, manganese, beryl and the lithium bearing minerals spodumene and lepidolite have been mined by ASM.

Historically, the government has made efforts to reform the mining sector to increase foreign investment and strengthen governance, but efforts to formalize the ASM sector have been largely unsuccessful. With a renewed strategy for the ASM sector's development created in 2018, the government has been aiming to formalize the sector and increase government revenues (DELVE 2021). The ASM sector in Madagascar can be classified in five different types of activities according to differences in the number of miners per operation, the required investment and the funding model, and the technology involved, as shown in the following table.

| Type | Number of workers | Investment in $US | Funding model | Materials mined | Mining Methods | Trading |
|---|---|---|---|---|---|---|
| Individual scraping | 1 | 10 | Worker's own resources | Pegmatite minerals (beryl, tourmaline) | Excavation less than 6 m deep, diameter 0.6 to 2m | Individual |
| Mining unit | 2 – 6 | 15 – 20 | Workers' or buyers' resources | Gold, ruby, sapphire, fine or ornamental stones, fossils, mineralogical collections | Wells up to 10 m deep or open pit quarry | Individual or collective |
| Informal cooperative | 6 – 30 | 125 – 250 | Workers' or buyers' resources | Pegmatite minerals (beryl, tourmaline, quartz, ...), ruby, sapphire, gold | Pits with 10 m sides and 20 to 25 m depth or cut face up to 50 m | Collective |
| Informal enterprise | 6 – 60 | 250 – 1250 | Promoter's resources | Gold, ruby, sapphire, garnet, emerald, labradorite | Trench, stepped pit or cut face | Collective |
| Mechanized mine | 6 – 60 | 250k – 2,000k | Promoter's resources | Ruby, sapphire, emerald, gold, building materials, industrial minerals | Open pit mining | Collective |

**Table 5. Type classification of the ASM sector in Madagascar (Source: Newsletter of former trainees of the study center of raw materials, 2004, cited by DELVE 2021).**

A recent interview with the president of the small scale mining association revealed that 90 % of the gemstone mines are self-funded and sponsoring is realized mainly by Sri Lankan or Chinese companies (personal communication with FOMM, July 2023). For 2018, the USGS estimated gemstone production to 6600 kilograms of sapphires, 180 kg of rubies, and 15 kg of emeralds, 350 t of tourmaline and 180 t of amethyst, among other gemstones. The USGS assumed that the gemstone production of Madagascar comes mainly from artisanal mining sites (USGS 2022). For the period 2018 – 2021 the annual export values for precious stones were between USD 30-40 million. The total export value for this three-year period was about USD 126 million. However, gemstones in Madagascar are not exclusively mined by artisanal miners. The USGS reports that the Norcross Madagascar Group (NMG) of the United States produced amazonite from its mine in the Amboasitra Region (USGS 2022). Additionally, there is evidence, that an Italian mining entrepreneur using semi-industrialized mining technique is currently involved in the mining of tourmaline in the region of Ibity.

Madagascar's official accumulated gold exports for the period 2018 – 2020 were about 6.7 t with a total value of about USD 257 million (UN Comtrade database). However, the 2018 National Action Plan to reduce and/or eliminate mercury in ASM in the framework of the Minamata Convention estimated annual national production for local artisanal miners at about 7.8 tons of gold while the annual production of foreign national operators (e.g., commonly Chinese stakeholders) was estimated at a minimum of 6.2 tons of gold, combining to an estimated 14 t of

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gold in 2018. In October 2020, the export of gold was suspended by the Ministry of Mines and Strategic Resources in order to address the illegal exploitation dominating the sector (DELVE 2021).

For the mica production in Madagascar the accumulated export volume during the period 2017 – 2021 was about 216,000 t of mica products with a total value of about USD 46 million. In 2019, Madagascar was the second largest exporter of mica worldwide accounting for about 32 % of the global trade. Based on the volume exported annually and estimates of productivity per miner per year, there are probably at least 20,000 people involved in mica extraction, about 20% of whom are women and 2,000 individuals are involved as sorters (DELVE 2021). However, besides ASM operators, some industrial mining companies are also involved in mica mining (USGS 2022).

While official figures on employment are sparse, artisanal and small scale mining is reported to be the second-largest job provider in Madagascar, behind agriculture, employing one million workers. Participants in the ASM sector are classified primarily as permanent or migratory/rush participants. In both cases the sector provides the allure of increasing household incomes and alleviating poverty. Despite significant contributions to the Madagascar’s economy and local livelihoods, artisanal mining has also been associated with considerably adverse impacts on health, safety, social harmony, the environment, taxation revenue, as well as corruption and illicit trade (DELVE 2021).

## 9.3 ECRM deposits amenable to ASM exploitation

From the various ECRM, nickel, cobalt, natural graphite and titanium are only mined in large-scale mining operations. The Ampasindava mine is the site for a possible large-scale rare earths mining project for ionic clays but is still on hold because of missing environmental permits and ownership problems.

Tantalite and niobium (officially exported in the form of columbite concentrate, 5.2 t Ta content in 2010), beryllium (exported in the form of beryl minerals, 25 t in 2022), lithium (exported in the form of spodumene and lepidolite ores, estimated at 6,200 t in 2022), manganese (exported in the form of ore, 1,990 t in 2020), rare earths in the form of bastnaesite (exported in the 1960s), strontium in the form of celestine (exported in the form of geodes and ore in the 1960s – 1980s), copper (exported in the form ore, 510 t in 2019) and natural barite (exported in the form of ore, 94 t in 2017) has been mined in Madagascar in the past and at present within the frame of small scale and artisanal mining activities. The production share with regard both to the global mining production or to the ASM production of these commodities can be currently considered as small to insignificant.

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### 9.3.1 Columbite-tantalite, beryl and Li-minerals

Beryl, columbite-tantalite as well lithium minerals (spodumene and lepidolite) are produced from pegmatite deposits in Madagascar (see figure below). Two types of mineralized pegmatites can be distinguished in Madagascar. On the one hand, there is the heterogeneous type with a steep quartz core and the surrounding zones of mica and large feldspar as well as the proper mining zone, containing minerals of value; on the other hand, there are the less heterogeneous, flat-bedded, albite-rich pegmatites that contain gemstones, like tourmaline and different beryl varieties, columbite-tantalite, spodumene and lepidolite (Andritzky 1998).

The heterogeneous type hosts nests of beryl, columbite-tantalite and lithium minerals (spodumene, petalite and amblygonite) in the productive zone at the edge of the quartz core. Included in the outer zone of the pegmatite white mica and sometimes cassiterite are found. The lithium-rich mica is called lepidolite and can also be extracted from pegmatites (Andritzky 1998). According to the prevailing price levels for the different minerals the mining groups working the pegmatite ore bodies change their location and their mining objective. During the high-price period for lithium in period 2021-2022, artisanal miners focused on extracting spodumene and lepidolite and abandoned tourmaline mine shafts in the same area.

The pegmatite fields Berere-Tsaratanana (a lepidolite sample from this location has been analyzed by BGR in July 2023 and resulted in 4.65 % $Li_2O$), Vohambohitra, Betsiriry, Antsirabe-Itasy, Ibity-Sahatany (a lepidolite sample from there analyzed by BGR resulted in 2.95 % $Li_2O$), Vorondolo, Analalava and Malakialina-Ampandramaika belong to this type. In the period 1950-1960, these pegmatites yielded about 300-600 t beryl, 10-20 t columbite-tantalite and lower quantities of bismuth and lithium minerals. In 1967 BGR reported that besides gemstones, lepidolite had been produced as by-product in smaller charges at the deposit of Sahatany. The lepidolite was disseminated heterogeneously in small pockets in the deposit (Fricke 1967).

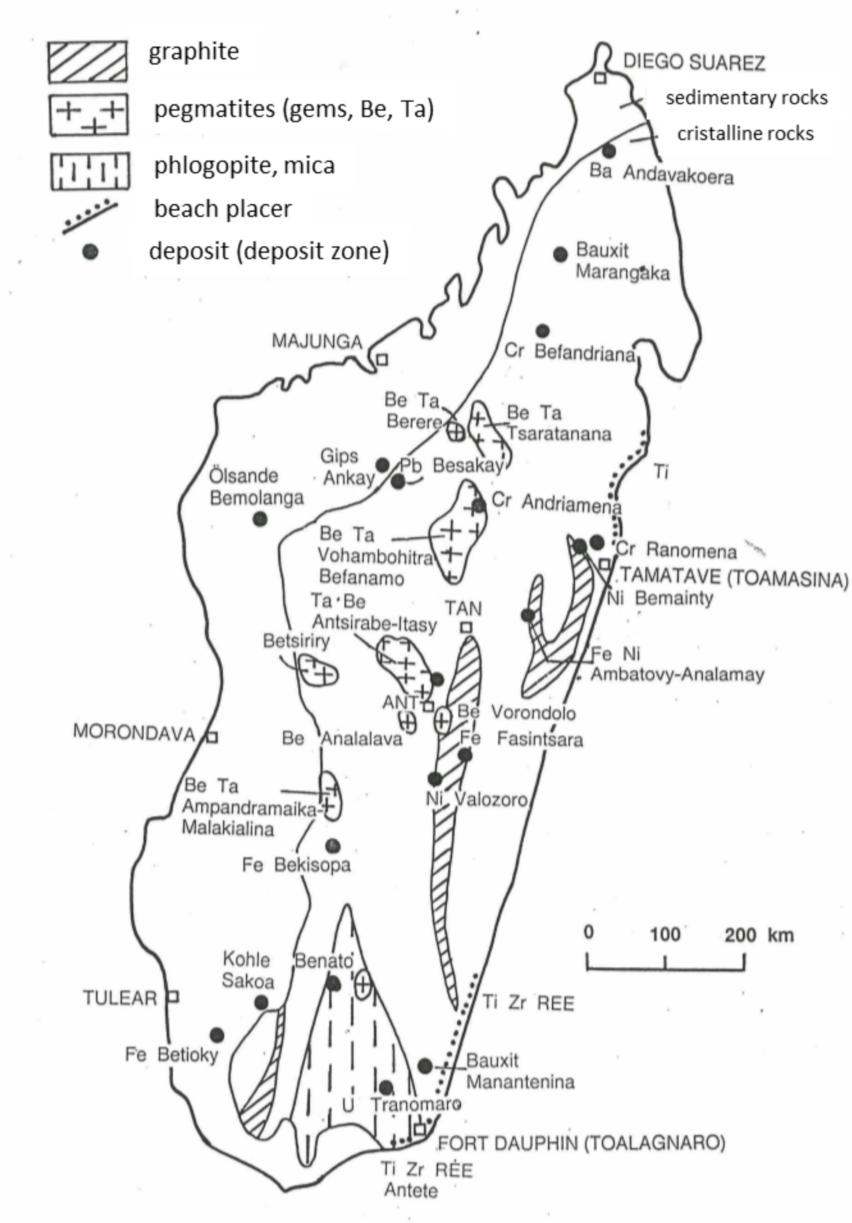


**Figure 14. Mineral deposit locations in Madagascar, without gold and gemstones (Andritzky 1998).**

A typical example of the pegmatite fields that are located in a distance of about 60-100 km east and south-east of the capital of the Vakinankaratra district, Antsirabe, and close to the city of Betafo, is the Anjanabonoina pegmatite. This pegmatite is of the sodalithic type and an important source for beryl minerals. But columbite-tantalite, spodumene and lepidolite have also been found here. The main pegmatite body at Anjanabonoina is heavily weathered and eroded, and is bounded by alluvial deposits. The shape resembles an inverted, flat, oblong dish 800 m in length and 2 to 12 m thick. The basal surface is in contact with a laterized slate, and the sides are bounded by quartzite (Wilson 1989).

Some zonar structured pegmatites in the pegmatite fields of Antsirabe-Itasy additionaly contain uranium-bearing columbite-tantalite. Around 100 tons of uranium minerals were extracted from the pegmatites in the Itasy-Antsirabe area at the beginning of the 20th century. The pegmatite field of Bevaondrano contains more than 10 pegmatite bodies. According to a reference from the geological Institute of the former German Democratic Republic, these uranium-bearing pegmatites can have ore grades of the eluvial material of 140 – 200 g of columbite-tantalite per cubic meter of ore (Institut für Mineralische Rohstoff- und Lagerstättenwirtschaft 1985).

The majority of lithium-bearing minerals in Madagascar shows lithium grades of 2-4 % $Li_2O$. This grade normally is too low to be sold as unprocessed ore to the world market. Typically, at normal price levels, the ore and concentrate grades that are needed for processing in China are at least 4 % $Li_2O$, but better 6-7 % $Li_2O$ (this is the typical grade of spodumene concentrates exported from Australia). Since the massive price increase of lithium that has begun in 2021 and continued through 2022, local market observers reported that Chinese companies were buying lepidolite and spodumene concentrates in Madagascar in order to collect and ship them to China, where the first upgrade to concentrates and then the further processing of the concentrate to the final lithium chemical product took place.

These Chinese companies in Madagascar engaged middlemen of Malagasy nationality who prefinanced the ASM activities for spodumene and lepidolite mining and facilitated interim storage of the ASM production. The prefinancing was used by the miners for the sinking of new shafts and the development of tunnels and stopes. As compensation the middlemen received the production of the pre-financed mines. After an interim peak of the Chinese business activities in 2022, in 2023 the Chinese mineral buyers started to disappear again. This is probably caused by the currently decreasing price level for lithium products on the world market.

### 9.3.2 Rare Earth Elements (Bastnaesite)

The rare earth mineral bastnaesite is a carbonate and was mined by ASM activities in the period 1960 – 1971 in the area of Marovoalavo –Ankaditany, close to the city of Ambatofinadrahana (BGR 1986). The ASM activities aimed at the outcrop of a vein and related residual enrichment zone close to the vein structure, producing between 300-600 t of bastnaesite. Both the geological structures at Maravoalavo and the similar bastnaesite structure at Ankazobe, located in the vicinity of Marovoalavo, were studied by BGR in 1980s (Andritzky 1986). The bastnaesite occurrence at Ankazobe South and North has a resource potential of about 10,000 t of ore @ 6 % bastnaesite (5.5 % REO with 1.0 % La and 3.9 % other $RE_2O_3$). The mineral occurrence of Marovoalavo – Ankaditany may still contain a residual amount of about 10 t of bastnaesite at a grade of 0.5 kg/m³; this corresponds to about 40,000 t of ore. The ore structure at this occurrence is about 400 m long, 20 – 50 m wide and has a thickness of 1 m. Local enrichment zones in this occurrence could still be of interest to artisanal miners.

### 9.3.3 Strontium (Celestine)

Celestine was exploited by ASM in the region of Sakoany close to the city of Mahajanga in north-west of Madagascar (Rieck 1988). In the period from 1965 – 1987, about 378 t of celestine ore and concentrate was produced and in part exported (BGR 1988). Apart from their use as raw material for the industry of strontium chemicals, the celestine geodes are also valuable for mineral collectors. The mining consisted of digging exploration shafts with a depth of 4 – 10 m until the sandy marl layer that contains celestine geodes is encountered (Rieck 1988). The resource potential at Sakoany was estimated by BGR to several 100,000 t of celestine. The annual global production of strontium minerals in 2022 was about 350,000 t, indicating that the resource potential at Sakoany could be significant for the global strontium supply.

### 9.3.4 Barite

The group of late Panafrican hydrothermal mineralization likely includes the Andavakoera barite veins in northern Madagascar, which also contain trace amounts of sulphides and gold. The estimated resources amount to some 100,000 t of barite (Andritzky 1998). There are indications that ASM activities in that area produce a low volume of barite.

### 9.3.5 Copper

The Vohibory stratigraphic sequence contains occurrences of sulfidic copper mineralization in quartz veins and in amphibolites. Smaller zones of near-surface cementation copper ores with contents of 10 - 20% Cu were extracted by manual means in some places. The Geological Survey of Madagascar reports a resource of about 5,000 t Cu at Besakoa (Besairie 1964). However, there does not seem to be any reserve potential for larger industrial production. The same is true for the nearby copper mineralization in Karoo sandstones (Andritzky 1998). The Geological Survey of Madagascar reports a resource of 1,500 t copper at Ambatovarahina (Besairie 1964).

In the region of Vohemar, copper containing veins in intrusive rock strata are found. The copper ore genesis is supposed to be similar to the genesis of chromite. The copper grades of the ore can be quite high; however, the iron content is also elevated. There is evidence that ASM operations produce a low volume of copper minerals as direct shipping ore.

### 9.3.6 Manganese

Manganese ore deposits are found in the regions of Mahajanga, close to the city of Maevatanana, and in the region of Ampanihy (Besairie 1964). At Ampanihy the manganese is related to the stratigraphic zones that are designated by Besairie as “System of Graphite” and “System of Vohibory”. Average ore grades are 28 – 35 % Mn. Manganese is mined in artisanal mining operations and sold to Chinese ore collectors.

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## 9.4 Artisanal ECRM mining and processing

Columbite-tantalite and other pegmatite ore minerals are produced by ASM in the above-mentioned pegmatites. The advantage of mining in the majority of pegmatites in Madagascar is the strong weathering and alteration of the feldspar contained in the pegmatite bodies close to the surface. Similar to artisanal pegmatite mining in Central Africa, this makes digging, washing and concentration of the stable columbite-tantalite, beryl and spodumene crystals relatively easy, as no blasting and crushing is necessary. On the other hand, it is more difficult to mine underground in the soft rock or to establish an open pit with stable pit walls, making mining more dangerous.

Due to the heavily altered pegmatites, mineral concentrates can be produced by simple manual ore washing techniques, e. g., in a washing pan. In order to be capable of processing the ore, ASM workers regularly work in the rainy season. This may lead to slope stability issues and mining accidents, as the clayey material surrounding the open pits often starts to slide into the pit in wet conditions. Most mines targeting columbite-tantalite and gemstones that, in the past, used mechanized mining equipment have now been closed for economic reasons. Currently, most mines use manual technologies for the ore extraction and separation, like hammer, chisel, crowbar and wooden hand hoist. In a few more industrialized mines, pneumatic or electric pick hammers for the extraction and water pumps for drainage are in use. The maximum mining depth officially accessible to ASM in Madagascar is limited by the mine safety regulation to 20 m. This also limits the exploitability of targeted pegmatite deposits.

## 9.5 Production and trade patterns

### 9.5.1 Lithium

As shown in the figure below, exports of lithium ore and concentrates have increased from a very low level of several dozens of tons in 2018 to about 6600 t in 2022. In 2023, during a field visit by the authors, the national mining association estimated the production capacity for lithium minerals at about 1000 t/month; it could probably still increase in the future. The bottleneck for the production is the local transport infrastructure.

The value of the lithium ore exports to China in 2022 was about USD 8.7 million. The spodumene is sold at the mine site with a price of 600 ariary/kg that corresponds to about EUR 120 /t. The Li-bearing mica lepidolite is sold at 3000 ariary/kg that corresponds to EUR 600 /t. The usual value of white mica at the mine site is only EUR 30 /t. The price difference between spodumene and lepidolite can be explained in part by the generally lower lithium grades of spodumene ore compared to lepidolite ore in Madagascar but also reflects the difference in demand. Supposing an average export value of EUR 1200 /t it can be concluded that mine site return is between 10 and 50 % of the export value. The average export value of spodumene concentrate from Australia

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in 2022 was about USD 3,000 per ton. The higher value of Australian spodumene to lithium minerals from Madagascar is caused by the higher grade of $Li_2O$ (about 6 % compared to 3 – 4 %) and the lower bulk transport costs for the shipment from Australia.

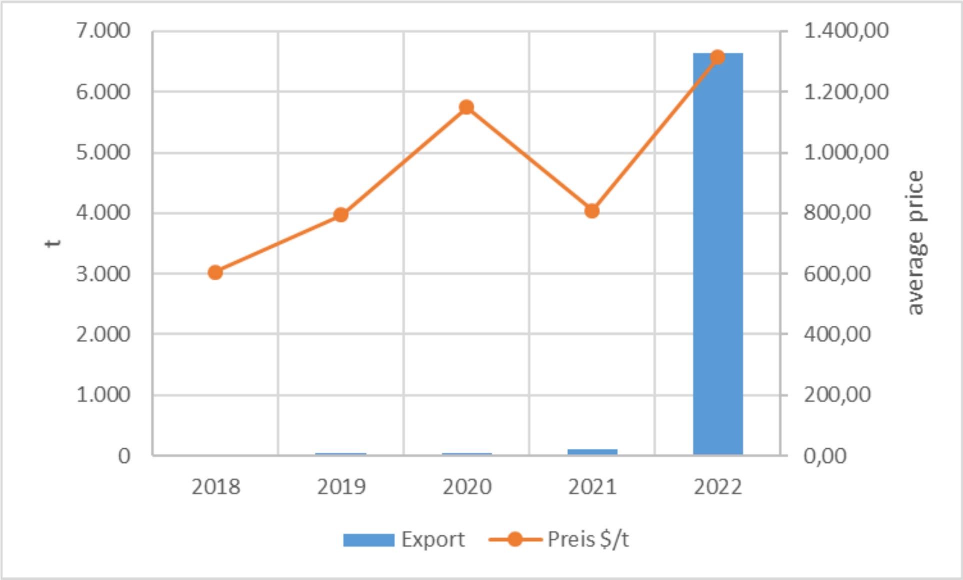


**Figure 15. Exports of assumed lithium-minerals (HS code 253090) from Madagascar to China and their average prices (UN Comtrade database).**

In July 2023, during a field visit by the authors, a lithium miner and trader close to Ibity reported that currently their trade volume is about 25 – 26 t of lithium minerals every 2 weeks and that they sell their production to Chinese companies which carry out the export to China. The $Li_2O$ content of the spodumene concentrate that is coming from their own concession is 4 – 5 % $Li_2O$ and the grade of lepidolite that they buy and sell as middlemen is about 2 – 2.5 % $Li_2O$.

### 9.5.2 Beryl

In the period from 1948 – 2022 a total of about 8,000 t of beryl was produced in Madagascar (see figure below). This represents a share of about 1.7 % of the global production in the same time span and represents a rather important mineral volume. For 2018, the USGS reported an estimated production 16 t of beryl in quartz concentrates (USGS 2022).

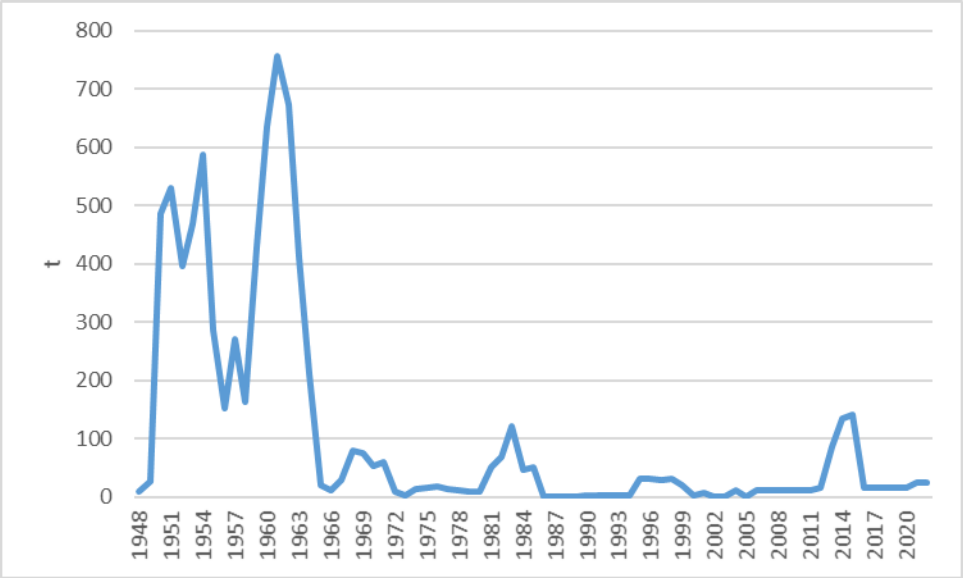


**Figure 16. Historical annual production of beryl concentrates in Madagascar (BGR raw material database 2023).**

### 9.5.3 Copper

With reference to international market prices, the average price level of copper exports suggests an average copper content of the ore around 10% Cu. It can be assumed that the exports of copper minerals are derived from ASM production. The grades of the exported copper ores can be as low as 4 – 6% Cu, on average they are 10 – 15%, and exceptionally they contain to 30% copper; the latter corresponds to the copper content of copper minerals like chalcopyrite (ca. 34% stoichiometric Cu content).

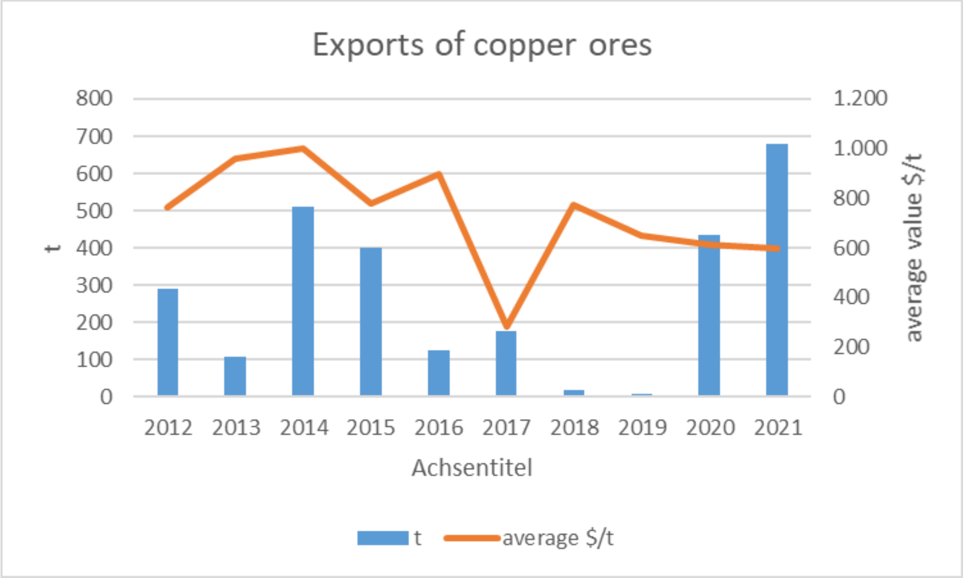


**Figure 17. Exports of copper ores from Madagascar (UN Comtrade database).**

### 9.5.4 Manganese

There is a recent increase in the export volume of manganese ore. In 2020 about 2,000 t ore were exported mainly to China. The unit value of these exports was between USD 100 – 300 per ton over the past decade. Typical manganese ore for the local exports has manganese grades between 28-35%. Upgrading or smelting of the ore does not take place in Madagascar.

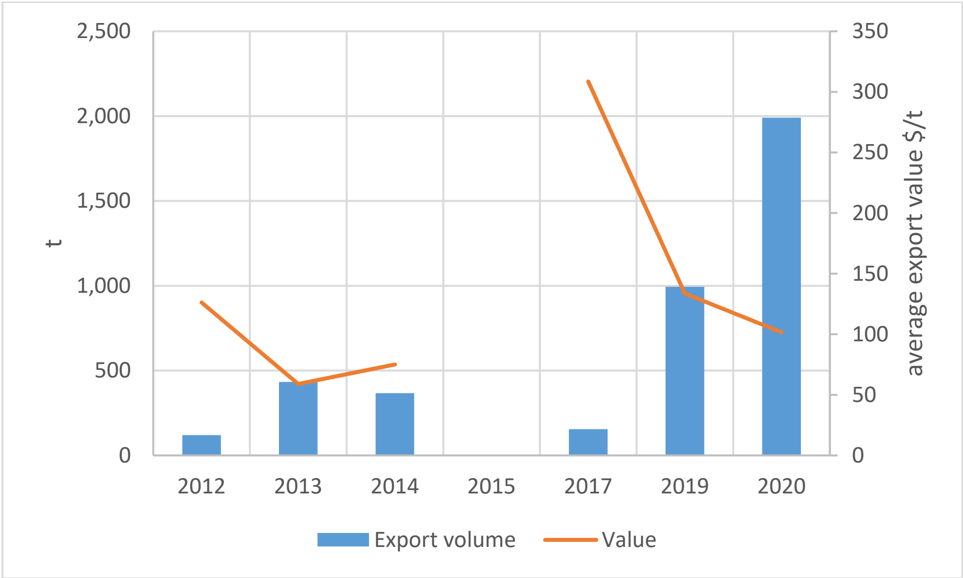


**Figure 18. Exports of manganese ores from Madagascar (UN Comtrade database).**

### 9.5.5 Columbite-tantalite

There is evidence from local market observers that the current mining capacity for columbite-tantalite in Madagascar is about 62 t of concentrates per year. The average grade of the exported coltan concentrate is about 8 – 12% Ta and 27 – 33% Nb. An important by-product of coltan mining is beryl. Presently, the production is sent to the Chinese market that, according to local sources, offers higher prices than the Indian market, which also used to purchase columbite-tantalite concentrates from Madagascar in the past. The export grade is controlled by the exporter using handheld X-ray fluorescence analysis. Either the tantalum or the niobium content of the coltan concentrate is paid for in commercial transactions. Usually, the tantalum content is the base for the transactions. Since the niobium content of some concentrates is quite high, this practice is considered as unfair by Malagasy miners. A problem for exports is the scarcity of valid small-scale mining licenses, proof of which is a precondition for obtaining an export permit.

## 9.6 Potential future ASM ECRM production opportunities

Developing the ASM sector in Madagascar will require comprehensive reforms in terms of sector formalization and government support. A first hint of the ASM ESRM potential can be obtained by the small-scale mine permit register of the national mining cadastre, BCMM. The permits in different stages of progress have a total number of about 42,000 squares (carrés) and cover about 14,500 km² of surface area of Madagascar. The distribution shown in the figure below illustrates that beryl has the most mentions in small-scale mining licenses. It should be kept in mind that other minerals, such as gemstones, columbite-tantalite and cassiterite are closely associated with beryl in pegmatites.

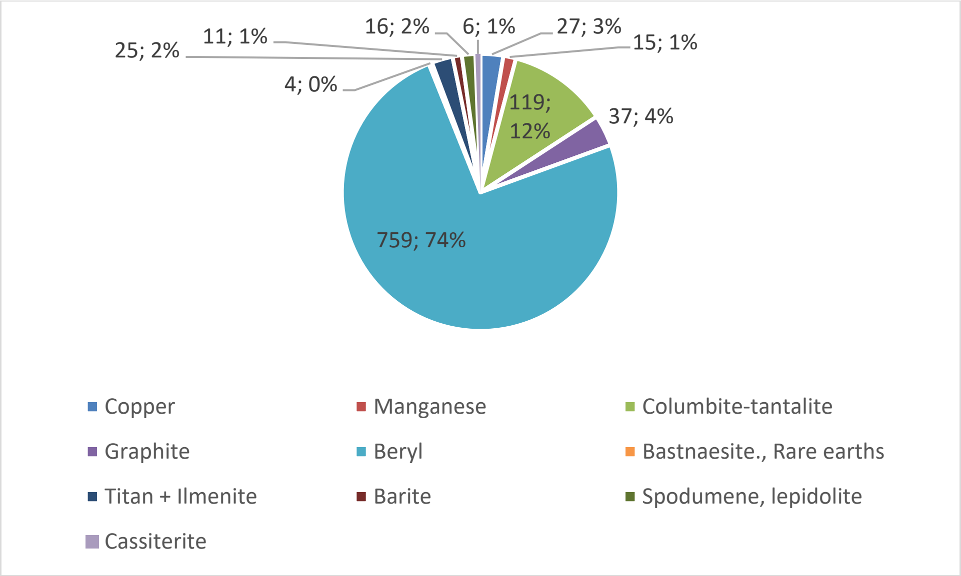


**Figure 19. Number of small-scale mining permits (PRE) in Madagascar with corresponding ECRM mining target (multiple denominations are possible; data used with kind permission of BCMM).**

The ASM sector in Madagascar could increase its supply of ECRM, especially that of lithium ores and columbite-tantalite concentrate, if modern equipment/tools were introduced in order to improve the mining and processing productivity. At the same time, the transport infrastructure requires improvement, for instance by developing road transport, harbour warehouses and ship loading systems. A possibility to increase the general mining efficiency of the ASM sector would be the introduction of multi-element mining processes, since the ASM mining groups usually focus only on one particular type of commodity, even when there are several possible mining by-products.

Since 2021, lithium has become an attractive commodity for ASM, as prices grew tenfold compared to the late 2010s. In 2022-2023 they are still far higher than the levels seen prior to 2021. Additionally, it is nowadays possible, at least in China, to process lepidolite ore and produce lithium chemicals from the contained lithium. In Madagascar, besides lepidolite, spodumene is probably of high interest as the spodumene from deeper underground mines, in contrast to the weathered surface near ore zones, is frequently not altered or weathered, resulting in relative high lithium grades of the mineral. Concerning lepidolite, there is only very limited information available on the tonnage contained in the pegmatites; however, there are indications of areas of rich lepidolite zones in pegmatites.

Columbite-tantalite is a commodity with a steady, but low output from the ASM sector in Madagascar. The current number of artisanal miners producing columbite-tantalite is small and exports are hampered by missing export licenses. This also has to do with mining sector restrictions currently set by the government. There are numerous pegmatites containing columbite-tantalite mineralization. Several pegmatites have already been in production for a long time and therefore the easily accessible parts of the deposits have already been mined out. It is possible that there are more pegmatites with favourable preconditions like grade, distribution and grain size of the columbite-tantalite grains that make them a good target for ASM activities. The production could possibly be increased by a stronger focus on exploration, although this would require further pre-financing by supply chain partners as well as formalization and support.

There are geological reports and evidence from the past mining history indicating that the artisanal mining of celestine, a strontium mineral, could experience a revival. The current artisanal miners do not seem to remember the past celestine mining activities since no small-scale mining license mentions celestine or strontium minerals as a mining target.

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# 10 Morocco

## 10.1 Background

Since 1960, almost all ASM operations in Morocco are found in the mining regions of Tafilalet and Figuig (NE Morocco) where they have been governed under a special mineral regime—the Zone Centrale d'Achat et de Développement de la Région Minière du Tafilalet et de Figuig (CADETAF—Central Purchasing and Development of the Tadialet and Figuig Mining Region). This ASM area is separate from the 1951 mining regulations, which cover all exploration and exploitation of large-scale operations in the rest of the country. Designed in part to address the increase in informal ASM activities that had overtaken the area following the collapse of industrial mining operations in the 1950s, the decree of 1960 (Dahir no. 1-60-019) created the Zone CADETAF to formalize and manage small-scale mining operations of barite, lead, and zinc. The CADETAF zone, bordering with Algeria, has a surface area of 60.000 km² and is largely covered with desert. The CADETAF public institution was created at the same time. CADETAF reports to the Ministry of Energy, Mines, Water and Environment and is mandated to manage and provide technical support services to small-scale miners operating in the zone, conduct research and exploration, and help commercialize and develop production (Essalhi et al. 2018).

## 10.2 Overview of the national ASM sector

In 2021, the country produced 38.1 million tons of phosphate ore with a value of US$ 10.5 billion. Beyond phosphate, Morocco is also recognized for its global output shares of arsenic (12%), barite (15%), cobalt (1.4 %), fluorspar (0.9 %), silver (0.75 %) and lead (0.65 %) (USGS 2022). Of these, barite is the only mineral, which has a considerable portion derived from artisanal and small-scale producers, estimated to account for 30 – 50 % of the country's production. In the period 2016 – 2020 the ASM sector in Morocco was producing about 4.5 – 7.5 % of the global barite supply (CADETAF 2020). Traditionally, ASM activities also exploit small amounts of lead and zinc ores that usually are not associated with barite veins. However, in industrial mining in Morocco it is common to exploit vein structures that contain lead, barite and fluorspar minerals in complex ores (BGR 1975). More recently, the southern part of the country has witnessed a growth in small-scale gold mining (DELVE 2019).

## 10.3 ECRM deposits amenable to ASM exploitation

For a long time, the Drâa-Tafilalet region had an appreciable silver-cobalt-zinc-lead-barite production that are frequently related to the same type of geological setting. Several hundred of zinc-lead-barite veins are known and have been the subject of mining works. Most barite veins deposits are hosted in the Anti-Atlas part of Drâa-Tafilalet region that is made of Precambrian bed-rocks and their Paleozoic cover. Details are shown in the following two figures[3]. No barite deposits have been found in the Hamada and Ouarzazate-Boudenib basin. Only a few deposits are located in the Jurassic series of eastern and central High Atlas and in the Variscan inlier of Ahouli-Mibladen (Essalhi et al. 2018). Besides barite veins, stratabound and the karstic deposit type are also found. The latter two types are more appropriate for industrial barite mining.

In ASM of barite veins in Morocco, the important geological data of the vein thickness, depth and lateral extension of the vein structure and of the ore quality are mostly unknown when mining starts, since exploration work is not done in advance and, as a result, a mine planning does not exist. The mining operation is starting at the outcrop and carried out for as long as the mine revenues cover the operational costs, resulting in a high barite price dependency of the activity.

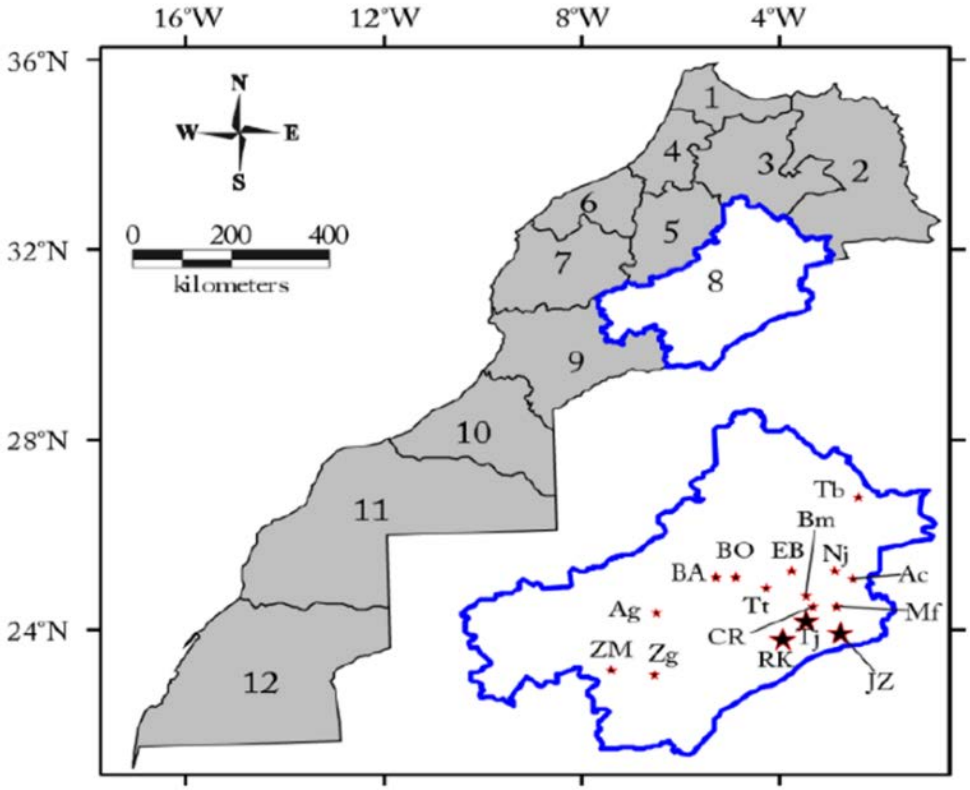


**Figure 20. Geographical position of Drâa-Tafilalet region in Morocco, and position of some artisanal barite mining zones into the region (map of the region in blue; Essalhi et al. 2018).**

[3] Regional abreviations used in the map: Ac- Achguig, Ag- Agdz, BA- Bou Adil,Bm- Boumaiz, BO- Bouizriri Ouest, CR- Chaib Ras, EB- Erfoud Boulaagadi, JZ- Jbel Zorg, Mf- M'fis, Nj- Njakh, RK- Ras Kammouna, Tb- Tabouaroust, Tj- Tijjekht, Tt- Tikertouchène, Zg- Zagora, ZM- Zagora Milha.

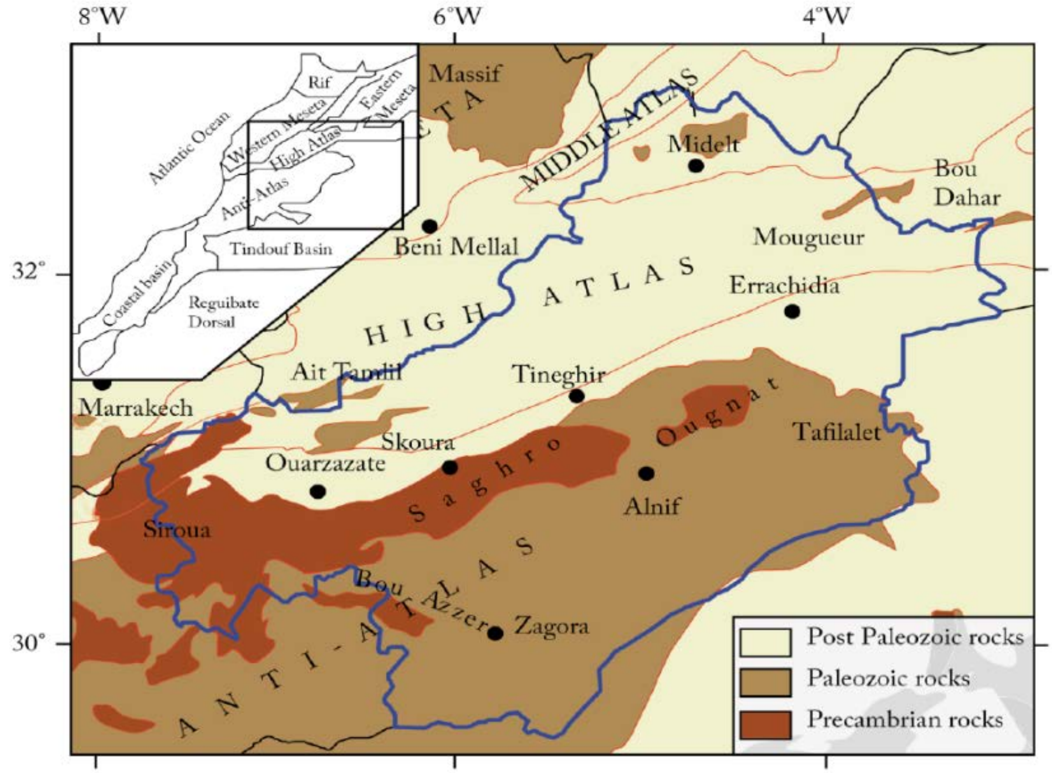


**Figure 21. Geological map of Morocco's Drâa-Tafilalet region showing the Anti-Atlas zone that is relevant for barite mining (Essalhi M. et al. 2018).**

According to data provided by Essalhi et al. (2016), typical dimensions of barite veins that are mined with ASM techniques are 400 – 2000 m length, 40 – 130 m depth and 3 - 8 m thickness, resulting in an ore tonnage of 250 – 500,000 t per vein. This corresponds to the average annual ASM production of barite in Morocco. Assuming the geological occurrence of about 100 veins in the Tafilalet and Figuig region and considering that the historic barite production started about 70 years ago, the remaining barite resources would suffice for at least another 30 years of ASM production, without changing the currently employed mining technology.

## 10.4 Artisanal ECRM mining and processing

Since the known barite vein deposits outcrop, they are easy to discover and can be exploited by simple mining methods, derived from quarrying. Generally, the mines workings in the CADETAF zone show no modern mechanized mining techniques. Usually, the mines follow the sub-vertical vein structure and progress from the surface to the depth (max. depth until 130 m) producing a trench-like open void. A few mines also construct shafts and underground stopes, but this is less frequent. The hard rock in the mine is drilled and blasted and the fragmented ore is hoisted to the surface by using cranes that are located at the void edge. At the surface, the ore is separated from the waste material by handpicking and the high-grade ore is transported by trucks to stockyards of CADETAF. There, the run-of-mine ore is assayed and sold to industrial barite processing plants in Morocco. The quality of the barite ore is mostly complying with the American Petroleum Institute standard for the preparation of drilling muds. In such a way, only crushing and milling has to be realized in the industrial processing plant and a further upgrading of the $BaSO_4$ contents is not necessary.

## 10.5 Production and trade patterns

CADETAF is responsible for the commercialization of the small-scale mining production. From the official selling price that is derived from auctions or is negotiated directly with industrial buyers in Morocco the transport costs and the administration costs of CADETAF are deducted and the net value is disbursed to the miners (CADETAF 2020). However, currently most of the barite production in Morocco is coming from industrial mining operations including the by-product barite production from lead mining. The following table presents the ASM barite production in the period 2016 – 2020 and its commercial parameters. In 2020 the ASM barite production was sold to 12 Moroccan companies. The largest buyers were Broychim with a share of 52% and ADO Barite Morocco with a share of 24% of the ASM production in 2020.

| ASM Production of barite | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|
| Barite ore mt | 298617 | 472102 | 516390 | 538360 | 331744 |
| Average Buying price DH | 500 | 400 | 350 | 350 | 285 |
| Exchange US$/DH | 0,102 | 0,103 | 0,107 | 0,104 | 0,105 |
| Buying price in $ | 51 | 41,2 | 37,45 | 36,4 | 29,925 |
| Total value of production M$ | 15,229 | 19,451 | 19,339 | 19,596 | 9,927 |
| Avg return at mine site | 72% | 62% | 69% | 69% | 64,50% |

**Table 6. ASM production of barite in Morocco (DH = Dirham).**

The production decline in 2020 showed that the ASM sector was significantly affected by the impacts of the Covid pandemic that also influenced the global economy negatively. It is interesting to note that in 2020 about 185 small-scale operations were still active with a total number of about 1066 miners (including lead and zinc mining). That is a significant decline against 298 ASM operations in 2019. The average revenue for a barite miner in 2020 can be calculated to at least US$ 9300/yr, that is a significant income considering the remoteness of the region and that the average Gross National Income in Morocco is only about US$ 4000/yr.

## 10.6 Potential future ASM ECRM production opportunities

ASM activities in Morocco could play a role for the European supply with barite since the Moroccan ASM share in global barite production is at least 4.5%. However, currently the ASM production is mostly sold to the petroleum industry that use the American Petroleum Institute standard to control the quality of barite products. The ASM mining activity of the barite in Morocco suffers from many problems and dysfunctions related to exploration, exploitation and treatment. This situation decreases the economic value for the barite at the mine sites (Essalhi et al. 2018).

Most of the barite veins are exposed on outcrop; therefore, the artisanal miners use trenches to extract barite, they rarely use shafts and galleries in underground mines. Consequently, the deep part of the barite veins is abandoned as soon as the extraction becomes delicate and expensive. The accessible barite resources in the ASM sector could be increased if modern underground mining systems were introduced. This would help to maintain the supply of barite from the ASM sector in Morocco to the EU over longer periods. The UN Comtrade database shows that at least 50% of the natural barite exports from Morocco in 2020 was sent to European countries.

The extracted barite ore at the mine site is only handpicked and at the CADETAF stockyard, the ore is not subjected to any type of processing or dressing like, for example, washing, jigging, flotation, crushing or grinding. The introduction of enhanced processing techniques could improve the grades of the barite products and reduce the amount of harmful substances, opening the way to barite markets other than the petroleum industry. However, the scarcity of water needed for most processing activities would present a challenge in the CADETAF zone.

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# 11 Mozambique

## 11.1 Background

The majority of the Mozambican small-scale miners is working on state owned land without any mining permits, making the activity illegal for many miners. The government is conducting controls both of the legal and illegal ASM sites in the whole country, with a special focus on mine safety and the use of mercury in gold mining. Despite being illegal, most ASM sites are not closed by the government, because the government tries to convince the miners to build cooperatives and to apply for a mining concession as cooperative. These cooperatives are in some cases well organized entities and sometimes only loose groups of workers.

## 11.2 Overview of the national ASM sector

The majority of ASM workers is working in gold, followed by construction material, clay and sand, and then by precious and semi-precious stones. Critical raw materials mined via ASM in Mozambique comprise tantalum and, very recently, lithium. There is also an unknown quantity of niobium contained in the tantalite concentrate, but the miners only get paid for the tantalite. Mining of these commodities only represents a very small part of the national ASM sector. There are also reports about cassiterite bearing pegmatites in Alto Ligonha (Naiuma pegmatite and others), but ASM mining for tin (Sn) is not reported.

The ASM sector in Mozambique was assessed in 2021 by the Ministry of Natural Resources and Energy (MIREME 2022) and the National Statistics Institute (INE). A total of 1577 active ASM sites were visited, representing according to the statistics 229,680 miners. One ASM site in this assessment "Censo" does not correspond to one individual group of workers or to one smaller cooperative, but to a focal area ("focos" in Portuguese) of small-scale mining activity instead. The 483 ASM sites for gold are on average involving almost 300 miners each. Almost 60 % of the total number of small-scale miners in Mozambique are working in the gold sector. Another 23,000 (10 %) are working in the mining of precious and semi-precious stones. Another big area of small-scale mining are construction materials, including clay for brick production and sand and rocks for construction. There are more than 900 focal areas for these small-scale mining activities with almost 70,000 miners. Small-scale coal mining is playing only a minor role with 8 focal areas and only some 500 miners, although large scale coal mining is the most important mining activity in Mozambique. However, in Mozambique the coal is not used for heating and for cooking due to harmful elements contained in the mined coal. Instead, charcoal is used for these purposes. Tantalite is mined in the Zambezia Province in 14 small-scale areas (Alto Ligonha pegmatites), but only 172 miners are involved, according to the Censo from 2021.

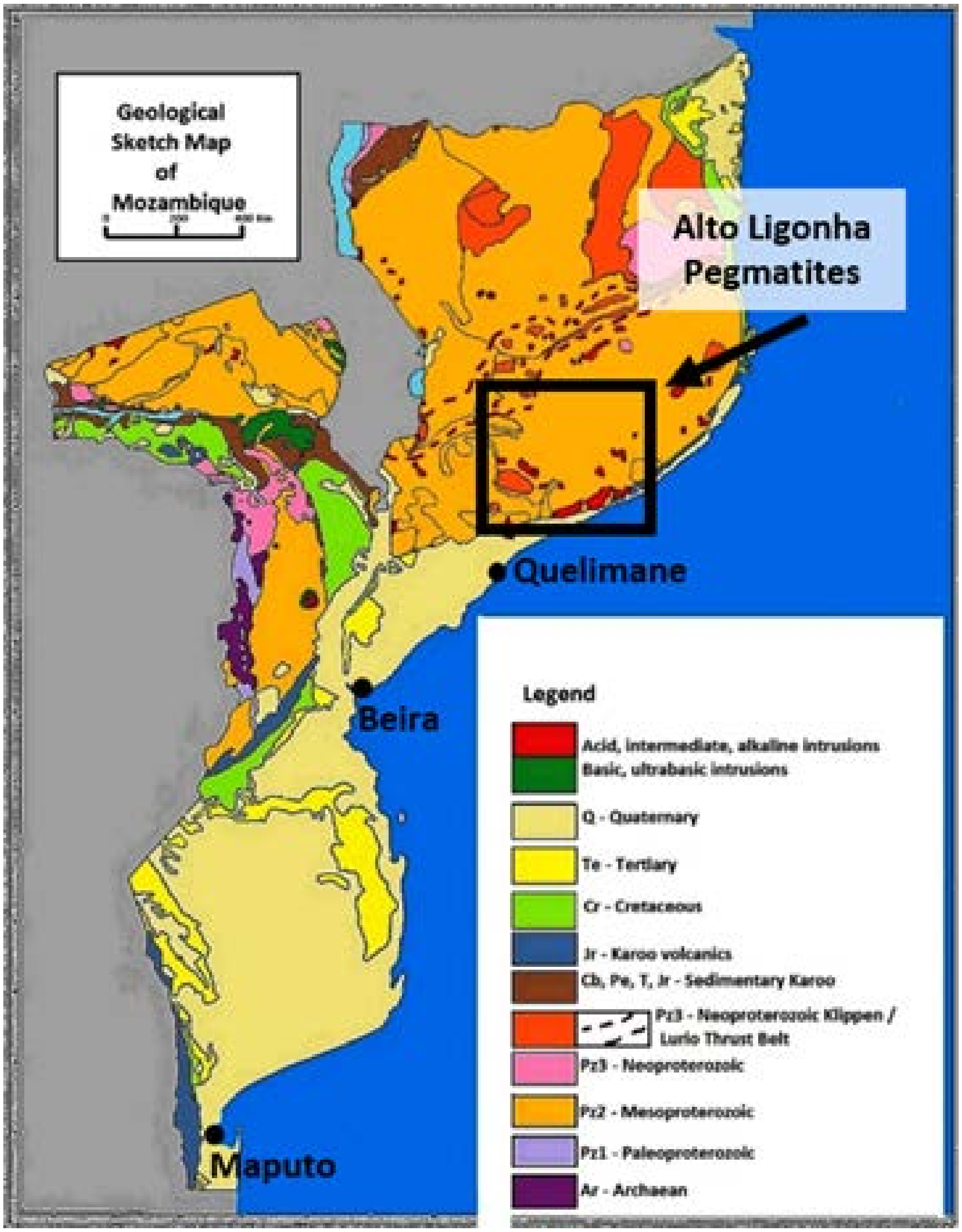


**Figure 22. Geology of Mozambique, including the main area of ECRM production of niobium and tantalum (Lächelt et al. 2019).**

Other sources focusing on the ASM sector of 3TG in Mozambique (BGR 2022) provide figures of 100,000 to 200,000 miners (referring to IGF 2017; Mondlane 2017) in the small-scale sector of Mozambique, which is comparable to the above mentioned figures, however, these numbers do not include the 70,000 people working in the mining sector of sand, clay and construction material. The above mentioned BGR study (BGR 2022) also reports a high degree of informal miners, too. This shall be caused due to high structural barriers to formalization.

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Graphite is not included into any report on small-scale mining, although this commodity is abundant in Mozambique and, elsewhere, is usually mined in relatively small industrial mining operations and ASM. Small-scale mining on this raw material is known from many other countries, e.g. the neighbouring Tanzania, although only in small quantities.

The Censo (MIRIME 2022) also gives many details about additional mining service providers, apart from the miners, including workers whose only task is, for example, to carry ore material, to process the ore, to supply food for the miners, or to provide other services including the trade of the raw materials. According to the Censo (MIREME 2022) around 800,000 people are directly or indirectly working in the ASM sector. But there also some inconsistencies in the report. The revenue of the 230,000 small-scale miners is given with 1.85 billion Metical, which is equivalent to only around USD 30 million. This translates to an average income of the miners of only USD 130 per year, although 75 % of the miners reported ASM as their principle source of income. Additionally, the Censo (MIREME 2022) gives an average artisanal miners' income per month of 5,816 Metical, which corresponds to around USD 90 per month. Extrapolating this monthly income of USD 90 per worker to the annual income of all small-scale miners would correspond to around USD 250 million or 15.8 billion Metical. At current gold prices, this value is equivalent to around 3.6 t of Gold, an amount that is roughly reported as imports from Mozambique by the United Arabian Emirates (UN Comtrade Database 2023).

## 11.3 ECRM deposits amenable to ASM

From the various ECRMs only tantalite has been mined in Mozambique in the past and at present. Average production of industrial mining (relatively small-scale) and ASM together, has been around 40 t of $Ta_2O_5$ per year. Tantalite occurs in LCT (Lithium Caesium-Tantalum) pegmatites, which occur in the Alto Ligonha area in the Zambezia Province. Lithium is also abundant in these pegmatites but has not been mined in the past, as the grades of the lithium bearing minerals were usually too low or the minerals could not be processed economically. There are several reports about the pegmatites of Alto Ligonha. Especially Lächelt (2004), Lächelt et. al (2019), Leal Gomes et al. (2008) and Marques (2017) give a good overview about the pegmatites. Since 2021/2022 there are reports that lithium was mined in smaller industrial operations and also by ASM, mainly in the form of petalite, a lithium containing mica. A third commodity that has a potential to be mined by ASM is graphite, which is abundant in various known deposits. It is currently mined by Syrah Resources in the Balama Project, which is currently the biggest single graphite mine in the world and a smaller operation (Ancuabe) by GK Ancuabe. Both deposits are mined in open pits. There are several additional deposits with high grade and tonnage especially in the Cabo Delgado Province in the north of Mozambique. Although mining of graphite by small-scale miners is known from different parts in the world, there are no reports about such activities in Mozambique. One reason might be the lack of experience in this sector or the lack of transport infrastructure to ship graphite ore to processing facilities abroad. Due to the relatively low value of such ores or pre-concentrates the transport is more difficult to manage compared to gold, precious stones or tantalite.

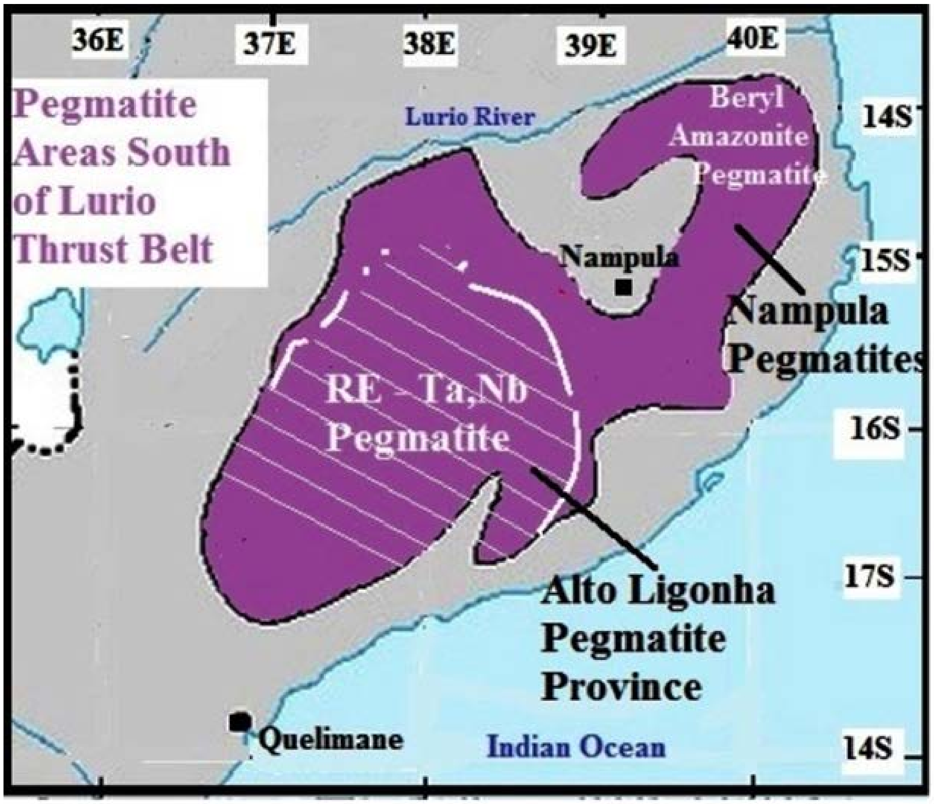


**Figure 23. Location of the main zone of tantalum- and niobium-bearing pegmatites (Alto Ligonha pegmatites), north and northeast of Quelimane, Mozambique (Lächelt 2004).**

The Alto Ligonha Pegmatite Province forms part of a 170 km long belt, orientated northeast–southwest and extends from Mocubela, in the south, to Alto Ligonha, in the north. Numerous other smaller, less significant pegmatite districts are located in this belt, within an area of approximately 200 km radius around the town of Alto Ligonha. The entire region is referred to as the Alto Ligonha Pegmatite Province or the Northern Mozambique Pegmatite Province and encompasses almost every pegmatite in Mozambique (Dias & Wilson, 2000; CGS, 2006). Currently there is only one pegmatite mined using a mechanized process. This deposit is named Morrua. Most of the pegmatites tend to be subeconomic when evaluated for mining in recent years. In order to achieve mining feasibility the pegmatites rather need to be assessed on the basis of all their exploitable mineral assemblages. The pegmatites in general contain a complex mineralogy of which the following have been recovered in the past and are of potential economic importance:

- - Rare metals, especially coltan;

- - Lithium minerals;
- - Rare-earth and radioactive elements;
- - Gemstones and mineral specimens;
- - Industrial minerals like quartz, feldspar and kaolinite.

Most mines aiming for tantalite that used mechanized mining equipment in the past have been closed for economic reasons. Since 2010 artisanal workers took over several mines like Muiane, Naipa, Morrua, Marropino, Nampossa and Mita located in the Alto Ligonha pegmatite province. Nevertheless, the figures from the latest Censo show that now, only 172 miners are involved in ASM mining of tantalite. The concentrates also yield niobium, but the miners only get paid for the tantalite. Tin is also abundant in several pegmatites, but the grades are either too low or the enriched zones too small. ASM is not mentioned in the Censo of the Ministry of Mines and Energy (MIREME 2022). The advantage of doing mining in the majority of pegmatites in Mozambique is the strong weathering and alteration of the feldspars in the pegmatite body, which makes digging, washing and concentration of the stable tantalite crystals relatively easy, as no blasting and crushing is necessary. On the other hand, it is more difficult to mine underground or to establish an open pit with stable pit walls, making mining more dangerous. Due to the heavily altered pegmatites, tantalite concentrate can be produced with a washing pan. To be capable to process the ore, ASM workers regularly work in the rainy season. This may lead to slope stability issues and mining accidents, as the clayey material surrounding the open pits often start to slide into the pit in wet conditions.

Official figures for tantalite production (concentrate tonnage; grade/tantalum content not provided) in 2019 gave 131 tonnes, increasing to 209 tonnes in 2020 (EITI, 2020; INAMI, 2020). There are three principal tantalite producers in Zambezia Province, with the majority of official production conducted by the Highland African Mining Company who own three active mining concessions for tantalite and associated minerals totalling an area of around 15,000 ha in Zambézia province (Mining Cadastre). The company reported a production of 173 tonnes in 2020 (83% of total official production) and 101 tonnes in the first half of 2021 (87% of total official production; INAMI, 2020), resulting in an ASM production of 36 t

Due to the high degree of alteration most of lithium bearing minerals, like spodumene, have also been altered/destroyed. The majority of Li-bearing minerals shows lithium grades of 2% $Li_2O$, too low to be sold as unprocessed shipping ore to the world market, which needs ore and concentrate grades of at least 4%, but better 6 -7 % $Li_2O$. During the price increase of lithium that began in 2021, it has been reported that Chinese companies were buying lepidolite concentrates in Mozambique, to collect and ship them to China where they first upgrade the ore to concentrates and then the further process the concentrates to the final lithium carbonate product. According to the Instituto Nacional de Minas (INAMI) this process is illegal, as there are no concessions for petalite mining in Mozambique. Therefore, INAMI also did not approve the application of a petalite concentration plant in 2022/2023, as the applicant could not explain from which mines or ASM sites the feed material would be sourced.

It is possible, that there still is a potential for Li-bearing pegmatites, especially in areas of less altered pegmatites, but the general geological lithium potential is assumed to be small to medium.

## 11.4 Artisanal ESM mining and processing

Currently, only tantalite and the lithium containing mica petalite are ECRM being produced by artisanal miners in Mozambique. The amount of petalite is completely unknown, as ASM mining is not done by cooperatives with a valid mining license, but only by individual small scale miners, who trade their production illegally. Lepidolite mining is not included into the Censo of 2022 (data from 2021), although it is known that mining activities for Li-containing lepidolite began during the price boom in 2021.

Tantalite is produced by ASM in the above-mentioned pegmatites of the Alto Ligonha area in the north of the Zambezia Province. Due to the usually strong alteration of feldspars, the pegmatites cannot be mined underground. The minerals can be extracted relatively easy by shovels. The concentration is done by hand panning, especially in the rainy season. Some material is also reported to be sold to larger mechanized companies that use jigs and shaking tables for the concentration process. One issue of tantalite concentrates is the high radioactivity, due to contained uranium and thorium in the minerals. In some cases, concentrates have to be diluted, in order to reduce the level of radioactivity. Export of radioactive material up to class 7 is possible from the port of Nacala.

## 11.5 Production and trade patterns

Production levels can only be given for tantalite concentrates. According to INAMI statistics (INAMI 2020), 10 - 20% of the annually mined tantalite is produced by artisanal miners. The production of tantalite in ASM and industrial deposits has been relatively stable in the last ten years. According to BGR estimates the average annual tantalum production in Mozambique was around 50 t of tantalum content. Official figures are difficult to interpret, as there is only the tonnage of the exported concentrates provided, without the grade. These 50 t would lead to an ASM production estimate of 5 - 10 t of contained tantalum per year. The main shipping destinations of both the ASM and industrial tantalite production in Mozambique are Thailand, China, and the USA.

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## 11.6 Potential future ASM ECRM production opportunities

Since 2021, lithium has become an attractive commodity for ASM, as the international lithium price grew tenfold and is still (2023) far higher than the levels seen before 2021. Additionally, it is nowadays possible, at least in China, to process the lithium containing mineral lepidolite and to transfer the contained lithium into lithium carbonate. In Mozambique, spodumene is probably not considered as the lithium containing mineral of highest interest, as the surface near spodumene is frequently altered and/or heavily weathered, resulting in reduced lithium grades of the mineral. Concerning lepidolite, there is only very limited information available on the tonnage contained in the pegmatites of Alto Ligonha. In the pegmatites of Muiane, Morrua, Naipa, Moneia and Maria I, there are reports of areas of pure lepidolite zones (Correia Neves et al. 1972). Unpublished reports of INAMI mention the exploitation of smaller pegmatites by artisanal miners, but no numbers of produced tonnage can be given.

Tantalite is a commodity with a steady output from the ASM sector in Mozambique. However, currently the number of artisanal miners producing tantalite is small. There are numerous pegmatites containing columbite-tantalite grains. Several pegmatites have already been in production for a long time and, therefore, the easily accessible parts of the deposits have already been mined out. It is possible that there are more pegmatites with preconditions like grade, distribution and grain size of the tantalite crystals that make them a good target for ASM activities. The production could possibly be increased by a stronger focus on exploration, but the current circumstances in Mozambique itself as a mining country and on the world market for tantalite seem to hinder a higher production.

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# 12 Namibia

## 12.1 Background

In Namibia, the term "small-scale mining" (SSM) is used as opposed to artisanal and small-scale miners (ASM). SSM refers to mining with minimal machinery and/or simple technology with very low capital requirements (Linus, 2023). Throughout its history, Namibia has been renowned for its diverse range of high-quality semi-precious stones. SSM and prospectors are primarily responsible for extracting these stones, with most mining activities concentrated in three regions: //Kharas, Erongo, and Kunene (Figure 24). Due to the limited economic feasibility of large-scale mining operations, small-scale miners rely on basic equipment and simple technology to exploit small mineral deposits. Compared to other nations, Namibia's SSM community remains relatively small, largely due to the country's modest population. Approximately 5000 – 8000 Namibians derive their livelihoods from the small-scale mining sector, a notable figure considering the country's population of only about 2.6 million people.

The small-scale mining sector plays a crucial role in Namibia's Minerals Policy of 2002 and is governed by the Minerals Act 33 of 1992 ("Minerals Act"). The Minerals Act regulates the prospecting, exploration, and exploitation of solid minerals throughout Namibia. It encompasses various licenses, approvals, and restrictions that are applicable to the mining sector as a whole, with specific relevance to the SSM sector. The Ministry of Mines and Energy (MME) serves as the regulatory authority for mining activities and has a dedicated division to support SSM operators in all aspects of the mining process. This includes assisting with license acquisition, conducting sample testing, and facilitating mineral export procedures. To address any disputes that may arise, the MME has established the Minerals Ancillary Rights Commission (MARC) as a mechanism for conflict resolution within the SSM sector. MARC focuses on mediating conflicts related to land access between SSM miners and private landowners, particularly when a mineral license area overlaps with privately owned properties. MARC's primary objective is to facilitate agreements that ensure both access to land for SSM miners and appropriate compensation for landowners.

The Minerals Act stipulates that all prospecting, exploration, and mining activities are prohibited without the appropriate license. In the small-scale mining sector, there are two primary licenses:

- Non-exclusive Prospecting License: This license allows the holder to conduct prospecting activities, extract specified minerals listed on the license, and sell them with the approval of the mining commissioner. It does not grant exclusive rights to the designated area, meaning multiple parties can hold non-exclusive prospecting licenses for the same geographic area. As a result, the application fees for non-exclusive prospecting licenses are cheaper than those for exclusive prospecting licenses.

- Mining Claims: This license enables the holder to engage in both prospecting and mining activities, extract specified minerals mentioned in the license, and sell them with the approval of the mining commissioner. Additionally, the holder is permitted to construct supporting infrastructure within the claim area.

SSM licenses are exclusively reserved for Namibian citizens or corporate entities in which only Namibian citizens have ownership. This restriction aims to promote local participation in the mining sector. Compared to licenses for large-scale mining, SSM licenses have lower acquisition costs, quicker feedback on applications, and less stringent technical or financial requirements for applicants. The issuance of SSM licenses is overseen by the Mining Commissioner, who governs the SSM sector, in contrast to licenses for the large-scale mining sector, which are issued by the Minister of Mines and Energy. However, despite the reduced administrative requirements, many SSM operators face challenges in formally registering their sites due to the distant location of the license administrative center from the mining sites.

Similar to large-scale mining, obtaining an Environmental Clearance Certificate (ECC) is a prerequisite for SSM licenses. The ECC application requires applicants to provide details of the proposed mining activity and assess potential environmental impacts. The ECC requirements have been identified as a barrier to formalizing SSM operations. Acquiring an ECC typically involves significant capital investment, which is often inaccessible to SSM operators. To address this issue, organizations such as the United Nations Development Program have provided funding for district-scale Environmental Scoping Studies in SSM hotspots, facilitating the acquisition of ECCs.

Small-scale mining in Namibia coexists with established large-scale mines. At present, small-scale miners have taken steps to form associations based on regions or mining districts, aiming to advocate for their interests and address their specific needs. As of now, associations have been established in three regions: Erongo, Kunene, and //Kharas. However, in most other regions of the country, small-scale miners continue to operate without formal recognition or association representation. The formation of these regional associations demonstrates the proactive approach taken by small-scale miners to organize themselves and have a collective voice in the industry. It allows them to collaborate, share information, and work towards addressing the challenges they face. The goal is to further expand the formation of associations across the country, ensuring that small-scale miners in all regions have a platform to represent their interests and contribute to the development of the sector. The Ministry of Mines and Energy (MME), in collaboration with Regional and Town Councils, is actively engaged in the ongoing endeavor to formalize a larger portion of these miners. However, it is important to note that the process of formalization is progressing slowly. Efforts are being made to streamline and expedite this process to ensure that small-scale miners across the country receive the necessary recognition and support in their operations.

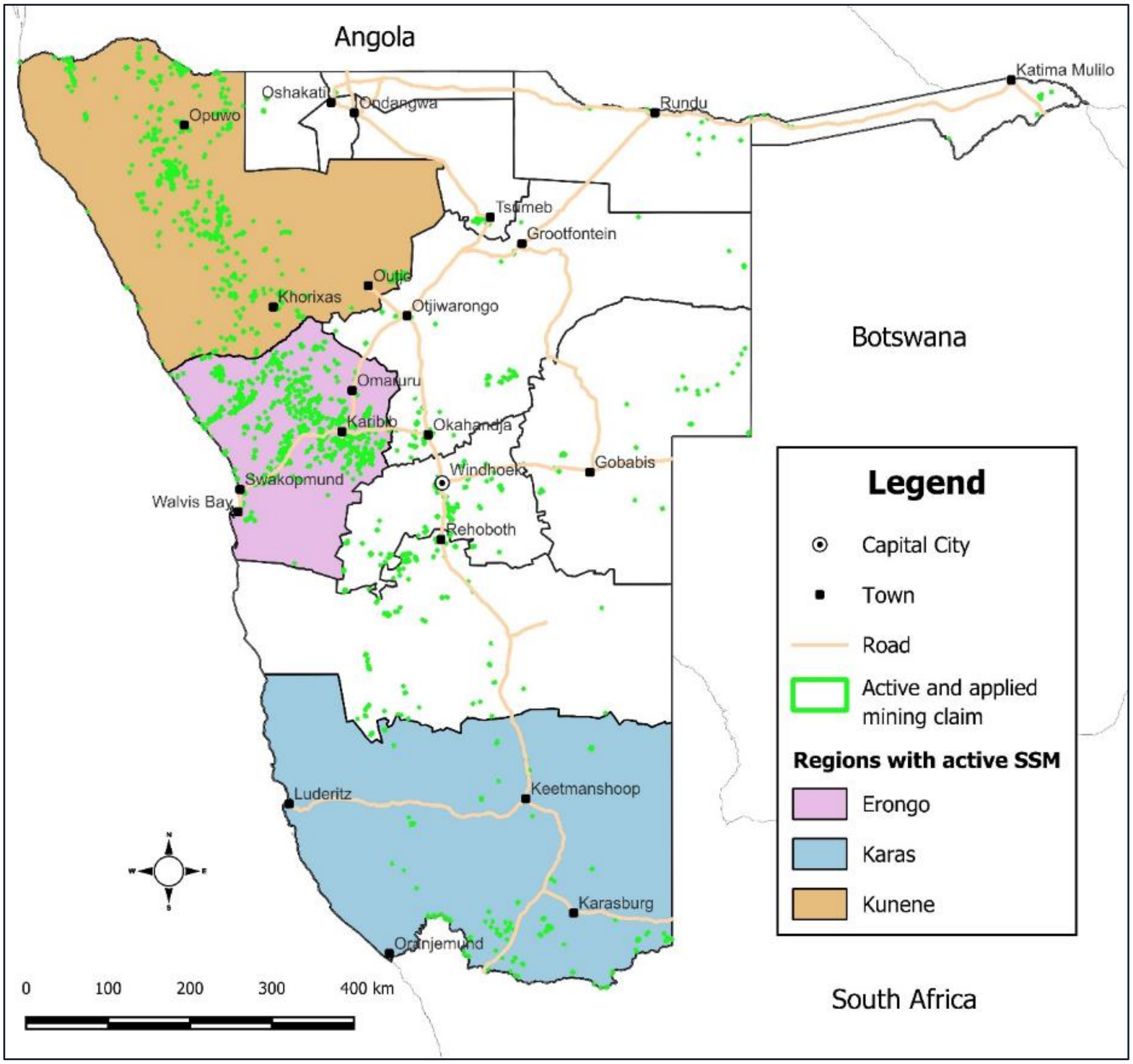


**Figure 24. Map of Namibia showing the regions where SSM are active. The green outline indicates the active and applied for mining claims (source: map drafted by the authors based on internal mining cadaster data by Namibia's Ministry of Mines and Energy as of June 2023).**

## 12.2 Overview of the national ASM sector

The small-scale mining (SSM) sector in Namibia encompasses a range of commodities, including ECRM such as copper, tin, tantalum, fluorspar, and lithium, as well as non-ECRM commodities like semi-precious stones and dimension stones. The semi-precious stones found in Namibia include green, blue, and multi-color tourmaline, green and orange garnet, aquamarine, rose quartz, amethyst, agate, sodalite, topaz, among others.

Within the SSM sector, production is predominantly focused on mineral specimens and semi-precious stones, accounting for approximately 80% of production. Production is predominantly from the central Erongo region and northern Kunene region. The estimated annual production value of semi-precious stones and collector's specimens, including value-added products, is valued at around USD 8 million (Priester, 2017). It is worth noting that only a small portion, roughly 10-20%, of all mined semi-precious stones in Namibia undergo cutting and polishing processes within the country. The cutting and polishing of semi-precious stones involve three main participants: informal individual cutters and polishers who operate with limited business organization, equipment, and skills; formally registered individual cutters and polishers who have undergone training to enhance their skills and formal lapidary small and medium enterprises (SMEs) that often integrate vertically with jewelry manufacturing. To facilitate the development of cutting and polishing expertise, Namibia has established two gemstone training centers located in Karibib and Keetmanshoop, providing basic training in these areas.

Namibia produces a wide variety of dimension stones, consisting mainly of marbles, granites, diorites and sodalite. Most of these dimension stones are exported as raw blocks, with only a small quantity cut and polished locally (Musiyarira et al., 2016). The production of dimension stones constitutes 10% of SSM production. These activities are predominantly located in the Erongo region.

Tin and tantalum are found in Namibia's central regions. Small-scale miners focus on the extraction of cassiterite (tin ore), and tantalite (tantalum ore). The tin and tantalum together with fluorite and copper constitute ±5% of SSM production. Small scale miners extracting tin ore in the mining settlement of Uis sell their products to the Uis Tin Mine (Andrada Mining). The mine accepts unprocessed ore containing a minimum of 60% cassiterite (based on visual inspection) but tends to receive ore containing between 70% and 80% cassiterite. Production and supply to the mine is erratic, ranging between 50 kg to 1 ton of tin ore per month. This is because the small-scale miners do not specialize in the production of one commodity but would target minerals based on demand – often oscillating between sites with semi-precious stone and those with tin and tantalum.

Small-scale mining and production of copper ore (9-13 % Cu based on grab samples) are predominantly carried out in the Kunene region, specifically within the Kaokoveld mining district, in Namibia. This area has become well known for rare copper specimen samples. The Kaokoveld mining district is a hub for small-scale miners, housing multiple mining operations, and it is supported by at least two processing facilities that receive the miners' products. These processing facilities, in turn, sell their copper concentrate to the Dundee Precious Metals Smelter located in northern Namibia. The two known production facilities within the Kaokoveld district have a combined output of approximately 150 tons per month of 10% copper concentrate. The mining activities in these regions are generally formalized and provide employment for up to 50 people at each site. In some instances, individual small-scale miners provide ore to the privately owned crushers. Other areas in Namibia where copper is mined on a small scale include the Rehoboth area in the Hardap region and the Omaheke region.

## 12.3 ECRM deposits amenable to ASM exploitation

The small-scale miners in Namibia extract tin, tantalum and lithium ore from pegmatites of varying sizes. The Northern, Central and Southern tin belts of the Damaran orogeny intrude the Damara belt as highly differentiated magma, undergoing slow crystallization (pegmatites) or rapid crystallization (aplites). Within the pegmatite belts, there are numerous individual pegmatite swarms that contain significant quantities of rare metals and semi-precious stones. Unfortunately, the ore grades mined by small-scale miners in the Uis-Karibib area remain unknown due to the absence of testing facilities. In the southern region of //Kharas, the notable pegmatite swarms are the Tantalite Valley and the Sandfontein-Ramansdrift areas, which are situated close to the Orange River. Small scale miners in the region operate informally and production data and information on ore destination/buyer is therefore not available.

Small-scale mining of lithium in Namibia is an emerging sector within the country's mining industry. The lithium ores in Namibia are primarily found in the same pegmatites hosting tin. Small scale mining is confined to the Erongo region within the Damara pegmatite belts and the main lithium-bearing mineral is lepidolite. With the increased interest in lithium, miners exploiting pegmatite-hosted minerals have started stockpiling lithium in the hope of finding buyers. On occasion, lithium bearing ore is sold to local businessmen with ties to international lithium markets.

The copper deposits in Kunene are found in sedimentary rocks that were deposited in rift basins between continents. These basins are dominated by carbonate rocks of the Otavi Group, which overlay the Nosib terrigenous sediments. The copper deposits occur in stratiform formations that contain disseminated and partially oxidized minerals such as pyrite, chalcocite, galena, and bornite. These mineral formations are hosted within intercalated limestones, slates, shales, and dolomites. In addition to the stratiform deposits, contemporaneous vein and stockwork mineralization is also present. This includes quartz and quartz-chlorite-carbonate veins and stringers that contain copper and lead sulfides. Furthermore, copper-rich breccias can be found within the carbonate units (Bowell et al., 2013). All three types of mineralization have undergone significant oxidation up to a depth of 50 meters. In this zone, numerous secondary copper minerals have formed because of oxidation and weathering of the primary ore. Interestingly, the supergene enrichment of copper at the base of the oxidation zone does not exhibit the typical mineral assemblage of cuprite and native copper. Instead, copper silicate minerals are present (Bowell et al., 2013). As far as the authors know, the SSM do not selectively mine the ore but targets both the sulfide and oxide ores.

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Fluorite deposits targeted by small-scale miners are primarily found in the Erongo region. Fluorite -rich veins and pockets are found in the Sorris-Sorris granites, Salem granites, and the Erongo mountain granitic complex. Small-scale miners extract fluorite crystals valued for their aesthetics, predominantly from the Erongo mountain while bulk fluorite ore is sourced from the Sorris-Sorris and Salem granites. The production of bulk fluorite ore by small-scale miners is sporadic in nature. Local fluorite buyers approach the miners with specific requirements for a certain quantity of ore. The miners then focus their efforts on fulfilling these orders. Once the order is completed, the miners shift their mining activities to other commodities. Due to the sporadic nature of the small-scale mining operations, it is challenging to verify the exact grades and quantities produced. Nevertheless, national records indicate that Namibia exported 11,000 kg of fluorite between January 2021 and September 2022. This export volume can be attributed solely to small-scale mining since large-scale production of fluorite in Namibia ceased in 2014.

## 12.4 Artisanal ECRM mining and processing

In both central Namibia and southern Namibia, the pegmatites that contain tin, tantalum, and lithium are found as competent rock units with minimal weathering. In central Namibia, tin miners rely on manual labor and basic tools to extract the ore. While some operators possess jackhammers, most small-scale miners utilize hammers, chisels, and picks to break up the rock. Excavation is carried out using shovels, and the broken ore is manually sorted based on visual inspection and then stockpiled for sale without any additional processing. Mining is highly selective, operators carry the bulk ore in buckets to the mine site or to areas that are accessible by pick-up trucks, which then transport the ore to the large scale mine site. The excavation pits can vary in size, with depths ranging from 5 to 30 m, widths between 3 and 10 m, and lengths spanning from 6 to 20 m. Once the pit reaches a depth of 10 to 30 m, removing waste material becomes challenging, prompting miners to typically abandon the pit and search for a new ore body.

The copper deposits in the Kunene region, which are exploited by small-scale miners, form a north-south trending belt spanning approximately 34 km. The desired host rocks in these areas are typically competent and hard, covered by a thin layer of regolith (Bowel et al., 2013). Mining operations in the region vary, ranging from manual labor to semi-mechanized and fully mechanized processes. Some mining sites are equipped with earth-moving vehicles, such as back-actors, bulldozers, and heavy trucks (Odendaal and Hebinck, 2019). However, at local mining sites, small-scale miners predominantly rely on rudimentary hand-held tools like picks, hammers, chisels, and shovels. The small-scale miners extract copper ore from the sites and supply it to independent processing facilities. These processing facilities may operate with full mechanization comprising crushing with jaw crushers, ore grinding using ball mills, and gravimetric concentration on a shaking table. In some cases, vertically integrated small-scale miners have both semi-mechanized mining sites and processing plants. At certain mining sites, blasting techniques are employed to break up the in-situ ore. Subsequently, the fragmented ore is crushed and screened as part of the processing operations.

The rocks hosting fluorite-bearing veins may be partially weathered at surface but are generally highly competent. Operators typically work individually or in pairs, diligently tracing the mineralized veins. These veins are usually less than one meter thick and can extend up to 30 meters in length. The mining process involves the use of hammers, chisels, picks, and shovels. Excavated pits can reach depths of up to 10 m and widths of up to 3 m. Minimal stockpiles are kept onsite once the unprocessed ore is sold to the buyer.

## 12.5 Production and trade patterns

A few large-scale mining operators have implemented structured purchasing systems to facilitate the acquisition of ECRM commodities from small-scale miners. These systems ensure that the miners can sell their products and receive regular payments, providing them with a stable income to support their mining activities. The involvement of large-scale mining operators in purchasing ore from small-scale miners not only contributes to the local economy but also helps formalize and regulate mining operations in specific areas.

Apart from these structured arrangements, small-scale mining operators target three main types of buyers. Firstly, tourists serve as retail buyers, purchasing souvenir stones directly from artisanal miners. SSM operators market their goods along the roads leading to major tourist destinations. However, the number of tourists purchasing minerals is limited due to Namibian mineral export regulations. To obtain an export permit, tourists need to travel to the capital, and many are unfamiliar with the process. Consequently, some tourists either export minerals illegally or choose not to purchase them, resulting in reduced demand. Moreover, the quantities purchased by tourists are often minimal, further limiting demand for the minerals produced by artisanal miners. Secondly, middlemen play a role in the SSM communities by frequently accessing and purchasing low-priced products from miners. These middlemen have proximity to international markets where they can sell the products at relatively higher prices, thus making a profit. Finally, foreign buyers are prominent in the specimen and semi-precious stone sectors. They purchase minerals for personal collections or for various purposes related to their respective industries. Overall, the involvement of large-scale mining operators, tourists, middlemen, and foreign buyers contributes to the economic ecosystem of small-scale mining and the trade of ECRM commodities.

In general, it is challenging to gather comprehensive data on the production of ECRM commodities such as tin, copper, fluorite and lithium specifically from SSM sites. The ore extracted by small-scale miners is typically accounted for as part of the overall Run of Mine (where agreements exist with large scale operations), making it difficult to determine the exact production figures attributable to SSM. Additionally, the supply of various minerals from SSM remains sporadic due to factors such as market demand and the miners' involvement in other commodities. This irregularity is particularly noticeable during the tourist season when miners may prioritize selling certain products such as mineral specimen and/or semi-precious stones to take advantage of the increased traffic along the roads. Consequently, the quantity and consistency of ore supply from small-scale miners fluctuate depending on these factors.

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# 13 Niger

## 13.1 Background

Artisanal (or small-scale) mining is a reality in Niger: even though seasonal, it constitutes an activity generating an income for a significant proportion of the rural population. Mining products include gold and tin for export, and convenience goods like salt and natron. The country's 1993 mining code sets out the legal framework for the artisanal mining exploitation. Two titles regulate this activity: (1) the artisanal exploitation authorization delivered, by order of the Mining Minister, to natural persons with Nigerian nationality or to legal persons with Nigerien right. Valid for two years, it assigns a perimeter not exceeding 400 $m^2$ and 1 $km^2$ for the natural or legal person, respectively; and (2) the individual card valid for six months and delivered to the artisanal miners with Nigerien nationality (Razack 2002). For purchasing and marketing ASM mining products, there must be an authorization by the mining ministry.

## 13.2 Overview of the national ASM sector

Niger is the world's fourth biggest producer of uranium, which accounts for at least 70% of the country's exports and contributes to around 5% of the GDP (UNECA 2020). However, by value, the gold exports at least exceeded the uranium exports in 2020 by a factor of two. Niger also has considerable reserves in iron, coal and oil. In July 2020, Niger adopted a 15-year national mining policy which aims to diversify mining beyond uranium.

Salts, cassiterite and gold are exploited in the artisanal manner. Small-scale gold mining is practiced mainly in the Liptako region. Currently, no industrial mining companies are producing gold in Niger; there are three major projects on hold. This means that all of the Niger`s gold exports (in the period 2018 -2022 on average 7 – 8 t Au according to UN Comtrade) are derived from ASM activities. According to officials from the mining ministry, the industrial mines employ about 4,000 people, while ASM involves more than 500,000 people (Hassoumi 2017).

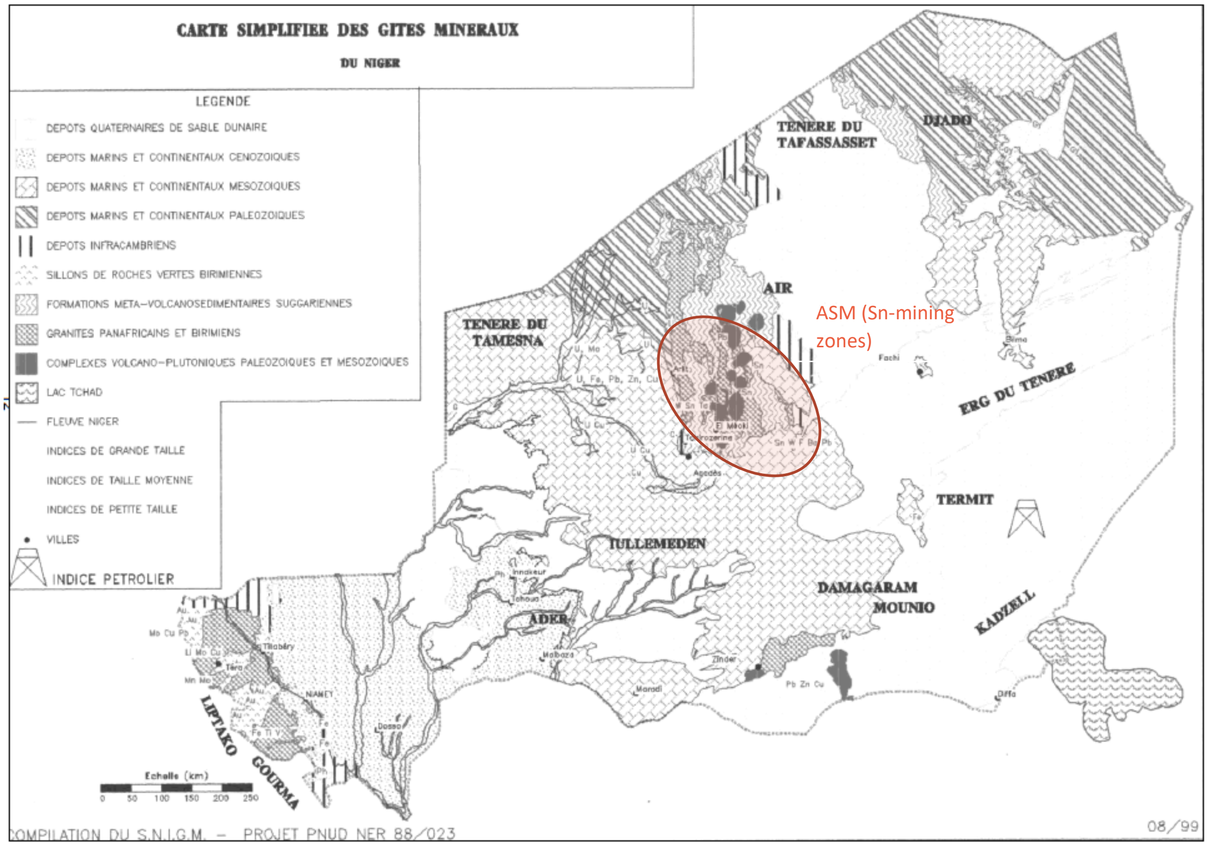


**Figure 25. Mineral deposit map of Niger (Razack 2002).**

## 13.3 ECRM deposits amenable to ASM exploitation

Tin is the only commodity from the ECRM list that is currently mined by ASM in Niger. The cassiterite extraction started at the end of the 1940s and was, until 1991, carried out on the Société Minière du Niger (SMDN) exploitation license by local artisanal miners native to the area. The ore was then sold back to SMDN. Following the liquidation of SMDN in 1992, the “individual” exploitation took over after a rapidly aborted attempt to regroup the small miners in a co-operative society. Since then, the ASM cassiterite production has been sold to merchants.

In Niger there are tin deposits of the alluvial and eluvial type. Primary tin deposits are found in Tarouadji, El’Mecki, Guissat and Timia; The native populations of El Mecki and mostly Tarouadji villages (located south of Aïr) exclusively practice the artisanal exploitation of cassiterite. These villages are situated 110 km and 78 km of Agadez, respectively. The artisanal miners’ population, estimated to a little more than 1000 people over the whole of the active sites, is entirely male. However, it must be mentioned that children participate in the exploitation works (Razack 2002). The initial resources of the tin deposits are estimated to contain several hundred tons of tin. As by-products of tin mining, tantalum and niobium concentrate is produced (CRGM 2016).

## 13.4 Artisanal ECRM mining and processing

Information about tin mining and processing is unknown to the author. However, it can be deduced from experience that simple, manual mining methods are employed. Because of the scarcity of water, the local washing and processing of tin ore is likely problematic.

## 13.5 Production and trade patterns

From 1992 until 2011, the USGS continuously reported an annual tin production of about 10 – 30 t tin content. Then, the production of tin in Niger ceased according to the USGS. In the last two USGS reports about Niger from 2017/18 and 2019 no indications for tin mining in Niger were provided.

For the last seven years the UN Comtrade database shows no exports of tin ore and concentrates from Niger. None of the main tin smelting countries noted direct imports from Niger. From these facts, it can be concluded that in case tin mining in Niger still exists, the production might be smuggled to the neighboring country Nigeria, which has its own vivid tin mining industry.

## 13.6 Potential future ASM ECRM production opportunities

It is improbable that the tin mining sector in Niger, including the sub-products of tantalum and niobium, could play an important role in the supply of Europe with these critical commodities, since the original resources were estimated to contain only several hundred tons of tin. In addition, the remoteness of the tin mining zone, water scarcity and the lack of infrastructure reduce the feasibility of major tin mining operations in Niger.

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# 14 Nigeria

## 14.1 Background

The Constitution of Nigeria, which came into force on 29 May 1999, is the main regulatory law overseeing the Nigerian mining sector. The Constitution gives primary ownership and control of all mineral resources in any land located in Nigeria to the Federal Government. The Federal Government can transfer the rights of the land and its resources to a third party for beneficiation purposes. This is overseen and controlled by the Nigerian Minerals and Mining Act 2007. "It […] vests ownership and control of mineral resources in the Federal Government, to hold and manage same on behalf of the citizenry, with rights to transfer said rights to qualified third parties" (Ben-Igwenyi & Nnamani, 2022). It also defines the roles of the Minister, the Mining Cadaster Office (MCO), the Mines Inspectorate Department (MID), the State Mineral Resources and Environmental Management Committee (MIREMCO). These entities execute the control on any extractive activity and supervise the prohibition of unauthorized exploration and exploitation of minerals.

To smooth the acquisition of licenses through the Mining Cadaster Office, the Nigerian Minerals and Mining Regulations were implemented in 2011. They regulate resolution of disputes, relationships with artisanal and small-scale miners, royalty-rates, etc. Current license types are: (1) reconnaissance permit, (2) exploration license, (3) small-scale mining lease, (4) mining lease, (5) quarrying lease, (6) mineral buying center license, (7) export permit, and (8) water use permit.

A small-scale mining lease has an area of > 0.02 $km^2$ (5 acres) and < 3 $km^2$. It is granted for a period of five years and renewable for another five years only (Ben-Igwenyi & Nnamani, 2022). To separate the artisanal mining operations and the small-scale mining operations, the Nigerian Minerals and Mining Act defined them as: (1) Artisanal mining: Mining operations limited to the utilization of non-mechanized methods within a small-scale lease; and (2) Small-scale mining: Artisanal, alluvial and other forms of mining operations involving the use of low-level technology or application of methods with low expenditure within a small-scale lease.

Many of the ASM type operations in Nigeria are not formalized yet, i.e., they do not operate as a registered economic entity on a formal small-scale mining lease. The government undertakes efforts to formalize these operations, e.g., by forming cooperatives. In practice, there are no fixed limits between ASM and small-scale mining, as both ASM and small-scale mining operations require a Small-Scale Mining Lease. These leases can be owned by Nigerian citizens, cooperatives and incorporated bodies (companies). Companies can have foreign capital or be from foreign origin, but they must have at least one Nigerian Director, according to the 2007 Act.

At the end of 2022, the number of granted small-scale mining licenses amounted to 2026, covering an area of 2399 $km^2$. This number is rapidly growing, with the last (20th June 2023) approved license number 2713 covering an area of 3115 $km^2$. The ASM production can be sold via an ever-growing system of licensed buying centers.

## 14.2 Overview of the national ASM sector

In Nigeria, over decades, the extractive sector was dominated by the extraction of oil and gas. Except for construction minerals, the mining sector was nearly completely neglected. Important construction minerals, like gravel, sand, crushed rock, and limestone, are mined mainly in big quantities in industrial pits and quarries, as well as – to a lesser degree – by ASM operations. Big industrial quarries and pits exploiting construction minerals (hard rock, gravel, sand, limestone) are located near the bigger population and industrial centers. Many other non-metallic (e.g., gypsum, clay, fluorite, baryte) and nearly all metallic commodities (e.g., gold, tin, tantalum, tungsten, lithium, copper, lead, zinc) are mined solely by ASM operations of very different size, standards and technologies.

Currently, ASM operators mine the following commodities: Construction materials (hard rock, gravel, sand, laterite, limestone, granite), industrial minerals (kaolin, gypsum, fluorite, barite), precious and semi-precious stones (beryl, tourmaline, topaz, agate, amethyst, etc.), ferrous metals (manganese-iron), rare metals (tin, tantalum, tungsten, niobium), base metals (copper, lead-zinc), lithium and gold (much of which is smuggled out of the country; e.g., Lyster & Smith-Roberts 2022). Mining of niobium-tantalum and tin has taken place for many years. Lithium-bearing minerals have already been mined in the past as well, as a by-product of gemstone pegmatite mining, but sold with low to very-low profit. After the rise of lithium prices in the last years, lithium mining has started to be a separate and relevant business. Artisanal and small-scale gold mining has shown a strong increase over the last eight years, mainly driven by Chinese influence. ASM operations can be found throughout the country.

In 2015/ 2016, ASM in Nigeria directly employed about 0.5 million people, and produced indirect jobs for between 1.2 and 2.5 million people (Oramah et al. 2015). In 2022, the number of direct jobs is estimated at approximately 1 million, and an additional amount of 4 million depending on ASM or small-scale mining operations. A rough estimate of subsectors may set the number of ASM employment directly involved in ECRM to be between 1 – 5%, knowing that a gross part of ASM operations is involved in gold, gemstones and construction materials (note that no hard numbers exist).

The value of the entire Nigerian ASM production cannot be evaluated, as it contains a considerable share of locally consumed construction minerals. The value of the exported mining products equaled to USD 42.4 million in 2020, but there are significant data uncertainties as further described in the chapter on production and trade patterns. Table 7 shows on overview on the different ASM ECRM commodities, including the authors' evaluation of production importance as well as production figures registered with the National Bureau of Statistics (2021). From the used data source, it is not clear whether the production figures relate to the contained metal or to the mined ore mineral. It can be assumed that the figures relate to almost mono-mineralic concentrates of the mined mineral (this statement is supported by interviews the authors arranged with the ASM Department and the Nigerian Geological Service Agency).

| Commodity | Geological occurrence | ASM mining | Importance (0-3)[4] | Production 2019 (t) | Production 2020 (t) | Remarks |
|---|---|---|---|---|---|---|
| Tantalum | | | | | | |
| Baryte | Yes | Yes | 2 | 370 | 544 | mined from veins |
| Beryllium (Beryl) | Yes | Yes | 1 | 1.3 | 2 | by-product in pegmatites |
| Fluorspar | Yes | Yes | 3 | 4730 | 17,557 | mined from veins |
| Copper (sulfides, oxides) | Yes | Yes | 1 | 30 | 0 | mainly from veins |
| Lithium (spodumene, lepidolite) | Yes | Yes | 2 | 133 | 0 | pegmatites |
| Manganese | Yes | Yes | 2 | 1100 | 15,000 | laterites |
| Niobium/Tantalum (columbite/ tantalite) | Yes | Yes | 3 | 2221 | 796 | placers |
| Titanium (ilmenite) | Yes | (Yes) | 0 | 0 | 0 | in Sn/Ta placers |
| Tungsten (Wolframite) | Yes | Yes | 1 | 3100 | 0 | placers? |
| Tin (Cassiterite) | Yes | Yes | 3 | 2437 | 1703 | placers |
| Baryte | Yes | Yes | 2 | 370 | 544 | mined from veins |

**Table 7. Mining Status of ECRM in Nigeria (2019 and 2020).**

## 14.3 ECRM deposits amenable to ASM exploitation

The spatial distribution of selected ECRM occurrences in Nigeria is presented in Figure 26. One can assume that at most of the ECRM occurrences at least some ASM operations take place.

[4] Key: * 0 – none; 1 – low; 2 – medium; 3 – high

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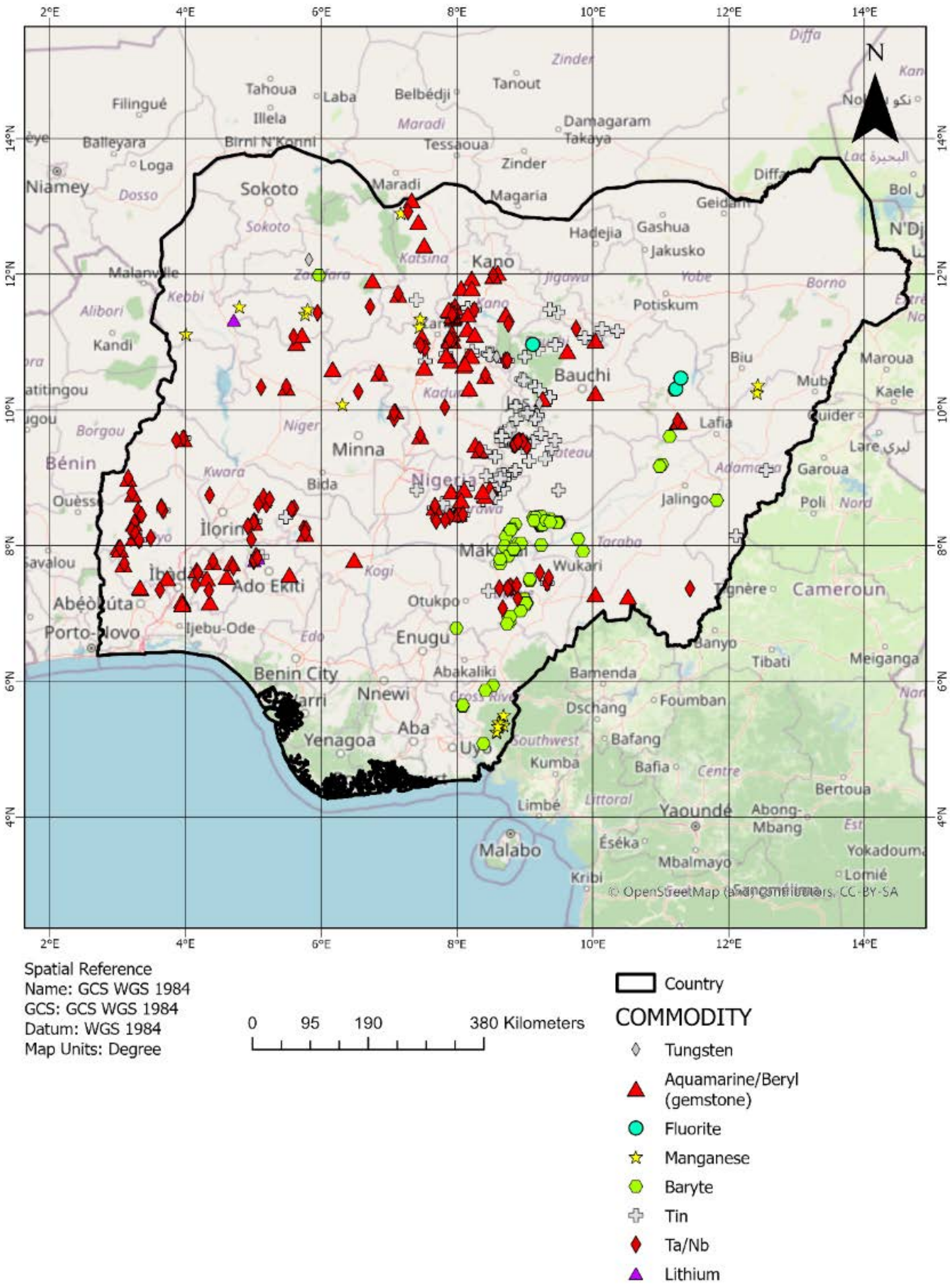


**Figure 26. Spatial distribution of ECRM geological occurrences in Nigeria (source: authors' plot based on ASM database of Nigeria's Ministry of Mines and Steel Development, accessed in June 2023).**

Known tin occurrences in Nigeria are located mainly in the center of the country. According to Ogunyele & Akingboye (2018), 80% of tin comes from secondary sources such as placers. At Jos Plateau, tin and tantalum-niobium are currently mined from placers and historical tailings. The production share of historical tailings is about 65% while placers contribute about 35%. The source rock associated with these alluvial sites is associated with relatively young granites of Jurassic age which are notable for Sn-Nb-Ta (Ogunyele & Akingboye 2018).

The placers are both of recent and old concealed nature. They occur in large areas, mainly under a cover of 5 to 15 m. The thickness of the placer seam is 0.3 to 1m. Analysis of five field samples of Jos Plateau placer ore by portable X-ray fluorescence conducted by Beak Consultants in the framework of this study (in June 2023) showed the following average concentration: 150 ± 8 g/t Sn, 32 ± 10 g/t Ta, 57 ± 18 g/t Nb and 240 ± 50 g/t W.

Nigerian pegmatites are mined mainly to produce spodumene and gemstones. Both spodumene and lepidolite occur as lithium-bearing minerals. While there are only few such occurrences shown in Figure 26, these occurrences and mining activities are likely more widespread, albeit unregistered. According to local knowledge, there appears, at least in Nasarawa State, to be limited tin (and possibly tantalum) mining from hard rock sources as by-product of mining lithium-bearing minerals. However, this remains unclear since there is not much information available and further research is required.

Almost entirely, the mined pegmatites are relatively fresh and show very low to no alteration. The pegmatites currently worked come in different thickness ranging from a few centimeters (40 cm in the case of Anguwan Kade) to several meters (e.g., a site in Nasarawa contains a vein up to 40 m in thickness), typically running with a constant strike for tens of meters.

During this study, Beak Consultants performed portable X-ray fluorescence measurements of lepidolite from pegmatites at Anguwan Kade, Nasarawa State, showing comparably high Rb grades (up to 1%) indicating that its Li grades might be similar as typically found in such micas in other samples around the world. The ASM Department of the Ministry of Mines and Steel Development reported that spodumene contains 4-9% $Li_2O$, though the quoted upper value exceeds the stoichiometric maximum of lithium in spodumene (about 8% $Li_2O$).

Fluorite occurs in Nigeria in veins in the basement complex rocks of Kaduna, Zamfara, Kebbi and Kano, as hydrothermal deposits in the crystalline rocks of the Jos Plateau, and as pockets in the sedimentary basins of the Central and Northern Benue Trough associated to the Mississippi-Valley-Type mineralization. The known baryte occurrences are bound to fault systems of the Benue Trough. They occur mainly as hydrothermal veins. Typical high grade baryte has about 75-90% $BaSO_4$, with quartz and iron oxides.

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Although there are mentions of several copper occurrences in Nigeria, no large deposits and important copper mines are known so far. Occurrences of copper are found along with other base metals such as zinc and lead, while other cases have shown baryte as a main mineral. The major copper ores are chalcopyrite, associated with azurite and malachite, and occur in Nasarawa (within fracture-controlled veins), Bauchi, Zamfara, Niger and the Federal Capital District.

The manganese deposits in Nigeria are mostly epigenetic and related to laterites. They occur in two distinct geological environments, in the mobile belts in the northwest and in the granitic basement in the southeast and southwest. In the first, the reported contents are considered low (30% MnO), while for the latter, where primary deposits are probably of hydrothermal origin, higher concentrations of up to about 50% MnO occur.

## 14.4 Artisanal ECRM mining and processing

Tin and tantalum/niobium ore from placer deposits is recovered both in open cast and, in case of concealed placers, in underground mines. In open cast mines, the overburden is removed first to facilitate mining of the mineral seam. Operations often take place above the water table. In case of groundwater inflow, motor pumps are used to remove the water from the mines. Tailings deposits are mined as open cast mining using shovels and buckets. Hard rock deposits such as pegmatites are mined in open casts (pitting from the surface) or underground, where the ore is accessed by shafts and adits.

The degree of mechanization in small-scale mining largely depends on the technical and financial resources of the mining enterprise. In the last years, the traditionally mainly manual work has been progressively supplemented by modern technologies, mainly driven by external investors, such as Chinese companies. At the pegmatite mining site at Keffi, a modern excavator is used for fast overburden removal and whole rock mining, while hand-picking is used for separation of the minerals (gemstones and lithium-bearing minerals; in places, cassiterite is separated as well). Explosives are used to shatter the rock and allow the miners to carry on breaking the rock with hammers and chisels to separate the spodumene, which is then hand-picked and bagged. On placer deposits under cover, such as the cassiterite deposit Bayan Dutse (Jos) in the Plateau State, the typical equipment is a manual mono-rope winch and a compressor for ventilation. The ores are mined by using shovels and buckets.

The mineral processing technology of placer deposit ores (Sn, Ta, Nb) consists of simple sluice boxes in natural water channels or near-natural water channels: the water flows over the ore material and flushes the light minerals away. The ore material is usually moved using shovels. The approach is associated with high metallurgical losses. In similar conditions, in Rwanda, the authors found up to 1000 g/t Ta in the downstream sediments, while the grade in the mined ores was between 50 and 200 g/t Ta, indicating very low recovery rates.

The so-produced initial concentrates, containing a mix of heavy minerals, are further processed at mineral buying centers which are equipped with various modern separation machinery, such as air-based gravity shaking tables and magnetic separators. The gravity shaking tables are used to remove zircon, while the remaining material is transferred to the magnetic separator for production of the diamagnetic, paramagnetic, and magnetic fractions. Five initial ore concentrates from Jos Plateau analyzed by Beak Consultants via portable X-ray fluorescence for the present study showed an average grade of 42 ± 2% Sn, 0.3 ± 0.05% Ta and 2.0 ± 0.3 Nb, with high Zr content (10.9 ± 1.3%).

Where artisanal miners recover minerals and metals from hard rock deposits, processing largely relies on hand picking. For industrial minerals like fluorite and baryte, and for sulfide ores (Cu, Pb and Zn), the material is hand-picked, and the produced concentrate is sold to buying centers or mobile traders. Li-bearing minerals (spodumene, lepidolite) are entirely sold as hand-picked concentrates as well, without any further processing. There are several hundred mineral buying centers in the country, some of them are located closer to the mining sites, some of them are in bigger cities. The quality of the hand-picked concentrates is good, but this approach results in significant losses of the fine-grained ore mineral fraction.

From this point thereafter, there is no further processing to beneficiate the ore and it is exported as a concentrate. It is common to see mobile traders approach buying centers and acquire the material to then take it to a port for export. Lithium concentrates are solely exported as the original hand-picked spodumene and lepidolite. Once the material reaches an exporting point (e.g., Lagos) it is loaded to containers and shipped to their destinations. Therefore, most of the exporters are located/registered in the main ports.

## 14.5 Production and trade patterns

Nigeria participates in the Extractive Industries Transparency Initiative (NEITI) and this process generates some statistical data on mineral production and exports (Nigeria Extractive Industries Transparency Initiative, 2022). According to these data, the value of the exported ECRM production was USD 7.8 million in 2020. It is important to note, though, that (1) several ECRM are not covered by the NEITI data (e.g., lithium and fluorspar); (2) there are several gaps and inconsistencies in the NEITI data and between the NEITI data and the national production statistics; and (3) mineral smuggling occurs, especially in strongly insecure areas (e.g., Zamfara State) along a porous border, facilitated by a number of unregistered ASM mining activities – while this mainly refers to gold, relevant ECRM are affected as well.

For instance, the comparison between the production and export data of selected ECRM (Table 8) shows strong differences. While in 2019 and 2020 together only 30 t of Cu were registered for production, the reported exports were 3054 t in 2020. In contrast, the amount of exported tin concentrate was 351 t in 2020, compared to a tin concentrate production of 2437 t in 2019 and 1703 t in 2020.

| Commodity (ores and concentrates) | Exports in 2019 (t)[5] | Production in 2019 (t)[5] | Production in 2020 (t)[5] |
|---|---|---|---|
| Tantalum | | | |
| Baryte | Yes | Yes | 2 |
| Beryllium (Beryl) | Yes | Yes | 1 |
| Fluorspar | Yes | Yes | 3 |
| Copper (sulfides, oxides) | Yes | Yes | 1 |
| Lithium (spodumene, lepidolite) | Yes | Yes | 2 |
| Manganese | Yes | Yes | 2 |
| Niobium/Tantalum (columbite/ tantalite) | Yes | Yes | 3 |
| Titanium (ilmenite) | Yes | (Yes) | 0 |
| Tungsten (Wolframite) | Yes | Yes | 1 |
| Tin (Cassiterite) | Yes | Yes | 3 |
| Baryte | Yes | Yes | 2 |

**Table 8. Comparison of production and export data for selected ECRM commodities in Nigeria.**

Important ECRM commodities, such as lithium, do not appear in the NEITI reports. They might be hidden behind such names as mica powder, mica waste or crude mica (which certainly implies commodities of very different value). The estimation of the value of 1 kg of these commodities shows big differences, ranking for instance for "crude mica" between 0.3 and 344 USD/ kg. The same issue can be observed for many other commodities as well: e.g., exports under the ware category "Niobium, tantalum, vanadium or zirconium Other" are traded at values ranging from 0.04 USD/kg up to 180 USD/kg. These problems obviously have their background in wrong statistics or a wrong classification of the traded commodities.

Except of baryte, which is used internally as drilling mud for Nigeria's oil industry, the entire Nigerian ECRM production is sold on the international markets. The main buyers are China and Malaysia. Copper concentrate appears to be exported to Germany as well. In most cases, these production amounts are negligible compared to world production. The only exemption is tantalum for which Nigeria provides a considerable share of the world production (about 9% in 2019).

[5] Exports in 2019 based on Nigeria Extractive Transparency Initiative (2022); production in 2019 and 2020 based on National Bureau of Statistics (2021).

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## 14.6 Potential future ASM ECRM production opportunities

The Nigerian ECRM resource base is proven for tin, tantalum, niobium, fluorite, and baryte. The wide spread rare-metal pegmatites, mined today mainly for gemstones and to a lesser degree for lithium ore (spodumene), and the associated tailings, might become a more important source for a wider range of ECRM, including Be, Ta, Nb, Sn, and possibly REE (depending on intrusion chemistry), though grades are not documented. It would have to be verified whether ECRM might be economically extractable using a semi-industrialized, increasingly mechanized approach.

The potential for the identification of bigger amounts of sulfide-hosted ECRM such as Cu, Bi, Sb, and In is not clear so far. In the North of Nigeria, in areas with well-developed lateritic formations, related commodities as nickel, bauxite, and manganese can be expected. The application of modern artificial intelligence-based technologies for exploration targeting and the beneficiation of the recently gathered new national datasets (MinDiver program) may assist in identifying new ECRM mining opportunities in the country. At the same time, several aspects of the current ASM-based ECRM production would need serious improvement, including economic factors such as reducing metal losses to tailings through optimized use of processing equipment and by monitoring recovery rates, as well as in terms of improving environmental and health and safety standards of ASM operations.

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# 15 Rwanda

## 15.1 Background

The Rwanda Mining, Gas and Petroleum Board was established in 2017 to coordinate government efforts in these sectors and to oversee regulation and mining licensing. The new mining law was promulgated in 2018, replacing the previous Mining Law of 2014. This new law recognizes three types of mining licenses with different sizes: fifty hectares (50 ha) for a small-scale mining license; one hundred hectares (100 ha) for a medium-scale mining license and four hundred hectares (400 ha) for a large-scale mining license.

The new mining law strives for a higher degree of formalization and regulation of the mining sector. Comments to the new law voiced the fear that the government tried to push small ASM players out of the mining business since the new regulation of the sector sets duties and financial hurdles for mining in Rwanda that are difficult to overcome by the ASM sector (The East African 2018). This more rigid law includes a heavy emphasis on formalizing the ASM employment and operations to bring them under greater control (Munir 2020). This is in line with the efforts of the government to attract international mining investors and increase the value adding processing of minerals in the country itself (USGS 2021).

Rwanda is subject to Section 1502 of the U.S. Dodd-Frank Wall Street Reform and Consumer Protection Act, which defines traceability and due diligence requirements for the 3Ts and gold, the so-called conflict minerals. Consequently, this conflict mineral regulation, the Rwandan government signed an MOU with the tin and tantalum industry to implement the iTSCi scheme (ITA tin supply chain initiative) from 2010 onwards. The scheme aims to provide traceability and due diligence along local 3T supply chains. In 2017, Rwandan mineral supply chains were additionally subject to a global EU due diligence regulation with similar objectives. In addition, some mines in Rwanda stopped implementing iTSCi and instead have started implementing another industry scheme to facilitate mineral traceability.

## 15.2 Overview of the national ASM sector

Rwanda is one of the world's largest producers of tantalum and tungsten concentrates (outside of China) and also exports significant amounts of tin concentrates (all together referred to as the 3Ts). A significant share of the 3T production of Rwanda is still sourced from the ASM sector and nearly all of the production is resulting from mining practices with a high share of manual labor and low mechanization. Additionally, gemstones as well as refined tin and gold are exported. Gold is partly mined in the country, but the largest share of gold refined in Rwanda originates from other African countries. Recently also the exports of Li-minerals re-started, following a short period of similar exports in the 1960s. Rwanda also hosts a variety of mineral occurrences such

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as ilmenite, silica sands, kaolin, vermiculite, diatomite, clays, limestone, talcum, gypsum, and pozzolan that are important for the industrial development of the country.

Belgian mining companies started industrial mining in Rwanda in the late 1920s and controlled the mining sector up until Rwanda`s independence in 1962. After the independence, the government formed the Société Minière du Rwanda (SOMIRWA) in 1973 by joining all existing mining companies based on the pre-existing colonial structures and deposits. However, SOMIRWA never managed to be profitable and fell into bankruptcy in 1985 when the collapse of the tin cartel occurred, and the debts incurred with the smelter couldn`t be repaid. In consequence of SOMIRWAs liquidation unorganized ASM activities gained importance in Rwanda and accounted for all of Rwanda`s mining production in the period 1988 – 2002 but producing only about 30% of SOMIRWA`s former annual production.

Starting in 2001 there was a turnaround in Rwandan mining, when the government decided to privatize the dormant large-scale mining concessions. The former SOMIRWA concessions were tendered internationally in subsequent years. Several companies set up semi-industrial operations (involving artisanal miners) and re-started the production of 3Ts. In 2014 a new mining code was introduced that favored ASM operations. However, the recent mining code sets the focus on stronger control of the mining sector. In addition, the government shows again more active involvement in the sector with the establishment of state owned or influenced mining enterprises. The revision of the mining code served also to attract more international, middle-sized investors. The government describes the current situation of the Rwandan mining sector as "national mining boom" and assumes that the mining sector serves to enhance the economy of Rwanda.

Mining, both regulated and informal, is currently the fastest-growing employment sector in Rwanda. Rwandan mining is a blend of artisanal, small-scale, and large, formalized operations. According to the GIMCS Online Portal (last accessed in May 2023) there are 20 large-scale, 98 medium-scale and 72 small-scale effective mining licenses. In the past there have been also hundreds of informal artisanal mining operations. However, presently it is not possible to gauge exactly how many of these have been transformed to formal operations or are continuing to mine informally. The formal Rwandan mining operations employ more than 60,000 persons, but the informal ASM sector in Rwanda in the past at least additionally employed well over 34,000 miners.

Mining in Rwanda consists of extracting such minerals as cassiterite (tin), columbite-tantalite, - colloquially named coltan - (tantalum), and wolframite (tungsten) and gold. The total tin production in the period from 1930 until 2022 can be estimated to about 140,000 t of Sn content, the total tungsten production to about 23,000 t of tungsten content in the period 1958 – 2021 and the total tantalum production to about 6,500 t tantalum content in the period 1960 - 2021.

That makes about 0.7 % of the global tin production, 0.7 % of the global tungsten production and 15 % of the global tantalum production in these respective time periods. However, it has to be considered that a variable part of the Rwandan 3T exports has originated in the DR Congo and, to a lesser extent, other neighboring countries) so that not all exports correspond to actual Rwandan production. The actual share of smuggled 3T minerals varies through time and is impossible to quantify with any confidence.

In 2022, the country was the world's 5th largest producer of tungsten, the 12th largest producer of tin, and the 3rd largest producer of tantalum (USGS 2023).

In the period from 1959 - 1968 Rwanda was also a producer of lithium from the Li-containing mineral amblygonite. In this period a total amount of 9,000 t of amblygonite ore was mined at Rongi in the district of Gatumba (BRGM 1986) located in north-west Rwanda. Only recently, Rwanda restarted with the production of lithium.

As shown in the figure below, in the period 2017 - 2022, Rwanda earned an accumulated ~US$ 766 million from mineral exports of 3Ts and other mining products (without gold). This is roughly 10 % of the total export value reported in the UN Comtrade database for Rwanda. The largest shares of the accumulated export value have coltan and tin concentrates with roughly one third each, followed by tungsten concentrates that achieved a share of one fourth. It is remarkable that, in 2022, 5500 t of "other ores and concentrates" with a value of approx. US$ 68 million, were exported. The authors suspect that this might include exports of lithium ore that are known to have started in 2021.

In addition, the UN Comtrade database for Rwanda also includes gold that started to be exported in large volumes from the beginning of 2018 when the first gold refinery was launched in Kigali. The share of gold exports now achieves about 25 % of the total export value. However, the largest part of the refined gold production was not mined in Rwanda but originates from other African countries.

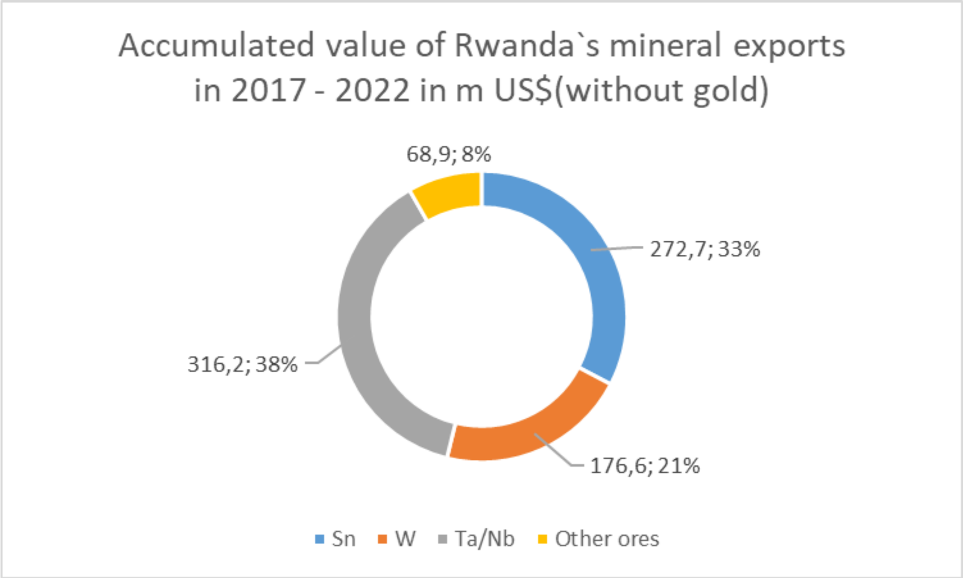


**Figure 27. Share of commodities for the total Rwandan mineral exports aggregated for the period 2017 – 2022 (UN Comtrade database). "Other ores" likely includes lithium concentrates, among others.**

According to the UN Comtrade database Rwanda started to export tin metal in 2019. The tin ingots were produced at the LuNa smelter near the capital Kigali. The LuNa smelter restarted the operation of the former Karuruma tin smelter that was built in 1980 to produce tin from concentrate coming from SOMIRWA. The LuNa smelter obtained the Conformant Smelter Status granted by the Responsible Minerals Initiative in 2020. In the period from 2019 – 2022 about 1500 t of tin ingots with a value of about US$ 38 million were smelted.

## 15.3 ECRM deposits amenable to ASM exploitation

The ECRM deposits amenable to ASM exploitation in Rwanda include deposits for tin, tantalum/niobium, tungsten and lithium. The present-day main production comes from semi-industrialized mine sites where artisanal miners frequently work for companies who are the holders of mining concessions or subcontractors who operate as intermediaries between mine works and mining companies. There was a transitional period in which artisanal mining evolved to small-scale mining and at certain locations to a more semi-industrial mining operation, frequently with the involvement of foreign mining companies. The metal recoveries in the ASM sector have been estimated to be as low as 10 to 30% resulting in the loss of significant mineral resources (Muchez 2014). On the other side recoveries of over 70 % in the ASM sector using very simple processing techniques recoveries have also been reported (BGR 2020). In mechanized operations the recoveries for tin could achieve 90 % and for tantalum 50 % (Kabatezi 2022).

More than 450 mine sites are and have been exploited (Muchez 2014) and more than 700 mineral occurrences are known in Rwanda (BRGM 1986). Many of these deposits and occurrences contain tin, coltan and tungsten. The Karagwe-Ankole Belt of Central Africa that passes through Rwanda forms a metallogenic province with principally Nb-Ta, Sn and W commodities. Niobium-tantalum and part of the tin are present in pegmatites that have a spatial relation with granite intrusions (Figure 28; Muchez 2014). Tin is especially concentrated in the greisenized cupolas of the granites or associated with coltan in variably altered zones in the pegmatites. In highly evolved pegmatites lithium minerals can also form in quantities and grades that are feasible to be extracted. For example, Li-minerals like spodumene, lepidolite and amblygonite were formed at the Rongi pegmatite in the district of Gatumba where amblygonite has been mined in the past (BRGM 1986]. In pegmatites, tungsten minerals like wolframite and ferberite can also be found as accessory minerals but are economically insignificant. The main tungsten mineralization occurs in quartz veins emplaced in metasedimentary rocks (with an age of 2160 – 1850 million years). Many of the tin mines, including the large tin mines at Rutongo, located in central Rwanda close to the city of Kigali, and Rwinkavu, located in eastern Rwanda, are exploiting quartz vein-hosted cassiterite as well. Quartz veins containing wolframite are exploited at Nyakabingo, located in north Rwanda, where a swarm of quartz veins in darks shales is mined, and at Gifurwe and Bugarama where tungsten minerals are associated to a quartz vein 'stockwork' hosted by dark shales (Figure 28).

The tin bearing quartz veins, for example, of the Rwamagana-Musha-Ntungaare area occur both in the granitic rocks and in metasediments. They have a thickness varying between a few millimeters to 1 m. On the scale of the outcrops within the mine site, no variation in vein thickness has been observed. A few veins with a thickness of up to 3 m have been observed. The length of the quartz veins is variable. Some quartz veins occur as pods, while others are continuous for more than 10 m. Most veins have a straight and regular morphology (Hulsbosch 2017).

The thickness of the tin and tantalum bearing pegmatites in the same area varies from a few centimeters to 5 m. Pegmatites can often be continuous over the entire outcrop and can attain lengths of several decameters. The dimensions of the pegmatites is generally larger compared to the quartz veins (Hulsbosch 2017). The grades of the ores can vary over a large range. In a recent BGR processing study, 11 representative ore samples from 10 mining sites were analyzed in the lab. The tin equivalent grades of the samples varied between 0.1 – 0.45 % $Sn_{eq}$. In one sample an ore grade of about 1.1 % $Sn_{eq}$ was calculated. The ore samples came from active mines from the regions of Gakenke, Muhanga, Rutsiro, Rubavu, Kamonyi and Ngororeo, located in the western part of Rwanda (Figure 28).

Indications for the resources are only found for large scale mining licenses. For example, the tin mine of GAMICO located close to Kigali is assumed to host about 9000 t of recoverable Sn. The grade of the ore is above 1.5 % Sn and the tailings of processing contain still about 0.3 % Sn (Thaisarco 2022). The Rutongo mine is estimated to contain approximately 54,000 t of recoverable tin. The deposit of Rutongo could be considered as one of the biggest cassiterite deposits in Africa (Thaisarco 2022). However, it can be supposed that most of the tin deposits are much smaller in size than the two examples mentioned here.

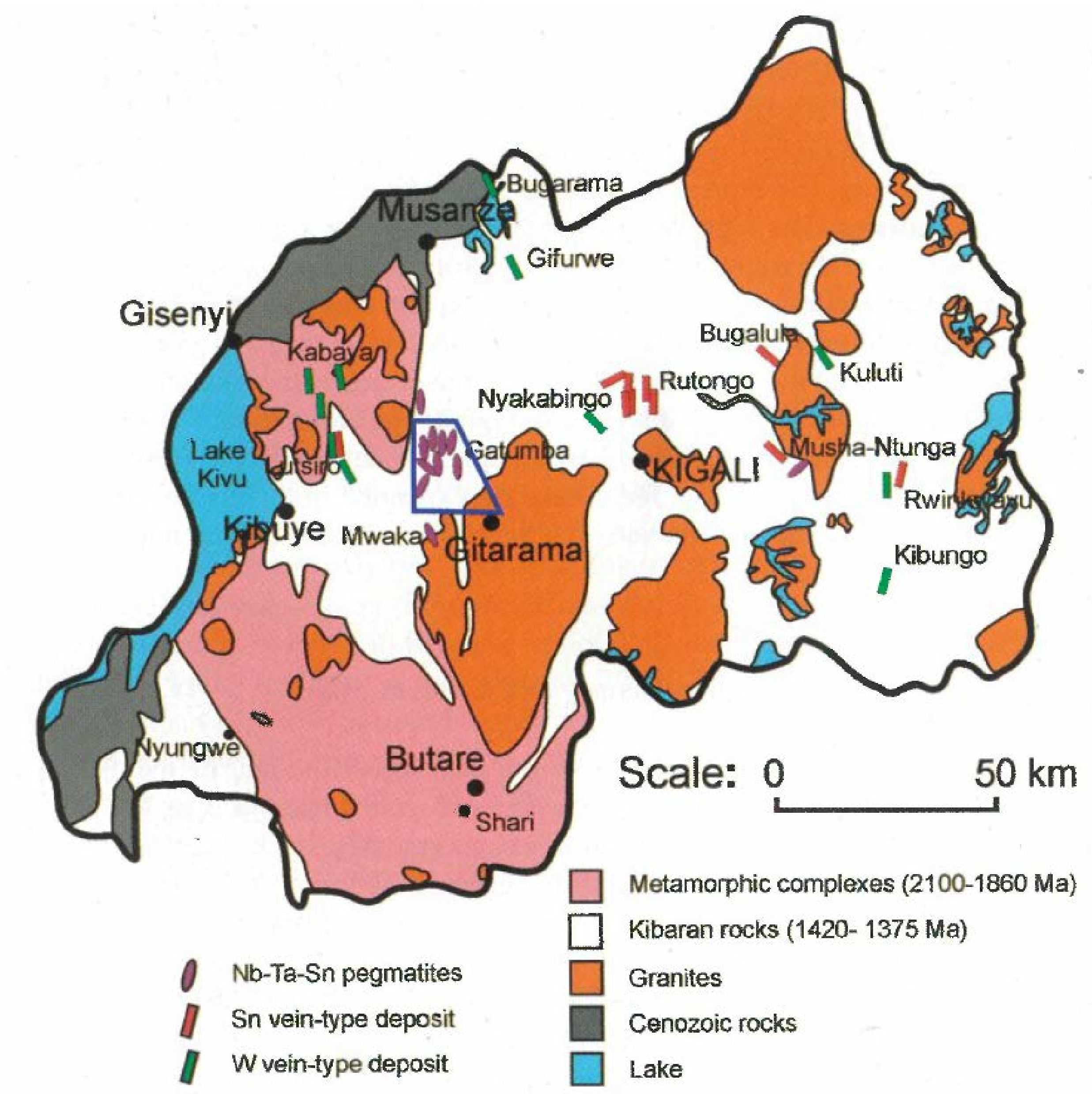


**Figure 28. Simplified geological map with the main ore deposits in Rwanda (Muchez 2014).**

The 3T-hosting pegmatites in some locations are known to contain Li-bearing minerals. This potential for Rwanda is not yet investigated and evaluated in detail. A recent mineral processing study of BGR (BGR 2022) showed that the tailings and slime fraction of the sorting process can have a Li-grade of up to 1.4 % Li2O. This is a lithium grade that can be considered as economically feasible for processing, depending on the metallurgical features of the different lithium minerals.

## 15.4 Artisanal ECRM mining and processing

Mining is usually realized manually by using hammer, chisel and pick in underground mines and open pits. At semi-industrial mine sites electric or pneumatic pick hammers are used for rock and ore breaking. In a few occasions, when low grade ore is extracted, hydraulic excavator and trucks are used to excavate the ore or to remove overburden material (for example at the coltan and tin open pit mines of Muriro and Rukaragata in Rwanda's western province that are operated by Power Resources).

Most of the pegmatites that are mined are heavily weathered in the upper parts, while most of the quartz veins represent relatively hard rock. In this latter case the production rates for manual mining are very low and mechanized excavation is required to maintain an adequate ore production rate.

In many cases of small-scale mining, the upgrading of 3Ts is still done by ground sluicing. In this traditional process, the raw ore is washed through a sluice that is dug into the ground of a slope to achieve the fragmentation of the ore and concentrate the heavy minerals on the floor of the sluice channel. The ground sluice can have a length of several hundred meters. To provide water for the washing process. Therefore, sophisticated water management is required. Ground sluicing is a very labor-intensive practice since many workers are required to operate the sluice and to remove the pre-concentrate that is further processed by panning and density sorting to a heavy mineral concentrate. These pre-concentrates are sold to buyers who do final upgrading and separation of the mineral fractions, sometimes assisted by magnetic separation, into specific mineral concentrates of tin and tantalum which are then exported. Operational disadvantages of ground sluicing are the maintenance of the costly water management system and the huge environmental impacts caused by uncontrolled erosion and tailings discharge. Larger companies can produce concentrates with export qualities on site by using crusher systems and state of the art gravitational processing plants using jigs and shaking tables that obtain high recovery rates.

The company Power Resources Ltd. is planning to process tantalum concentrates in a hydro-metallurgical tantalum refinery further into intermediate tantalum products, but this process is not yet operational. As already mentioned in the previous subchapter, the LuNa Smelter is a high-quality tin supplier located in Kigali. Besides of the tin ingots achieving or exceeding LME standards LuNa produces other semi-products obtained during the production process: tin dross, low Sn tantalum slag and tantalum concentrate.

A recent study by BGR demonstrated that the process recovery of value minerals was in some occasions as low as 20 – 30 %. The low recovery rate could be increased by using mechanized processing equipment in some cases (BGR 2017). In other cases, however, simple artisanal processing techniques are relatively efficient, and mechanization is not automatically associated with an economic advantage.

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In Rwanda, typical pre-concentrates of coltan at mine site level contain 8 – 25 % of $Ta_2O_5$. At the export level, coltan concentrates in Rwanda typically show grades of 25-30% $Ta_2O_5$ (Schütte & Näher 2020). Grades of cassiterite exports from larger operations are usually above 70 % Sn-contents. Small-scale mining operations usually achieve export grades in the range of 60 – 70 % Sn contents.

## 15.5 Production and trade patterns

Regarding ECRM, Rwanda is currently exporting tin, tantalum and tungsten concentrates and probably in the recent year also lithium concentrate. In the early 1980s a tin smelter had been operated in Rwanda until 1985. During this period, Rwanda was also exporting tin ingots. Since 2019 the tin smelter LuNa is producing and exporting tin ingots once again. The annual production capacity is currently about 700 -1000 t.

According to the national production/export statistics, the cumulative historical 3T exports of Rwanda are about 140,000 t of tin, 26,000 t of tungsten and 7,500 t of tantalum concentrates. However, the validity of these figures is somewhat limited since there has been some smuggling of 3T concentrates from neighboring countries to Rwanda. The following figure shows the evolution of ASM production or exports for the 3T minerals from 1930 to 2022.

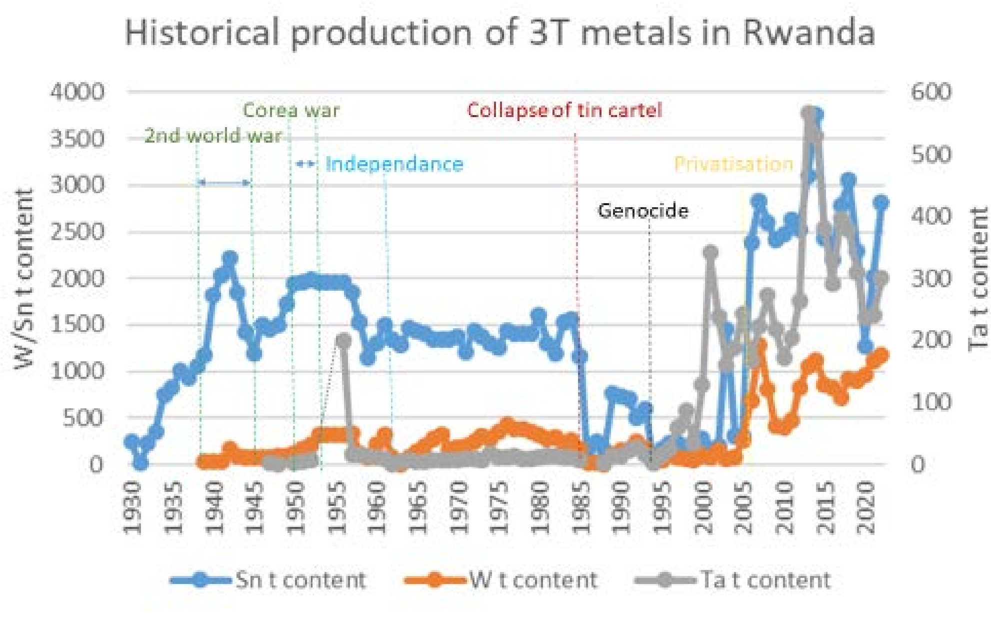


**Figure 29. Evolution of the estimated ASM-ECRM production (or exports) in Rwanda according to the BGR database (1957 – 2021), UN Comtrade database (2022) and BRGM database (1930 – 1957).**

It can be concluded from figure 3 that the production of 3Ts gained momentum after the privatization of the former SOMIRWA concessions that took place mainly in the period 2003 – 2006. In the last decade, the production of 3Ts has been relatively stable on a high level.

## 15.6 Potential future ASM ECRM production opportunities

Since the mining strategy of the Rwandan government currently foresees the formalization of the ASM sector there will be no further investment opportunities in the strictly artisanal, informal part of the mining sector. However, there is a need for investment in the formal, increasingly mechanized small-scale mining sector that has a high demand for technological innovation and that needs urgently an upgrading of the mineral processing systems that, compared to large-scale industrial mining, are considered inefficient. Moreover, sufficient 3T ore feed needs to be available to amortize processing equipment while sufficient expertise is important to optimize and monitor process efficiency.

The recycling of mining waste and processing tailings in Rwanda could be of interest for the ECRM production, since in many mining cases, lithium was not recovered during the processing at that time and the recoveries of 3Ts have been low both in some industrial mining sites and in artisanal mining in general.

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# 16 Tanzania

## 16.1 Background

In Tanzania, four types of mining rights/licenses are available for persons or companies. These are prospecting mining licenses, special mining licenses, mining licenses and finally, primary mining licenses. The first three types of licenses are appropriate for large scale and industrial mining (especially for foreign investment) since a considerable amount of investment is required to obtain and maintain the license.

The primary licenses type is especially adequate to small-scale mining. A primary mining license confers on the holder the exclusive right to carry on prospecting and mining operations in the mining area. It is granted for an initial period of up to seven years and is renewable. This type of license is granted only to citizens of Tanzania or Tanzanian companies (ABC Attorneys 2023).

The conditions that may apply to the holder of a primary mining license include:

- The right to erect the necessary equipment, plant and buildings for the purposes of mining, transporting, dressing or treating the minerals recovered during the course of mining operations;
- To pay the royalties due to the government;
- To stack or dump any mineral or waste product in a manner consistent with the Environmental Management Act;
- To implement the proposed plan for relocation, resettlement of, and payment of compensation to people within the mining areas if the area is occupied by surface rights holders; and
- The right to prospect within that mining area for any minerals other than gemstones.

Special legal provisions or licenses for informal mining do not exist in Tanzania (UNECA 2016). However, the Tanzanian government offers to the ASM sector credit facilities and grants, operates equipment hire/purchase and training centers and provides geological data. Tanzania has also established a multi-stakeholder partnership that includes LSM to support ASM. For example, the Tanzanite One Mining Ltd, a large scale gemstone miner, has been working with ASM and provides them with geological information and working tools.

## 16.2 Overview of the national ASM sector

Mining in Tanzania is carried out mainly by large-scale mining whilst ASM accounted for approximately 10% of Tanzanian gold production from 2014, i.e., 4 – 5 t of gold. Other estimates see the artisanal gold production in Tanzania even higher. There are estimates that at least 1.5 million people are associated economically to ASM (UNECA 2016). These include the service providers, financiers and miners themselves, though most of ASM remains informal. ASM mining is within all mineral commodities. The major fields of ASM in Tanzania are gemstones and gold. Regarding ASM of ECRM there are four commodities of greater economic interest: tin, tantalum, tungsten and copper. The IIED (IIED 2016) estimates that about 30,000 small-scale miners are working in copper mines.

The ECRM-exports of Tanzanian ASM in the period 2017 – 2022 had an aggregated value of at least US$ 24.4 million (UN Comtrade database). As shown in the next figure, the highest share for the exports came from tin concentrates with about 80 %, followed by tantalum concentrates. Since the GST (GST 2020) states that tantalum has never been mined it can be assumed that the reported exports of tantalum ores and concentrates are re-exports from neighboring countries. The share of copper ore and concentrates to the export value could be even much higher than indicated in the diagram. However, in 2020 the Bulyanhulu gold mine started with the exports of by-product copper concentrates. Because of this large-scale industrial production component, the export value of copper ores and concentrates achieved in 2022 represents a record value of about US$ 193 million. Because of these LSM copper concentrate exports it was not possible to find out the real contribution of the ASM sector to the copper export value. The USGS estimates the production capacity of the ASM at about 12,000 t of copper contents at Mbesa (USGS 2018). The exports of tungsten concentrates in the period 2017 – 2022 were considered insignificant. There was only one record of tungsten exports in this period and the weight of the exported tungsten concentrate in this occasion was 10 t. Tungsten concentrates in Tanzania are usually a by-product of the tin ore processing.

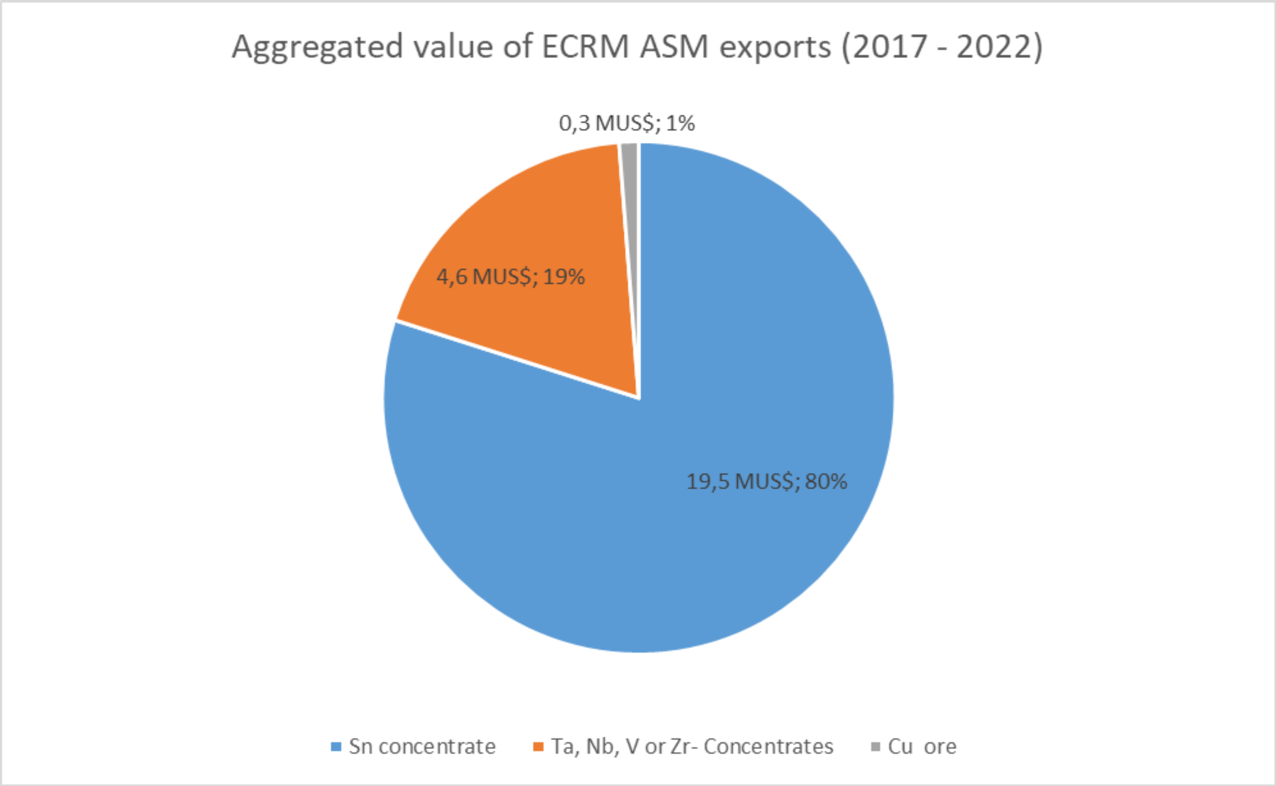


**Figure 30. Contribution of different ASM commodities to the value of Tanzania's ECRM exports in the period 2017 – 2022 (UN Comtrade database); exports of tantalum ores could not be verified by other sources. For 2022 the export of 1 ton of tungsten concentrate was reported.**

## 16.3 ECRM deposits amenable to ASM exploitation

In Tanzania there is only one mineral occurrence at Rulenge that contains along with tin also tantalum. The mineral occurrence at Rulenge has never been mined. The primary deposits of tin and tungsten have mostly a similar setting. The Geological Survey of Tanzania (GST) classifies them by their morphology into two classes: Stockwork deposits and dome-like disseminated, veinlets type, or deposits of the vein, lode, or reef type. Along with primary deposits there exist secondary deposits of tin and tungsten in placers.

### 16.3.1 Tin

Tin in Tanzania was discovered first in Kyerwa, in the northwestern part of Tanzania in the Region of Kagera and mining started in the 1920s. Most of the Tanzanian tin deposits are in the Karagwe-Ankolean system which geologically belongs to the Kibaran tin belt. From the 1920s until the 1970s about 6000 t of high-grade tin concentrates were produced in small-scale mines. The main production came from the tin fields located in Karagwe district in north-west Tanzania and most of the production was associated with alluvial mining. However, the placer tin deposits have been mined out and currently only some artisanal miners are producing cassiterite from small pits employing manual mining and panning techniques. The potential of the processing waste of alluvial or hard rock tin mining for other value elements has not been investigated so far. Possibly, tin occurs in paleo-placers that originate from primary deposits of the Karagwe-Ankolean System (GST 2015). However, it is unknown to the author if there were exploration activities in Tanzania dedicated to find paleo-placer of tin.

The primary tin deposits are frequently located in granites and in their immediate neighborhood, forming quartz veins and greisen stocks. The veins, mostly termed as reef type mineralization, have a maximum extension of several hundred meters. Their thickness is irregular, and the average Sn grade was around 0.15 % Sn (GST 2015).

A larger industrial tin mine that was also doing hard rock ore mining was the Kaborishoke mine, located in north-west Tanzania close to border to Rwanda and Uganda, where about 4.7 Mt of ore @ 0.04 % Sn was exploited producing 2600 t of Sn-concentrate with around 72 % tin content. However, this mine had to close because of the low tin prices in the 1980s. Exploration activities were carried out in the 1970s indicating resources of 350,000 t of ore at 0.04 % Sn content (GST 2015).

Since systematic prospecting and exploration activities using modern methods and covering the whole prospective area have never been carried out there is still the potential to discover tin deposits (hard rock and alluvial deposits) located in large anticlines in the roof of granite cupolas. However, Tanzania`s known primary Sn-deposits have proven to be small and low-grade, the placers have been extensively mined in the past and therefore it is expected that even when the tin mining sector is revived there will not be a high supply of Sn for the European market coming from Tanzania.

In Tanzania there are currently 32 inactive tin mines known, Fig 2. Inactive means that there is currently no valid mining license for the deposit and that the deposit is registered by the GST as mineral occurrence. Only the Kabingo mine located in the Kagera region in north-west Tanzania is registered as active. Most of the tin mines were small or very small in size during their operation. All of them were operating in the region of Kagera. In two mines, the metals tantalum and tungsten were extracted as by-products. Besides, there are about 260 registered primary licenses granted for tin with a maximum license size of 10 ha. The total area of all registered primary licenses for tin is > 731 ha.

Since 2021 there has been a significant increase of tin concentrate exports that was caused by the renewal of the activities in the Kyerwa deposits by the company Tutimex. The Kyerwa deposits are in the Kagera district in north-west Tanzania. In 2022 there were about 40 active mining sites in Kyerwa and the total production capacity of tin concentrates was around 55 t of tin and tungsten concentrates per month (Thaisarco 2022).

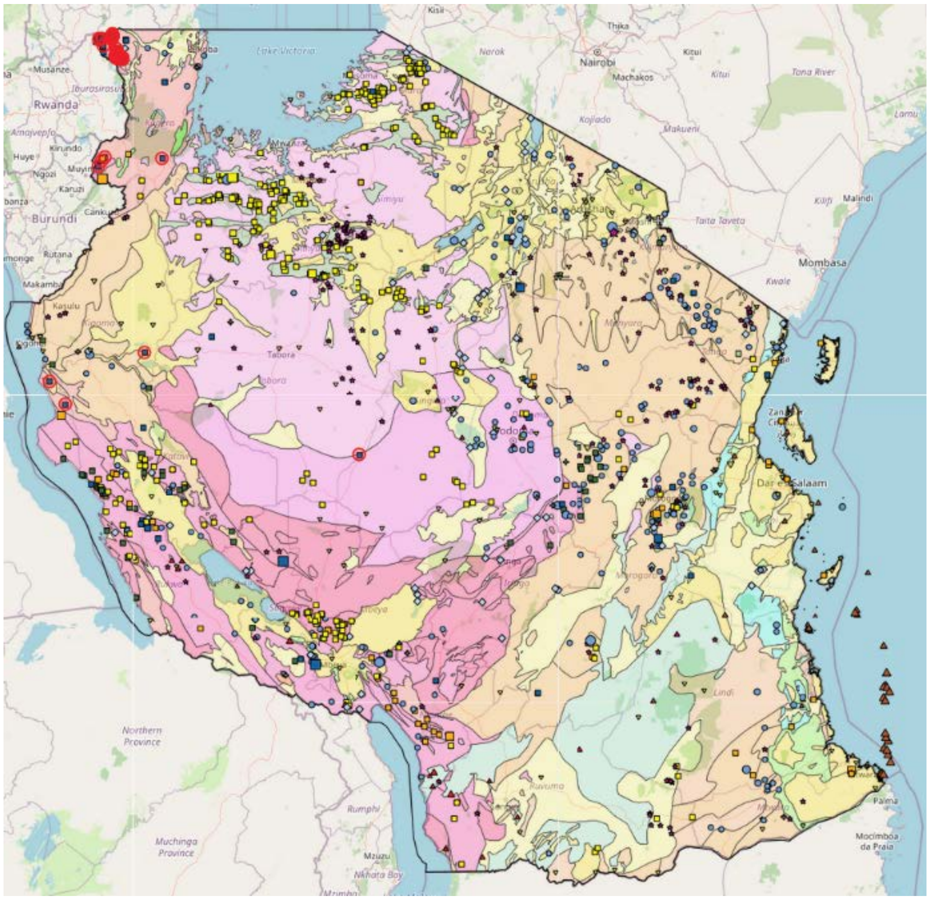


**Figure 31. Map of tin mining sites/deposits in Tanzania (in red encircled; GST 2023).**

## 16.3.2 Tungsten

In Northwest Tanzania tin and tungsten is bound to the Kibaran formations stretching from Uganda, Rwanda, Burundi, via Tanzania to the DRC. In Tanzania, small amounts of tungsten have been mined in the Karagwe tin field in the Kagera region between 1935 and 1956. The cumulative production in this period was 260 t, coming from eluvial deposits. Wolframite is also a common accessory mineral within several Au-bearing ores in the Shinyanga district (GST 2015).

In Tanzania in the past there were few working tungsten mines. One of them was a gold-tungsten mine and the second one was a tin-tungsten mine. Currently there are only two primary mining license applications registered for wolframite as commodity.

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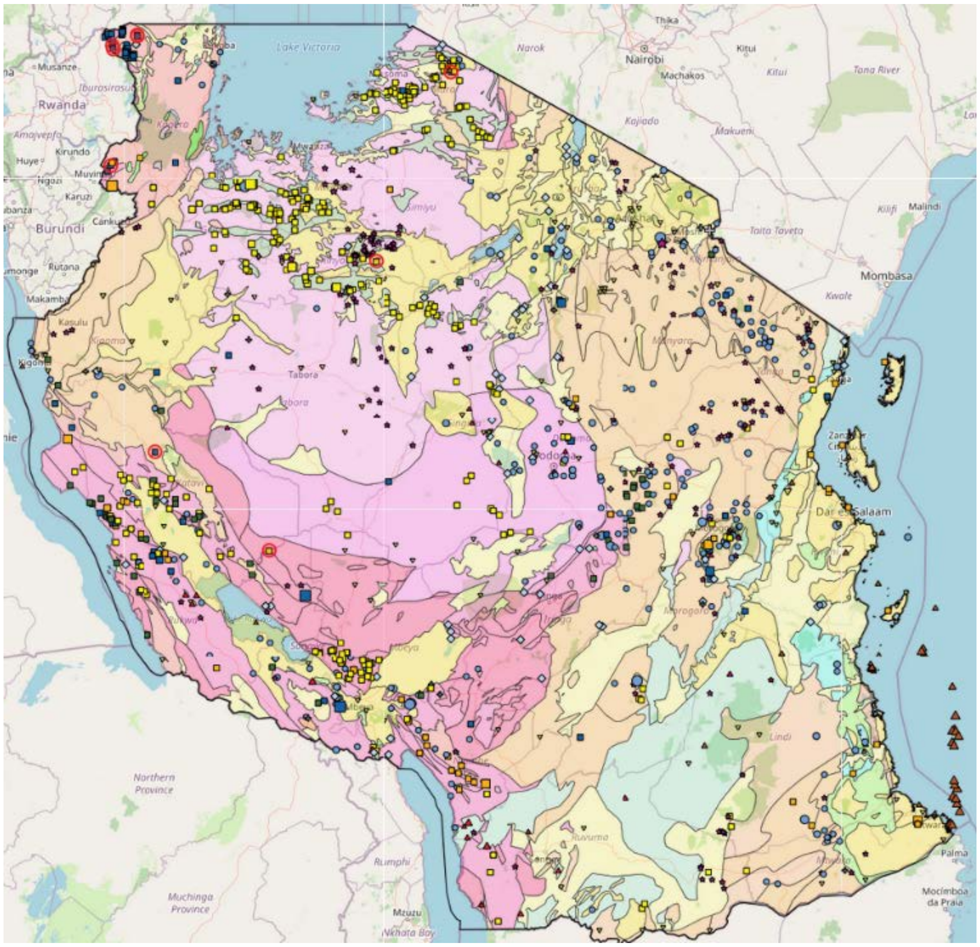


**Figure 32. Map of tungsten mining sites/deposits in Tanzania (in red encircled; GST 2023).**

## 16.3.3 Copper

In Tanzania, besides of the copper that is produced as a by-product of the industrial gold mining (about 30,000 t of Cu contents in 2022; BGR raw material database), there is some production of copper ore in the ASM sector. From the several types of copper occurrences that are found in Tanzania there are only some feasible for ASM mining. Since the Cu grade in primary rocks is usually low (about 0.1 % Cu) only the zones associated to particular lithological contacts and of secondary enrichment by weathering are of interest for ASM. Of special interest for ASM is Cu mineralization in Proterozoic meta-carbonates and amphibolitic rocks. Numerous small copper occurrences are known from the Mpwapwa area near Tambi in the district of Dodoma that were already mined during the German colonial period. The ores consist of primary sulfides, such as chalcopyrite and bornite. Usually, the copper ore occurs in small pockets and coarse-grained masses. Typical ore grades at Tambi are between 0.5 and 1.7 % copper content. In some samples from the Tambi copper occurrences the cobalt contents was elevated (up to 600 g/t Co; GST 2015).

In the years before 2015 only oxidized Cu ore was mined with grades varying between 0.5 – 2 %. High-grade Cu sulfide ores (up to 15-18 % Cu according to information from mine owners) are mined south of Tambi in the region of Dodoma (GST 2015). The copper occurrences at Tambi are considered by the Geological Survey of Tanzania GST as impregnations and mostly irregular in form (GST 2023). Similar copper ores are known from Mbesa, Southern Tanzania, Tunduru district, near the border to Mozambique. The analysis of two ore samples from Mbeza showed a grade of 2.7 % Cu and 20.9 % Cu (GST 2015). The USGS estimates the artisanal and small-scale mining capacity for copper in the Mbeza area of Tanzania of about 12,000 t/a (USGS 2018).

In Tanzania there are 39 active and inactive mining sites registered in the geo-economic database where copper has been mined as main commodity or by-product. Currently 18 large-scale mining licenses for copper and more than 1000 primary mining licenses for copper are recorded at the license database of the Geological Survey of Tanzania (GST 2023), shown on the following figure.

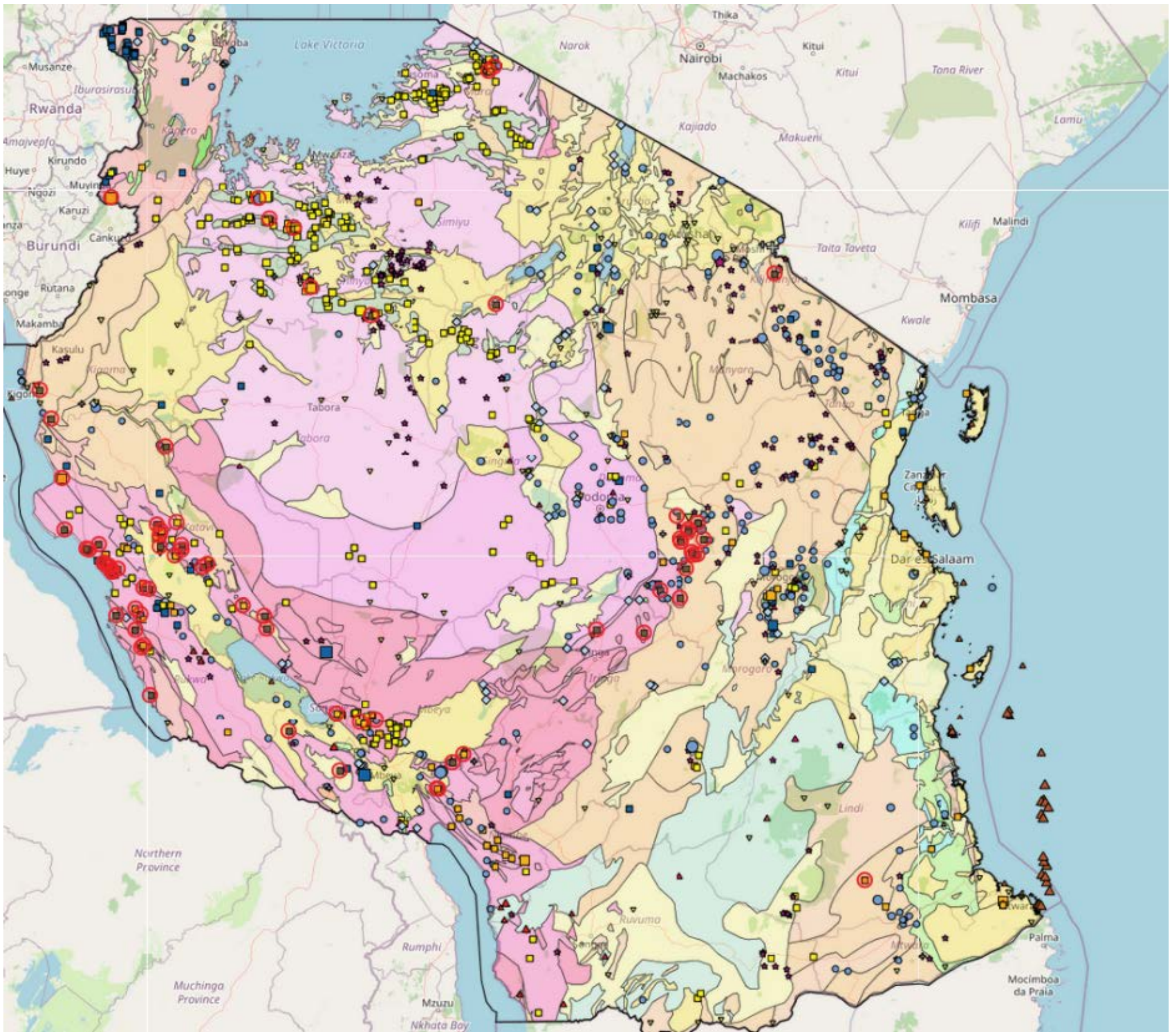


**Figure 33. Map of copper mining sites/deposits in Tanzania (in red encircled; GST 2023).**

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### 16.3.4 Other ECRM commodities

Other ECRM commodities like barite are found as occurrences and have no economic significance, because they are too small for industrial mining and the transport and marketing infrastructure is not sufficiently developed for ASM. Since barite is a gangue and accessory mineral of hydrothermal vein fillings it could probably be produced as a commercial by-product while mining other minerals for example in gold and base metal veins. There are four primary licenses for barite with a total registered concession area of 40 ha.

Cobalt is a possible byproduct of nickel-laterite mining that is not suitable for small-scale activities. Graphite is found in many occurrences in Tanzania. However, until now only modest amounts of graphite have been exploited in small deposits. At Mkalamo located in Pangani District of the Tanga Region several small-scale graphite occurrences are situated in the Proterozoic crystalline basement. The graphite is mined here by small-scale miners who are selling the material to Chinese traders. The flaky graphite layer occurs in strongly altered gneisses, possesses a thickness of on meter (maximum) and is dipping 60 to 70 °. The content of carbon is 27.9 % and sulfur is low (0.14% S; GST 2015).

In the geo-economic database of GST there are five inactive graphite mines registered in Tanzania. At present under the license type of primary mining license there are 96 licenses registered, with a maximum concession size of 10 ha. Since some deposits are considered as high quality graphite deposits (flakes, > 27% C), there is a potential for ASM that could supply European industrial partners.

Lithium has not been mined yet in Tanzania. Since the available information suggests that the pegmatites containing the lithium mineral lepidolite are rather small, they could be of interest for small scale mining. In particular, the area of Hombolo located close to the city of Dodoma shows some lithium containing mineral occurrences, that have been considered in the past as too small for industrial mining. However, the Li-grades that were determined in the course of the elaboration of the Minerogenic Map of Tanzania are at maximum 1.34% $Li_2O$ (for loose blocks of lepidolite at the outcrop, but other samples showed a lithium contents of < 0.12% $Li_2O$). The Li-bearing zoned pegmatite dyke at Hombolo is of lenticular shape about 30 m wide and over 100 m in length (GST 2015).

## 16.4 Artisanal ECRM mining and processing

Tin and tungsten production in Tanzania has largely occurred on a small scale both for underground and surface workings. In most operations, simple hand tools were used for the excavation work, at least in the upper levels of deposits that are weathered to a high degree. Pneumatic or electrical pick hammers, as for example used in the ASM sector of Rwanda, could be put at disposal by the concession owner to be able to extract hard rock material.

From ASM gold mining in Tanzania it is known that the most common mechanized tools are generators, compressors and water pumps. Generators are essential for any form of mechanization given the poor connection of mines to the electricity grid. Compressors serve to power pneumatic tools such as jack or pick hammers and hoists. Water pumps prevent operations from shutting down if they reach ground water levels or during the rainy season. However, most mines still operate without any form of mechanization, using only hammers, chisels and hand-operated hoists. It is important to note that mechanization is different from pit to pit, as it depends on the investment by the pit owner and other financiers (IPIS 2019).

Handpicking is employed when the ores occur as pockets with simple washing and concentration in pans where the ore is more disseminated. Hand washing and panning are also used where ores occur in residual gravels over or in eluvial deposits adjacent to pegmatites. There is no information available about further processing of pre-concentrates.

The copper minerals produced in ASM are high-grade and probably after hand picking can be sold as direct shipping ore to intermediary mineral buyers. The ore is excavated close to the surface in open trenches or in short underground adits. Aside from these artisanal operations, a number of small to medium-sized, foreign-backed companies engaged in Tanzania's copper sector and obtained mining licenses, but the level of their actual project development activities remains unclear (Schoneveld et al. 2018). In addition, a number of ASM-related copper processing operations have been set up in the country since the early 2010s. These operations were usually supported by external investors as well. Processing facilities active at some point include a froth flotation plant for copper sulfide ores, a copper leaching plant for copper oxide ores, and a small copper smelter. The commercial and logistical viability of these operations remained unclear as of 2018 (Schoneveld et al. 2018), although the increased copper prices since 2021 might re-ignite interest in this type of operations.

## 16.5 Production and trade patterns

Since 1925, tin has been exported from Tanzania in the form of concentrates. The total historic tin production is at least 6150 t of tin contents according to the BGR raw materials database. Copper production according to BGR data started in 1995. The accumulated exported copper content was about 17,500 t, as shown in the next figure. From this amount, a significant share came from ASM production up until 2020. Some large-scale industrial gold mines, such as Bulyanhulu, also produce copper concentrate as a by-product and used to send this to Zambia for smelting. Aside from copper concentrates, Tanzania exports copper matte, copper anodes and refined copper. For copper matte or anodes, a partial ASM origin cannot be ruled out. It is important to emphasize, though, that the major growth in Tanzania's copper anode exports observed since 2020 is probably related to regional logistical interruptions associated with the

Covid 19 pandemic, which blocked Zambian (and DRC) transit shipments through ports in South Africa, and led to re-routing of these shipments through Tanzania, Mozambique and Namibia.

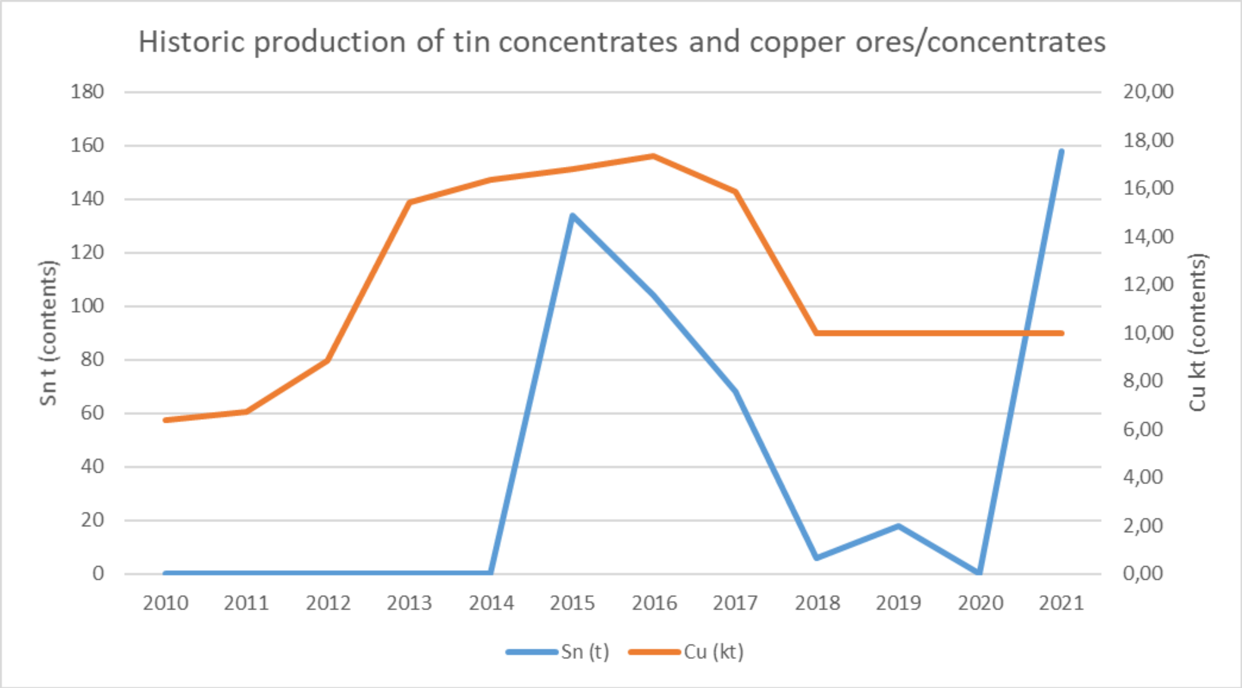


**Figure 34. Production statistics for copper ores/concentrates and tin ores and concentrates in Tanzania (BGR raw material database).**

## 16.6 Potential future ASM ECRM production opportunities

In Tanzania a large number of small showings of tungsten, tin and copper mineralization is found. Many of which have been mined in the past by small-scale miners going underground or in open pits. In part, these mineral occurrences belong to industrial mining concessions (license type: mining leases) and the concessions holders buy and resell the production of the artisanal working groups. However, there exist also artisanal mining zones from where the production is directly sold to traders or middlemen. The main obstacles for ASM are the lack of infrastructure, difficult supply to water and the complicated system of commercialization that has multiple stages of governmental involvement.

Because of their structural-tectonic control unknown mineral occurrences for tin and tungsten could be in large anticlines in the roof of granite cupolas. Since Tanzania's known tin and tungsten deposits have proven to be small and low grade there is only a small supply potential for the European market. For the EU the establishment of business relations to well organized mining companies could provide at best a moderate flow of tin and tungsten concentrates to the EU.

The development of small graphite and lepidolite mines by ASM that are considered too small for industrial mining could also be an option for EU supply with critical raw materials. The selling of graphite and lithium ore in small lots to Chinese businessperson in Tanzania and East Africa has already proofed that there is an economic potential for ASM activities.

The prospectivity of Tanzania for copper mineralization exploitable via ASM is significant and the country already has experience in terms of setting up small-scale copper processing facilities. It would be of interest to evaluate the feasibility of these processing operations in more detail, as a function of formal licensing requirements as well as local supply capacities, logistics and economies of scale.

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# 17 Uganda

## 17.1 Background

The new Mining and Minerals Act came into force in Uganda in 2022 and replaced the Mining Act from 2003. The new Mining Act has introduced new types of mining licenses distinguishing between large, medium, and small scale and also contains provisions that supports the formalization process of ASM including, among others, the establishment of areas designated for artisanal mining (Republic of Uganda 2022).

## 17.2 Overview of the national ASM sector

Uganda is endowed with over 50 different types of raw materials and ranks among African countries with the highest number of different raw materials although the potential for commercially viable exploitation has not yet been established for most of them. The Ugandan mining industry peaked in the 1950s and 1960s when the sector accounted for up to 30% of Uganda's export earnings. In 2017, mining and quarrying accounted for 0.6% of the GDP (UNECA 2023). This GDP share shows that mining in Uganda nowadays plays only a minor role. The main mining regions are in the southwestern, southeastern and eastern part of the country, as shown in the following figure.

Uganda is estimated to host a total ASM population of about 300,000 miners (Pact 2018), including 150,000 artisanal gold miners (IGF 2018). An estimated number of 1,700 miners are employed in mining tin, tungsten and tantalum (3T) ores (ARM 2018). However, the major part of the artisanal mining is taking place in the mining of construction and industrial raw materials. Although there is a limited official artisanal 3T production, it can be assumed that at least in the past an important part of the artisanal 3T production was smuggled into Rwanda (Schütte 2019). With the establishment of gold refineries in the country, Uganda has become an increasingly important gold exporter in the region with strong links to the UAE, to whom it exports 99% of its gold. Uganda is an important hub for smuggled minerals from the DRC and South Sudan, constituting a significant source of high-risk gold flows to Dubai. Uganda's mineral fiscal regime has been the subject of much debate, with low export taxes assessed as a significant contributing factor in the smuggling of gold out of the DRC (Levin Sources 2021).

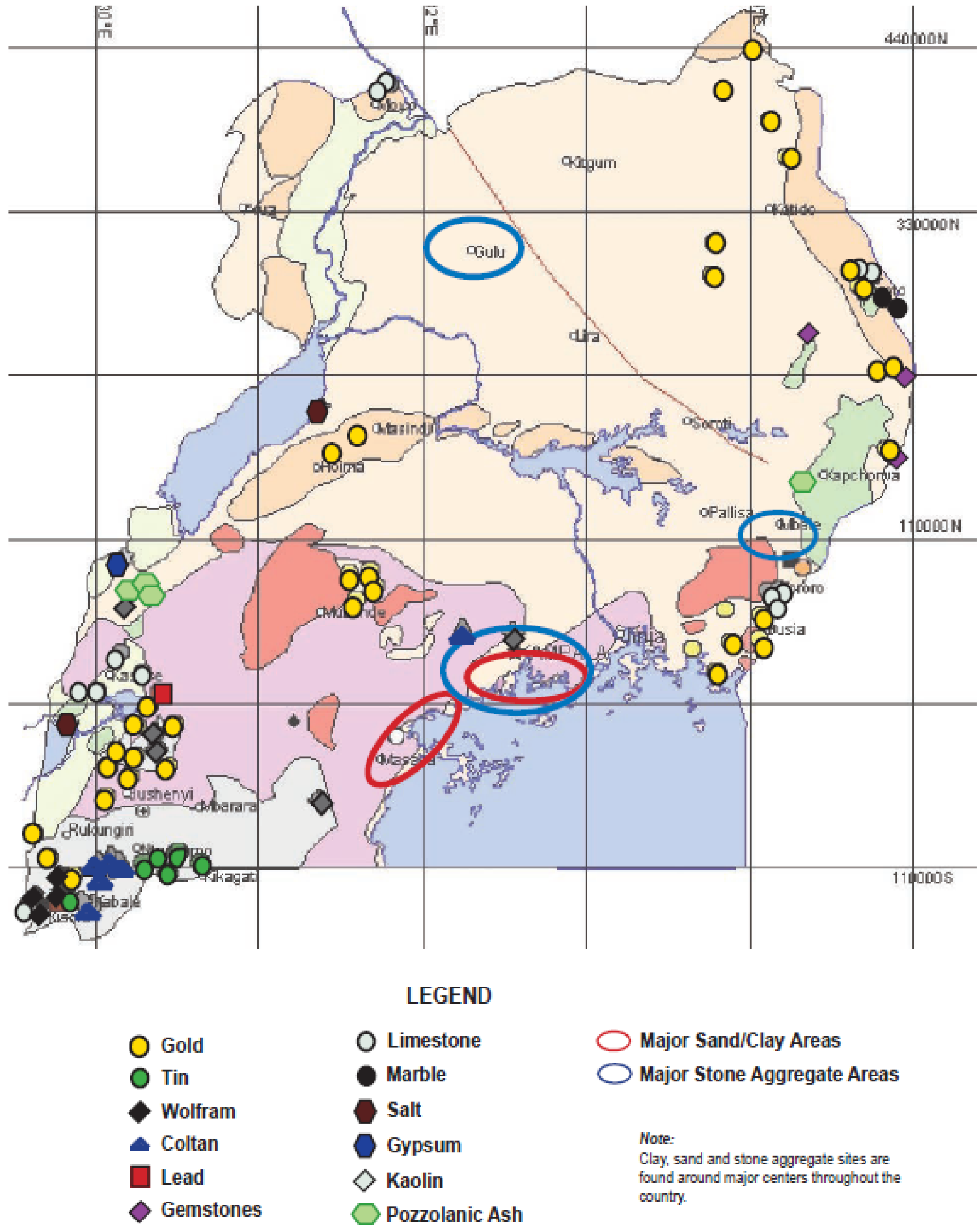


**Figure 35. Locations of main small-scale mining sites in Uganda (Hinton 2009).**

## 17.3ECRM deposits amenable to ASM exploitation

In Uganda, there are three commodities that have been mined by artisanal miners and are part of the ECRM list. These are tin, tantalum and tungsten, as shown in the following figure.

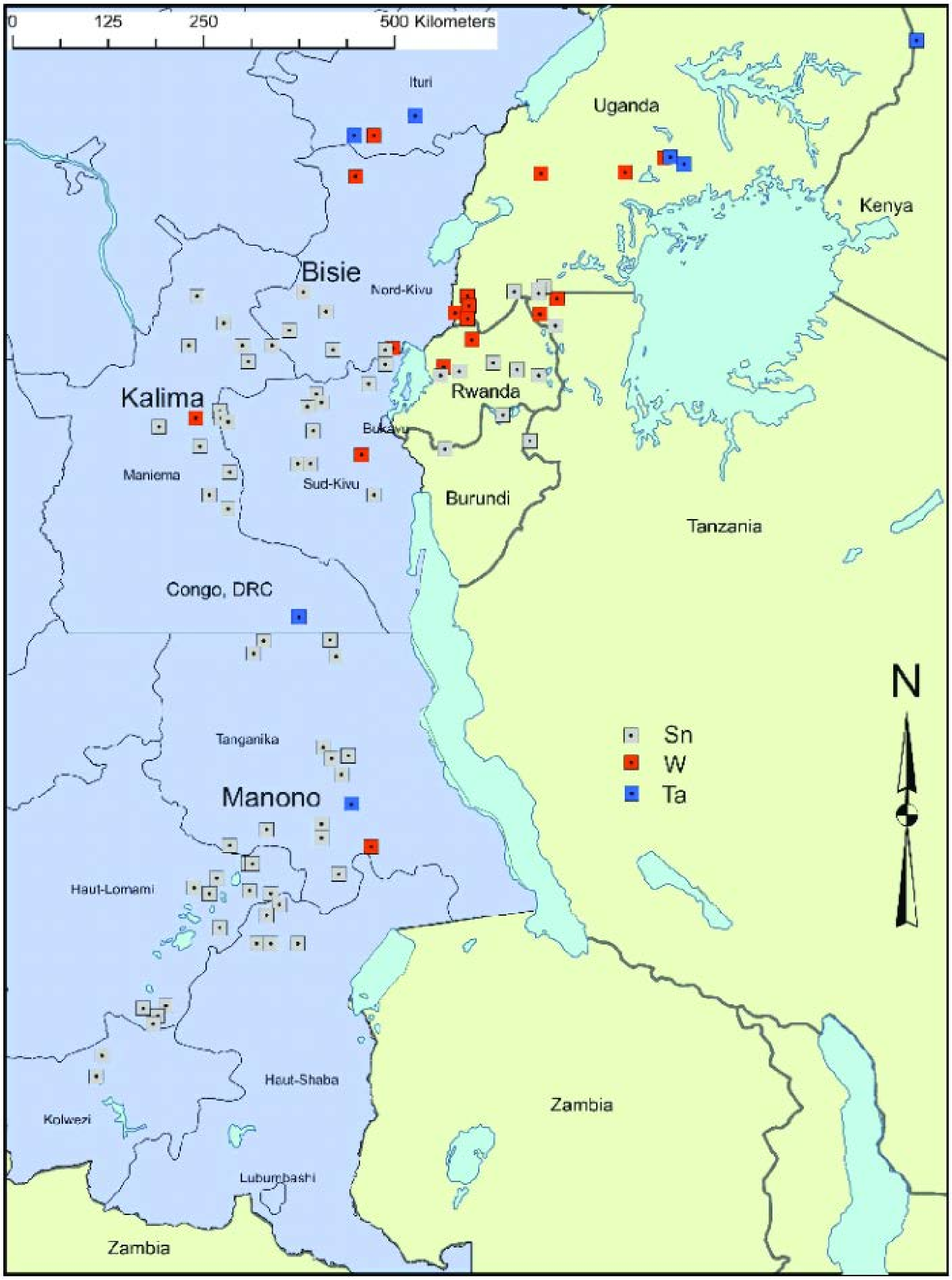


**Figure 36. Location map of selected tin, tungsten and tantalum occurrences in the Great Lakes region (Kinnaird 2020).**

### 17.3.1 Tin

The tin province of Uganda (all the cassiterite deposits known in Uganda) is hosted by the Mesoproterozoic North Kibaran fold belt which is composed of metamorphosed clastic sedimentary rocks, to syn-kinematic, foliated to isotropic porphyritic and pegmatite granite attributed to the North Kibaran Igneous Province. The system predominantly consists of argillites with arenites and silty rocks regularly distributed as thin bands throughout and cassiterite ($SnO_2$) is confined to pegmatites or quartz veins hosted by the shales and sandstones of this system. In close spatial relation to the pegmatites secondary, alluvial or eluvial mineralization occurs as well.

Tin mining in southwestern Uganda started in the 1920s. This mining concentrated on large veins and their immediate alluvium. In 1925 the first deposit at Kikagati in the Insingiro District was discovered, followed by Mwerrasandu in the Ntungamao District in 1926, Kaina in 1927 and Nyinamaherere in 1928. Additionally, cassiterite was exploited in countless small occurrences in the southwest of the country. The known mineral occurrences belong to a larger 3T-mineralized area extending from south-west Uganda south to Tanzania and extends west to Rwanda and Burundi. Coarse-grained cassiterite is primarily found here together with beryl and wolframite in irregularly distributed quartz-muscovite veins of slight thickness (rarely more than a meter wide). Stockworks and sheeted vein swarms occur at Rwaminyinya (Kisoro) and Kitezo (Mbarara) and these are likely to have large reserves (Nagudi 2011).

Uganda's tin concentrate production from 1927 to 2001 totaled about 13,000 t (Kinnaird 2016). The bulk of this production came from hard rock deposits with minor eluvial production but no alluvial production. The largest deposit was Mwerasandu (Ntungamo) and substantial production also came from Kikagati (Isingiro). Other producers were Rwaminyinya, Burama ridge (Kabale/Ntungamo border), Ndaniyankoko (Isingiro), Kaina and Nyinamaherere (Ntungamo). 1.0 Mt of ore at 2.5% tin are estimated to still exist in the district of Ntungamo and 2.5 Mt in the district of Isingiro according to the Ugandan Chamber of Mines and Petroleum (UCMP 2023).

The operation of the Mwerasandu mine that produced about half of the historical tin production has left a large pile of coarse tailings and waste, with an estimated quantity of 120,000-135,000 t while the fine tailings dump has 195,000 – 210,000 t (PLEXII 2023) probably still containing some residual cassiterite. A report submitted to UNECA by the Government of Uganda in 1968 indicated even an amount of about 0.75 Mt of processing tailings with a grade of 0.044% BeO (UNECA 1968). Tin enjoyed a monopoly in Uganda's mining sector until 1931 and this was followed later by a tin boom in the 1960's and 1970's favored by high tin prices. The mining concession at the Mweirasandu mine was hold at least until 2019 by the Germany-based Zarnack Holding.

During the financial year 2019-2020 the company African Panther Resources (U) Ltd exported about 14 t of cassiterite concentrate to Thailand with a value of about EUR 145,000 (EITI 2022). The average grade of the cassiterite concentrate is 70% Sn content.

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### 17.3.2 Tungsten

Wolframite in Uganda is found in two regions: Southwestern Uganda and the Singo area in Mubende. The major former wolframite producing mines in Uganda in 1960s to early 1970s were Kirwa, Ruhizha and Bjordal in southwestern Uganda.

Numerous tungsten deposits occur in quartz veins closely associated with granitoid intrusions. For example, at Nyamuliro (also called Bjordal Mine), Rushunga and Ruhija in Kabale district; Kirwa, Mutolere, Rwamanyinya, Mpororo and Bahati in Kisoro district; Kyasampawo in Mubende district, Buyaga in Lyantonde district and Nakaseta in Mityana district. Others are Kyasampawo and Mbale Estate in Mubende district and Buyaga in Rakai district.

These deposits occur frequently as vein swarms in graphitic horizons in the phyllitic rocks closely associated with granitoid intrusions. Tungsten occurs mainly as ferberite frequently as reinite pseudomorphs after scheelite. The main deposits that have been mined are Nyamuliro (Bjordal Mine), Kirwa, Ruhija, Mutolere, Rwamanyinya and Bahati in Kabale and Kisoro districts. In Bahati, tungsten occurs as wolframite with about 4% manganese in platy shining pieces grading >1% $WO_3$ (Nagudi 2011).

Uganda's wolframite concentrate production from 1935 to 2001 totaled over 5,000 tons and this came from the various low-grade deposits. Kirwa Mine, one of the large producers from late 1940's to 1979, still has a resource estimated at 1.25 million tons averaging 0.19% $WO_3$. Bjordal has been re-developed by M/S Krone Uganda Ltd. and later by Ki3R Minerals Limited. The production was up to 15 tons/month (Uganda Invest 2010).

During the financial year 2019-2020 the company Ki3R Minerals Limited exported about 76 t of wolframite concentrate to Canada and the Netherlands with a value of about EUR 330,000 (EITI 2022).

### 17.3.3 Tantalum/Niobium

Columbite and tantalite (together called coltan) constitute a group of minerals, often referred to as columbite if niobium is predominant and tantalite if tantalum is the major constituent (mineralogically, these constitute the end members of a solid-solution series). The niobium ores that occur in Uganda are columbite ($(FeMn)Nb_2O_6$) and pyrochlore $(NbCa)_2(NbTi)_2(OF)_7$. Tantalite is the principal tantalum ore mineral and occurs with columbite in pegmatites. Pyrochlore is not mined or processed in the ASM sector. The fragility of pyrochlore crystals causes their quick decomposition in the ore during weathering, resulting in a fine grain size distribution that is only recoverable by complex flotation processes that are not suitable for ASM.

Workable deposits of coltan are restricted almost entirely to SW Uganda. Columbite-tantalite occurs in pegmatites at Kakanena, Nyanga, Rwakirenzi, Nyabushenyi, Rwenkanga and Dwata in

Ntungamo district; Jemubi and Kabira in Bushenyi district; Bulema in Kanungu district; Kihimbi in Kisoro district and Lunya in Mukono district. The pegmatites are generally of small size with irregular metal distribution. Columbite-tantalite occurs either in pockets or as disseminated grains throughout the orebodies. The pockets tend to be closer to the core of the pegmatite. The proportion of Nb to Ta in the mineral varies considerably even in one deposit. Many varieties contain a small proportion of fergusonite that is a complex oxide of various rare-earth elements and weakly radioactive because of the thorium content. The pegmatites have usually undergone intense kaolinisation (except in Nyabakweri and Bulema) making it difficult to trace the original orebody in the deposit and to process the ore (Nagudi 2011).

During the financial year 2019-2020 the company 3T Mining Limited exported about 10 t of tantalite concentrate to China with a value of about EUR 160,000 (EITI 2022). The purity of the coltan concentrate is on average 30 %.

### 17.3.4 Lithium

Lithium has been exploited in the past only from the Nyabushenyi (Ntungamo district) and Mbale Estate (Mubende district) pegmatites in the past. These minerals of interest are mainly amblygonite and zinnwaldite but minor amounts of petalite and lepidolite have been found in Kabale. Amblygonite was also recovered from tin-bearing quartz veins at Mwirasandu and Lamwine in the Ntungamo district. Production of amblygonite from 1949-1969 was only 777 t. The lithium-phosphate amblygonite is not the standard mineral for the processing of Li-carbonate, but in past several process routes were proposed to recover lithium from this mineral. Most often, these Li-mineral containing pegmatites are small in size and the form of the deposits is irregular. However, these deposits are considered as suitable for small-scale production by local entrepreneurs (Nagudi 2011).

## 17.4 Artisanal ECRM mining and processing

Tin, tantalum and tungsten production in Uganda has largely occurred on a small scale both for underground and surface workings. In most deposits, simple hand tools are sufficient for excavation work, at least in the upper levels of deposits that are weathered to a high degree. Pneumatic or electrical pick hammers, as for example used in the ASM sector of Rwanda, could be put at disposal by the concession owner to be able to extract hard rock material.

Handpicking is employed when the ores occur as pockets with simple washing and concentration in pans where the ore is more disseminated. Hand washing and panning are also used where ores occur in residual gravels over or in eluvial deposits adjacent to pegmatites. Only in a few cases a jig is employed, where cassiterite occurs together with coltan. The jig product may be separated by handpicking or by magnetic separation at central processing plants that are operated by the concession holder.

In case there are small industrial concession holders, these companies organize the small-scale miners in groups and buy the preprocessed production from them on a daily basis. The pre-concentrates are further upgraded in small processing plants on the companies' sites until export qualities are achieved. The processing includes manual crushing, washing and separation of heavy minerals by gravitational means, for example by jigs and shaking tables.

## 17.5 Production and trade patterns

Since 2012, a part of the official production is derived from artisanal activities taking place in the concessions of mineral trading companies. According to the USGS data, the total recent ECRM production in the last 25 years can be estimated to be about 1,100 t of tungsten content, 550 t of tin content and 60 t of tantalum content. Additionally, about 25 t of niobium were contained in the exported coltan concentrates. However, it has been assumed that a substantial part of 3T minerals production of Uganda was smuggled to neighboring countries like Rwanda.

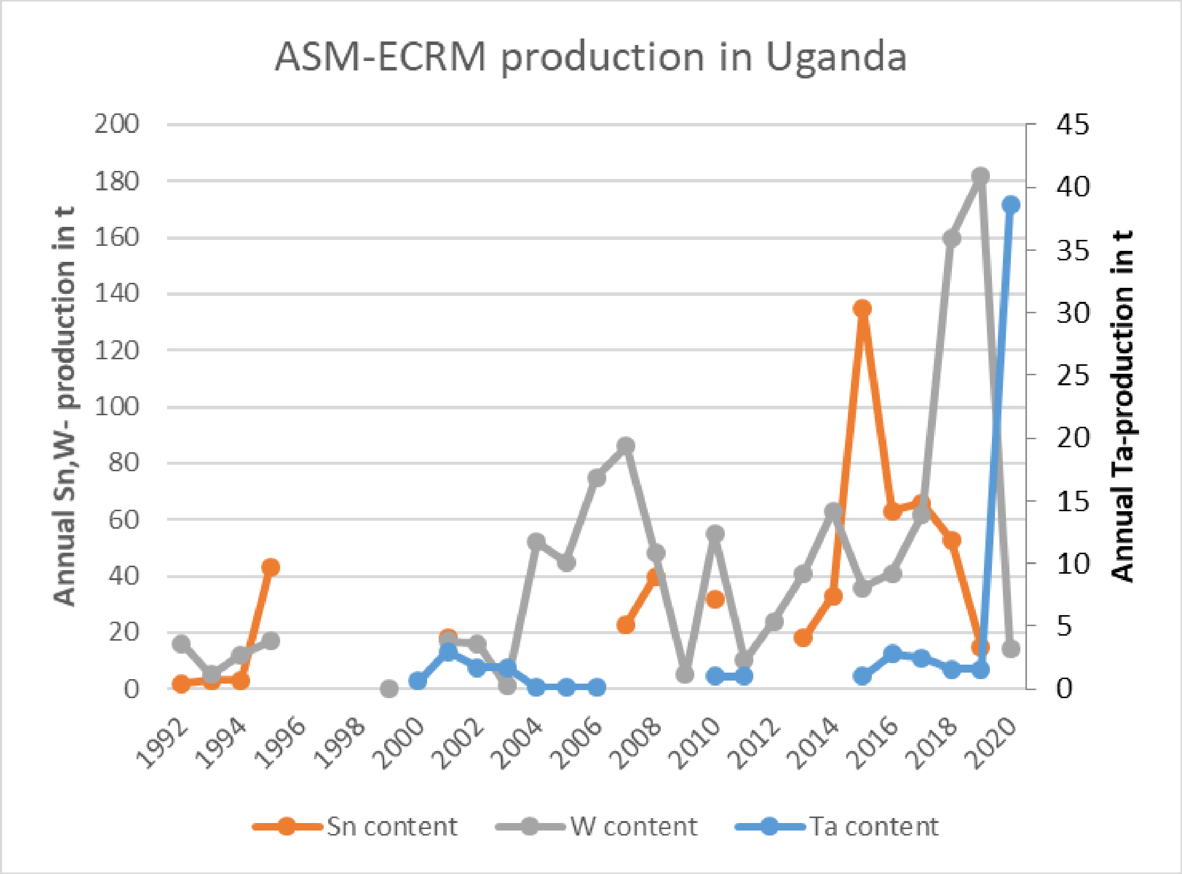


**Figure 37. Official production statistics for tantalum, tungsten and tin in Uganda (USGS statistics for Uganda 1996 – 2020).**

## 17.6 Potential future ASM ECRM production opportunities

In Uganda, a large number of small showings of tantalum, tungsten and tin are found, many of which have been mined by small-scale miners going underground or in open pits. In part, these mineral occurrences belong to industrial mining concessions (license type: mining leases) and the concessions holders buy and resell the production of the artisanal working groups. However, there exist also artisanal mining zones from where the production is directly sold to traders or middlemen. The government plans to establish buying centers for 3T-minerals and gold that shall guarantee transparent and competitive selling prices to artisanal and small-scale miners and, to their advantage, cut out the middlemen who buy their minerals at prices much lower than the market price (Arigye 2019). However, it is unknown to the author how many centers for the buying of 3T-minerals are already established and if they achieve the desired outcomes.

For the EU the establishment of business relations to these buying centers could provide at least a moderate flow of tin, tantalum and tungsten concentrates to the EU. The sustainable production could be supported by a re-evaluation of historical geological reports, for example from the German geological mission to Uganda that dates back to the 1970s (BGR 1973).

Since the pegmatite deposits in some cases contain also Li-bearing amblygonite or other minerals, an ASM production of lithium containing mineral concentrates seems possible. However, in this case the transport costs to an export harbor would be a hindrance to the profitability of marketing the otherwise relatively low-value concentrate. The process for the extraction of lithium must be developed taking into account the characteristics of the mineral. For small quantities of concentrates, this may not be feasible.

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# 18 Zambia

## 18.1 Background

Zambia is a significant producer of certain ASM commodities. Zambia's Mines and Minerals Development Act of 2015 differentiates artisanal as well as small-scale mining licenses in the ASM sector, as well as a special gold panning certificate. By law, persons engaging in ASM activities or owning small-scale mining companies must be Zambian citizens. Over the past decade, some local stakeholders have criticized the growing influence and economic participation of foreign nationals, especially Chinese, in the ASM sector. Throughout the years, starting with the gemstone sector and, more recently, the gold sector, the government has undertaken various efforts to formalize certain ASM subsectors while others, such as manganese mining, remain largely informal or illegal. As a consequence, the sector's organization appears somewhat heterogeneous, comprising formal and informal settings, and involving small-scale mining companies, cooperatives as well as individual artisanal mining groups. Sector formalization efforts partly seem to be politically motivated, as illustrated by legalizing the Jerabos' (local youth gangs) access to the Nkana copper-cobalt slag dump in Kitwe in 2018, in return for their support in the election campaign of the former Zambian president. This led to tensions when, in 2022, Zambia's new government decided to hand over access rights to the slag dump to formal cooperatives, emphasizing the role of local community members and women. Furthermore, Illegal miners sometimes enter industrial copper mining concessions and, when confronted by security forces, may destroy equipment and block local roads in protest.

## 18.2 Overview of the national ASM sector

ASM activities in Zambia comprise both mining of primary ore deposits as well as re-mining of copper slag dumps. The latter reflects the country's history of more than one hundred years of large-scale copper mining and smelting. Commodities currently targeted by artisanal and small-scale miners include manganese and copper-cobalt, as well as the non-ECRM gold, gemstones, and lead-zinc. There is historical ASM potential for tin (with minor content of tantalum-niobium) as well, but no significant production has been recorded in recent years. Overall, the Zambian ASM population is roughly estimated at more than 500,000 people. The authors could not identify estimates on the number of artisanal miners specifically working in the manganese or copper sector. On Black Mountain (see next paragraph) in Kitwe alone, there seem to be several thousand active miners, many of whom are members of youth gangs referred to as Jerabos. The following figure shows an overview focusing on Zambia's Copperbelt, Central and Luapula provinces where most of the important ECRM-related ASM activities are currently taking place.


**Figure 38. Map of Zambia's Copperbelt, Central and Luapula provinces, the country's centers for ECRM-related ASM activities. Map data is based on Bing as presented in S&P Global (2023).**

Artisanal and small-scale manganese mining focuses on the historic Mansa manganese district in Luapula Province while ore processing (beneficiation) takes place in Central Province, at Serenje and Mkushi. Manganese ore deposits and ASM production, though less clustered than at Mansa, are found in other Zambian provinces as well, particularly in Central Province. While Zambia's currently most productive industrial copper mines are located in the North-Western Province, ASM mining activities in this subsector are focused on the country's main historical copper-cobalt mining areas in the Copperbelt Province. This area still features industrial copper-cobalt mining conducted in parallel to ASM activities. Artisanal miners work on slags related to copper smelting and in abandoned or temporarily disused industrial mines. 'Black Mountain,' the slag dump related to the Nkana smelter in Kitwe, is particularly prominent. Artisanal miners further target the lead-zinc slag dump at Kabwe, termed Black Mountain as well. The Choma tin belt, located west of Lake Kariba in Southern Province, used to host historic small-scale production of tin (with minor tantalum-niobium), but current production, if any, appears to be sporadic and is overall insignificant.

In recent years, Zambia has experienced an artisanal mining gold rush taking place, in particular, in the central-southeastern parts of the country. Hilson (2020) notes "tens of thousands of gold panning activities". Furthermore, Zambia is an important producer of certain gemstones, such as emerald, amethyst, aquamarine, beryl, garnet, and rose quartz. The Zambian emerald production is of global importance. While ASM used to play an important role in the sector, their output has decreased and the partly state-owned Kafubu Gemstone Mining Company (Kagem, a joint venture controlled by Gemfields) currently accounts for 90% of national emerald production (Siwale & Siwale 2017). It is noteworthy that ASM operations in the gemstone sector tend to be formalized, as opposed to the ASM activities related to the manganese sector.

## 18.3 ECRM deposits amenable to ASM exploitation

The Zambian manganese deposits are dwarfed when compared to the giant manganese deposits of South Africa and Gabon, which show ore tonnages of up to several hundred million tons. Despite their high-grade mineralization, their economic viability for industrial mining has been questionable over the past decade. Only two industrial manganese projects are currently listed as active on the S&P Global market intelligence platform.

Their high ore grades, ranging from 40-70% at an average of about 50% Mn, as well as shallow mineralization levels make Zambian manganese deposits attractive targets for local artisanal and small-scale mining operations. Manganese mineralization occurs in different deposit types with superposed supergene enrichment caused by weathering. At Mansa in Luapula Province, the country's currently most important manganese mining area, mineralization is hosted by subvertical veins and lenticular orebodies, with a thickness of 0.5-3.5 m, pinching out down to 50 m depth, and with a strike length of >1 km (Watts, Griffis and McOuat Ltd. 1991). Mineralogically, these manganese veins contain barite, quartz, and fluorspar as gangue. Manganese is hosted by oxide and hydroxide minerals (manganite and hausmannite) that were later transformed into psilomelane due to weathering. In 1981, total resources down to 20 m depth in the Mansa area, comprising eight separate deposits, were estimated at 1.5 million tons, at a grade of 60-70% Mn (Watts, Griffis and McOuat Ltd. 1991). In 2015, local reserves were estimated at 15 million tons (Roskill 2015), though wording used in that source is ambiguous as to whether that refers to the Luapula Province alone or to the country as a whole.

Manganese deposits occur in other Zambian provinces as well (in particular in Central Province), where they are associated with mineralized horizons in metamorphosed sedimentary rocks (clastic and carbonate) and, sometimes, detrital secondary deposits. The deposits in these provinces, too, tend to show ore grades of 40-50% Mn. The orebody at Kampumba in Central Province, associated with important historical production, has a strike length of >2.5 km. The thickness of mineralized manganiferous horizons elsewhere reaches up to 10 m (Watts, Griffis and McOuat Ltd. 1991).

Copper mineralization in Zambia comprises different domains belonging to the Zambian Copperbelt; these domains correspond to Copperbelt Province, North-Western Province, and the Central Zambian Basin. The Zambian and Congolese Copperbelt together represent a district of sedimentary copper deposits referred to as the Central African Copperbelt (Hitzman et al. 2012). Overall, cobalt ore grades tend to decrease towards the south of the Central African Copperbelt, so that Zambia's cobalt production is much lower than that of the DRC. Copper-cobalt occurs as disseminated mineralization in sedimentary rocks (arkose and conglomerates, as well as black 'ore shales') and in sediment-hosted massive sulfides and in quartz-carbonate-sulfide veins. Mineralized sections have variable thickness ranging from 4-35 meters, with typical ore grades of 2-3% copper and about 0.2% cobalt. The most important copper-cobalt sulfides are bornite, chalcocite, chalcopyrite, covellite, cobaltiferous pyrite, and carrollite (Vitkova et al. 2010). A century of copper mining and smelting has left millions of tons of tailings and slag dumps which are of economic interest to artisanal miners, in addition to abandoned open pits or temporarily disused industrial mines. Slags are of particular economic importance. The Nkana slag dump in Kitwe is a prominent target of both ASM and industrial mining activities. It contains about 20 million tons of copper slag and may be attractive for artisanal miners as the slag has a higher cobalt-copper ratio than primary ore. The following table shows an overview on the copper and cobalt grades of copper slags and tailings in Zambia.

| Location | Copper grade | Cobalt grade | Reference |
|---|---|---|---|
| Nkana slag (Black Mountain) | 0.3 – 2% | 0.3 – 1.8% | Vitkova et al. 2010 |
| Nkana slag mixed with copper matte fragments | 9 – 35% | 0.7 – 2.4% | Vitkova et al. 2010 |
| Mufulira slag | 0.5 – 0.9% | 0.07 – 0.3% | Vitkova et al. 2010 |
| Chambishi slag | 0.2 – 0.4% | 0.2% | Vitkova et al. 2010 |
| Luanshya slag | 0.9% median, high-grade up to 9.5% | 0.24% median, high-grade up to 0.6% | Ettler et al. 2022 |
| Nchanga final (discarded) slag | 0.4% | 0.2% | Kakengela et al. 2016 |
| Nkana flotation tailings (Chambishi and Mindolo) | 0.1 – 1% | <0.1% - 0.6% | Scracek et al. 2010 |

**Table 9. Copper-cobalt grades of selected slags and tailings in Zambia.**

Tin mineralization of the Choma Tin Belt in Southern Province, responsible for almost all of Zambia's historical tin production, occurs in pegmatites hosted by metamorphic basement rocks (schists and gneisses). The belt has a total extent of 110 km and a width of 5-10 km. Tin mineralization in pegmatites is variably associated with tantalum (-niobium) and sometimes lithium. A minor part of tin mineralization occurs in quartz veins, rather than pegmatites, where tin may be associated with tungsten. Cassiterite is the principal ore mineral. In-situ tin grades are around 0.1% $SnO_2$ which is commonly too low to be of economic interest at tin prices observed over the recent decades (except perhaps during the short-lived tin price peak in 2021 and early 2022). Therefore, past production has focused on alluvial placers and eluvial deposits formed from the primary pegmatites. Most of these very small deposits, expected to contain less than 1 ton of tin content per individual deposit, have supposedly been mined out (Watts, Griffis and McOuat Ltd. 1991).

## 18.4 Artisanal ECRM mining and processing

Overall, the author found very little consistent information on the mining and processing techniques associated with critical metal recovery in Zambia's ASM sector. The academic and commercial literature on this topic appears to be sparse, although some information may be gained from videos of mining operations shared on online platforms such as Youtube. Based on these, both manganese and copper-cobalt ASM activities in Zambia show variable degrees of mechanization, ranging from basic hand picking to truck and excavator-assisted operations. Manganese ore beneficiation comprises crushing, washing, and screening plants. It is possible, though was not confirmed, that further processing steps may include dense media separation and flotation, as applied by small-scale manganese mining operators elsewhere (e.g., Myanmar). The lack of access to reliable power supply represents a challenge for setting up processing operations directly in manganese-rich Luapula Province; ore beneficiation therefore takes place in Central Province. In 2019, there were reports about a manganese smelter with an annual capacity of 40,000 tons of manganese being built in central Zambia. This smelter planned sourcing manganese ore from ASM operations and supporting the latter with mining equipment to increase their productivity (SMM 2019).

Accessing the slag mined by artisanal copper-cobalt miners at the Nkana slag dump sometimes requires blasting, a process that damaged houses in the Kitwe neighborhood in 2018. Therefore, when blasting again became necessary in late 2022, artisanal miners sought to enlist the support of the industrial operator (Nkana Alloys) in the process. Artisanal miners sell their ore copper-cobalt concentrates and slag material to local traders and small-scale processors. The small local plants process slag to concentrates via crushing, milling, use of shaking tables and flotation. A few small pyrometallurgical plants are in operation as well, processing slag to obtain a copper-iron-cobalt alloy (Kabobe et al. 2021). In general, for all these operations, metal recoveries are estimated at 50-60%; the resulting tailings are often dumped unsystematically. The high slag transport costs and local road deterioration from intense traffic represent economic challenges (Kabobe et al. 2021). Until 2018, it was thought that part of the ASM-processed material was eventually sold to the local Chambishi refinery for copper and cobalt recovery. However, the refinery has been closed since 2019 for economic reasons since its main supplier of feedstock was based in the DR Congo. With the introduction of a new mineral import duty of 5%, this business arrangement stopped being economically viable (Fastmarkets 2019).

## 18.5 Production and trade patterns

There was a time when the manganese mined in Zambia was used to produce dry-cell batteries in Luapula Province, but the company, Mansa Batteries, was closed in the early 1990s. In 2012, the government completed a feasibility study to revive battery manufacturing through Banguela Batteries Ltd. but did not succeed with this initiative. Recently, Zambia and the DRC have started co-developing a joint concept for a special economic zone on batteries (lithium ion rather than dry-cell batteries) that might also include manganese processing into cathode precursor materials. For now, however, Zambia exports most of its manganese as ores and concentrates, as feed for smelters abroad. China and India (the latter both directly and indirectly through the United Arab Emirates) show strong interest in manganese from Zambia and play an important role as investors in the local ASM sector.

From 2017-2021, Zambia exported, on average, about 200,000 tons of manganese ores and concentrates per year, with China as the most important trading partner (typically taking about 50% of Zambia's manganese ore, and sometimes more). These export levels represent a substantial increase compared to the 2012-2016 period, when Zambia exported around 50,000 tons of manganese ore per year, or less. The elevated manganese production and export levels related to Zambian ASM activities in recent years do not seem to show a direct correlation with global manganese ore price trends. Assuming a 50% Mn grade, the average value of manganese ore over the past decade (2013-2022) was US$ 262 per ton (on a Cost, Insurance, Freight China basis), with relatively moderate price fluctuations. Export data stored in the UN Comtrade database show that Zambia's manganese exports to China had lower average prices, around US$ 151 per ton from 2017-2019. In 2020-2021, export prices dropped to only $41 per ton. The reasons for this development remain unclear, as one would not expect major differences in ore grades.

Export records indicate that much manganese leaves the country in the form of ores and concentrates, as it may be of interest for smelters abroad to blend their own feed with the high-grade Zambian material. At the same time, shipping costs for road transport to seaports, Durban for instance, are high. Therefore, locally producing companies, especially from China, are expanding in-country smelting capacities. From 2015 to 2021, Zambia's manganese alloy production has grown at a compound annual growth rate of 80%, with a total output of 132,000 tons in 2021. In 2022, the smelters with the largest silico (and, to a lesser extent, ferro) manganese production capacities in Zambia were Tontoon, Amar Ferro Alloys and Southern Africa Ferro Alloys (with 28-54,000 tons annual capacity); there were five additional smelters with production capacities exceeding 10,000 tons per year (d'Harambure 2022). Exports of Zambian manganese alloys have strongly increased in 2020-2021, exceeding ores and concentrate exports in total value, though not (yet) in bulk tonnage.

Mine production data, for instance by S&P Global (2023), indicate that Zambia's copper output has risen slightly in recent years, from 710-760,000 tons (in 2013-2016) to the 800-865,000 tons range (in 2017-2021). As in the DRC, the contribution of ASM activities to Zambia's copper output is unknown but expected to be rather small compared to industrial copper production. Zambia's copper exports as ores and concentrates are typically in the order of 10,000-30,000 tons (bulk weight) per year, which might represent part, though not all of the copper produced by ASM. Some ASM-related copper, produced from ores and from slag mining operations, is also treated by local smelters and might contribute to Zambia's significant copper anode exports. Small quantities of copper ore (probably with very low cobalt grades) mined by ASM in southern Katanga Province, DRC, are reported to be sold clandestinely in Zambia and blend into local copper supply chains as well.

A robust estimate on the cobalt output by Zambia's ASM sector is not available. Considering in-country processing, cobalt might be included in copper concentrates or alloys, though it is not clear if miners are getting paid for the cobalt content. Exports of cobalt ores and concentrates have been very low in recent years, on the order of few 100 tons. Significantly larger Zambian trade in cobalt ores and concentrates in the past reflected activities by industrial mine operators, such as imports from the DRC to be processed at the Chambishi refinery. Chambishi might also have treated some ASM-related supply and recovered the cobalt included therein.

Zambia exports small quantities (typically less than 100 tons p.a.) of tin concentrate which, as noted above, might partly be associated with ASM activities taking place at the small Zambian tin deposits. However, these exported concentrates might as well have originated from the DRC and, thus, effectively represent re-exports (potentially subject to some in-country processing), as exemplified by the 80 tons of tin concentrate Zambia imported from the DRC in 2019.

## 18.6 Potential future ASM ECRM production opportunities

Notwithstanding the criticism voiced against Zambia's approaches to its ASM sector formalization (e.g., Siwale & Siwale 2017), the country has demonstrated certain capacities to achieve a certain level of control over parts of its ASM sector, including creating legal space for ASM in gold, gemstones and, partly, in copper. If Zambia's experience in this regard was transferred to and fully applied in the manganese and copper-cobalt sectors, this might create the legal space necessary to increase responsible investment in its ECRM sector. Building on an appropriate legal framework, investment opportunities might then target, for instance, increasing the rather low metal recoveries currently obtained by small-scale copper processors through optimized processing procedures and associated metallurgical studies. Beyond the economic perspective, these copper processing operations would also benefit from environmental impact assessments and improved ESG management.

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At the mine level, one could evaluate the feasibility for increasing artisanal copper (-cobalt) production from primary deposits, in addition to copper slags, for instance by delineating artisanal mining zones, similar to the model applied in the DRC. This would also serve to alleviate pressure on industrial copper concessions facing intrusions by illegal miners. It is unclear, though, whether Zambia still has significant mineral potential in this regard, as the country has been relatively well explored. In addition, such an approach may be difficult or impossible to implement for deeper-seated copper mineralization, as the extent of artisanal underground workings is limited. Therefore, setting up artisanal mining zones would need to be preceded by geological evaluations. The same applies to the manganese sector. The manganese sector is already experiencing positive, if somewhat unregulated investment dynamics, with Indian and Chinese investors playing an active role. Evaluating the manganese potential for ASM in Zambian provinces other than Luapula might be of interest. In terms of manganese processing, it would be interesting to evaluate the feasibility for further in-country value addition, for instance by integrating ASM-related manganese supply chains with the larger concept for a battery special economic zone seeking to produce battery precursor materials.

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# 19 Zimbabwe

## 19.1 Background

The ASM sector in Zimbabwe can be distinguished by the degree of its formalization and legality in two groups, namely: (1) Formal (legal) small-scale mining and, (2) Artisanal/informal miners. Formal small-scale miners are those miners who have registered their mining claims with the Ministry of Mines and Energy (MME) in accordance with the provisions of the Mines and Minerals Act Chap. 21:05 (1996). The miners operate, or at least attempt to, within the confines of Mines and Minerals Act, together with other relevant statutory instruments such as the Mining (Management and Safety) Regulations, 1990. In this group are small mining companies or private owners of small mines as well as mining syndicates and co-operatives.

The informal small-scale or artisanal mining sector in Zimbabwe comprises primarily unregistered gold diggers and panners. In several studies carried out on the subsector in Zimbabwe, nearly all the miners cited harsh economic conditions resulting from retrenchment of workers from paid employment and high unemployment levels as the main reasons for going into informal mining. The situation had been further aggravated by poor agricultural yields due to erratic rainfall patterns. This sector is highly nomadic (they hardly spend more than two years in one particular panning area). The only exception is when the panners are working on a huge tailings dump (as is the case in Bindura), or when the panners are working on rubble or reef material.

## 19.2 Overview of the national ASM sector

From the commodities mentioned in the mining production statistics of Zimbabwe, Table 1, only the mining of chromite ore has a high share of small-scale mining activities. All the other commodities are mined at medium or large scale. In the past about 40 – 50% of the chromite was coming from small-scale mines, since the thin and faulted chromite seams of the Great Dyke in Zimbabwe can only be mined in a small-scale method, whether conducted by small enterprises or cooperatives, or by more industrialized miners. This arrangement, called tribute mining, has created a near full-time dependency on mining, mostly from the mining co-operatives. This is the only sector, which is deriving almost 100% of its livelihood from mining. The chromite ore is sold locally and used in Zimbabwe`s ferrochrome smelting industry.

| | 2020 | 2021 | (%) Change |
|---|---|---|---|
| Gold (kg) | 20,873.3 | 31,477.2 | 50.8 |
| Diamonds | 2,670.5 | 4,224.3 | 58.2 |
| Platinum (kg) | 15,003.9 | 14,732.0 | -1.8 |
| Rhodium (kg) | 1,367.5 | 1,333.5 | -2.5 |
| Ruthenium (kg) | 1,026.3 | 1,249.2 | 21.7 |
| Chrome (tonne) | 1,272.1 | 1,432.0 | 12.6 |
| Coal (tonne) | 2,750.9 | 3,246.0 | 18.0 |
| Copper (tonne) | 7,932.8 | 8,650.0 | 9.0 |
| Nickel (tonne) | 16,479.9 | 16,213.0 | -1.6 |
| Palladium (kg) | 12,889.9 | 12,619.2 | -2.1 |
| Phosphate (tonne) | 45,083.5 | 39,819.0 | -11.7 |
| **Overall Mining Growth (%)** | **-9.0** | **18.2** | |

Source: Ministry of Mines and Mining Development, FGR, MMCZ, 2022

**Table 10. Zimbabwe mineral production statistics 2020-2021 (Reserve Bank of Zimbabwe 2022); it is believed that there is a typo and the units for coal and chromite are kilotons.**

Other commodities that were in the past extracted via small-scale mining in Zimbabwe – but currently apparently are not in production or only on a low level – are tin, tantalum, tungsten (part of the ECRM list) as well as emeralds. Additionally, the mining of lithium minerals has been carried out by artisanal miners in the past, driven by the present relative high prices for lithium ores (currently, local sales prices are about US$ 300/t of ore containing 2% of $Li_2O$). However, this activity is considered as illegal by the government of Zimbabwe, since the miners have no mining permits and the newest regulation on lithium issued by the government prohibits the direct export of lithium ores and requires the processing of the lithium ore in the country. Major artisanal mining activities regarding lithium in the past have been reported from Goromonzi and Mutoko in the north-eastern part of Zimbabwe and from Mberengwa in the central region. (ZELA 2023)

There is currently also an interest in reviving the emerald mining from the Sandawana emerald deposits; probably, this would be done in an industrialized small to medium-sized mining operation. At present, it could be possible that some micro-sized mines are still operating in emerald deposits in other deposits in Zimbabwe.

By far the largest part of the ASM sector in Zimbabwe is currently concerned with gold mining. The hyperinflation in Zimbabwe, the high gold price, the possibility to earn (cash) money on a short term and the availability of appropriate mining zones are the main drivers of the gold sector. It is estimated that around 0.5 million small-scale miners and 1.5 million artisanal miners are involved in gold mining in Zimbabwe (Fig. 1.), although just 25,000 are registered with the government, meaning much of the industry's practices, personnel and safety compliance are unknown (Mining Technology 2019). Gold mine explosion kills eight and injures two miners in Zimbabwe, 2019).

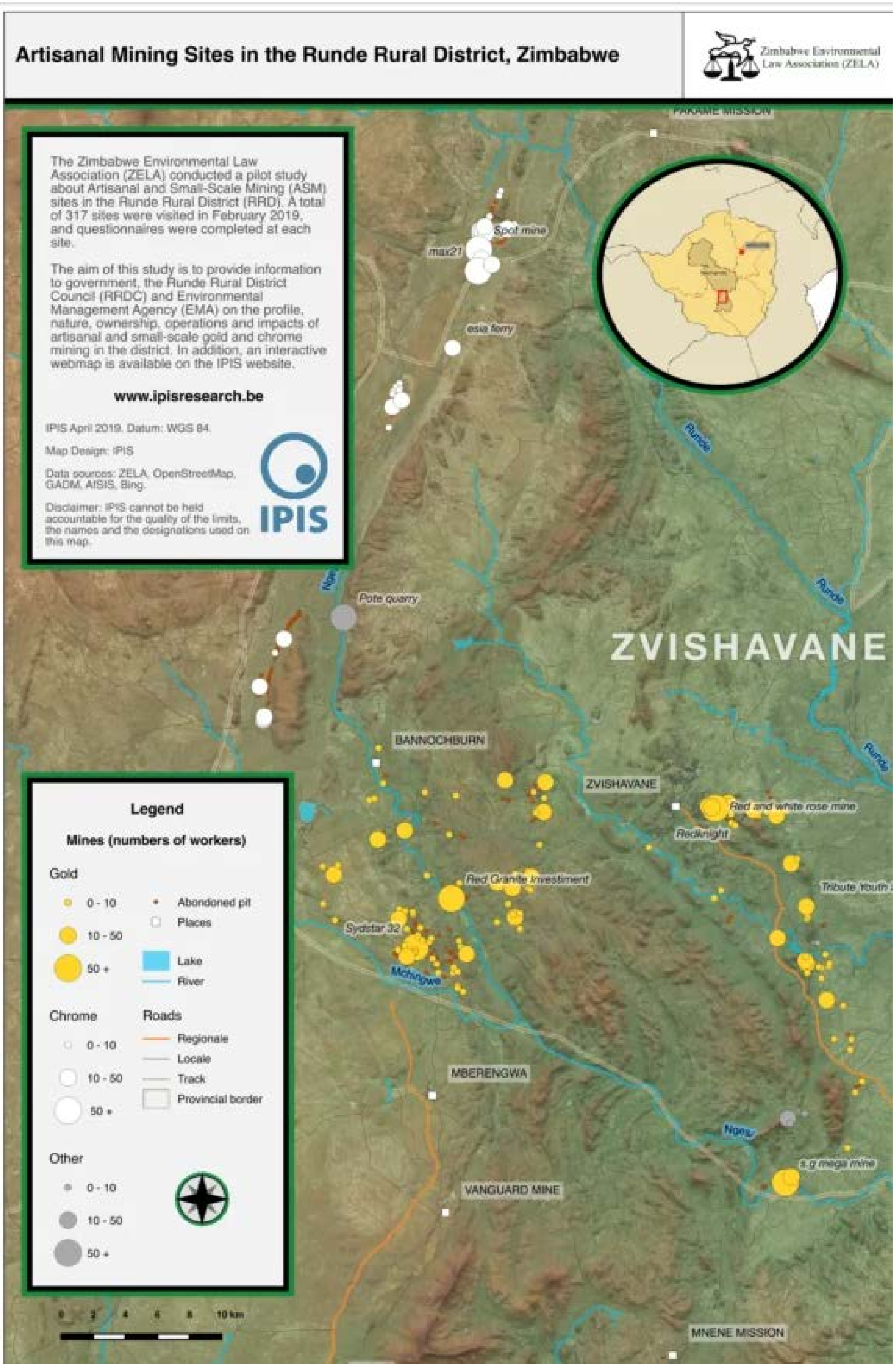


Figure 39. Gold and Chromite ASM sites in the Runde District, Zimbabwe (IPIS 2018).

The official gold deliveries to Fidelity Gold Refinery (FGR) rose to about 30 t in 2021, up from 19 t in 2020. The increase in gold deliveries by 55.5% in 2021 was largely driven by increases in production by both large-scale and artisanal and small-scale producers (RBZ 2022). Artisanal and small-scale gold output rose by 98.3% from 11.1 t in 2020 to 18.5 t in 2021, whilst large scale output rose from 9.3 t to 9.7 t during the same period. Additionally, there was a huge amount of unofficial production that is sold on the lucrative black market where the precious metal is believed to be then smuggled to neighboring countries, mainly South Africa. (Rosa Luxemburg Stiftung 2021)

## 19.3 ECRM deposits amenable to ASM exploitation

Lithium, tin, tantalum and tungsten minerals are found in pegmatite deposits that have ubiquitous occurrences all over Zimbabwe (BGR 1993). In the past, these pegmatites have also been sources for niobium, cesium, beryllium and gemstones. For example, the poorly explored Sandawana pegmatite field covers >100 $km^2$ of emerald and tantalum-rich aplites and pegmatites and the Beryl Rose pegmatite field contains over 100 Sn-Ta-Be pegmatites over a stretch of 24 km (Mugumbate 2014). Economically viable pegmatite deposits in Zimbabwe are generally classified according to their geological setting as greenstone belt and mobile belt pegmatites. Sn-Ta and Ta-Nb mineralization is usually associated with the mobile belt pegmatites in the west and north of the country and Li-Cs-Be are related to the Masvingo greenstone belt that contains the Bikita pegmatite that is presently the largest Li source in Zimbabwe.

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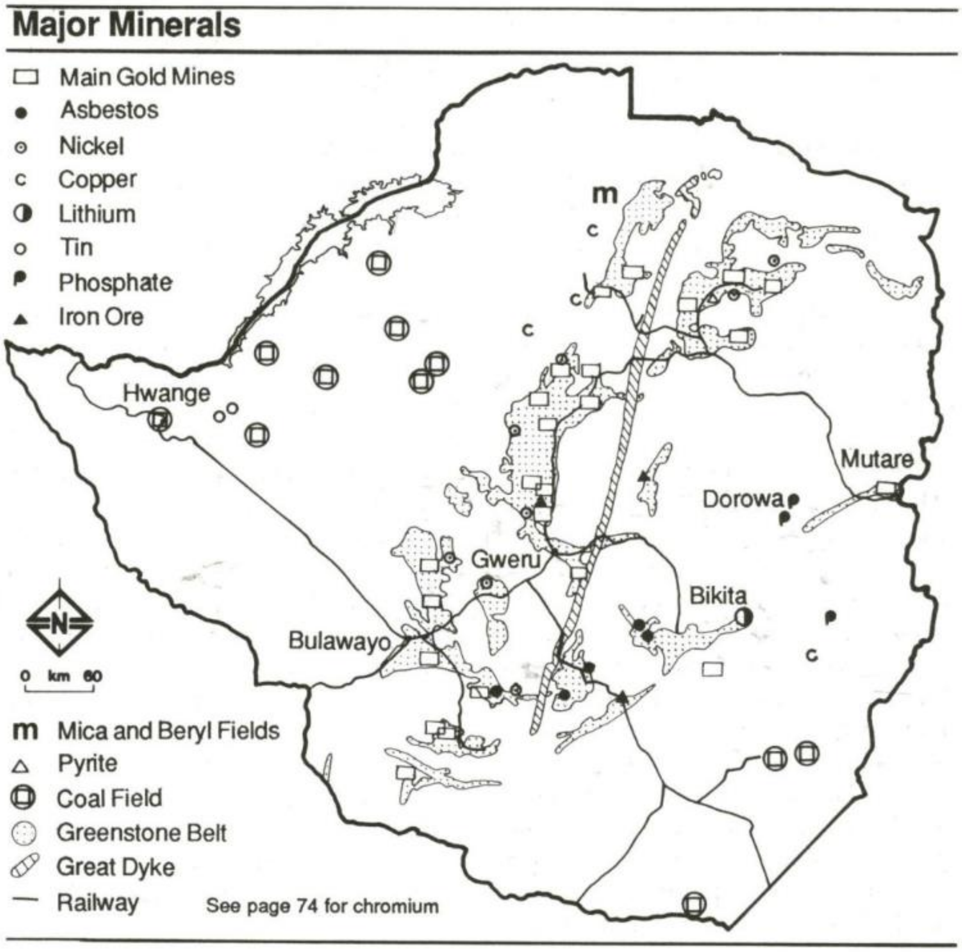


**Figure 40. Location of major mineral deposits in Zimbabwe (African Studies Center 2020).**

The mining of ECRM in Zimbabwe is strongly price dependent. At the current price level, there exists the potential to restart the mining activities for tin, tantalum and tungsten (3Ts) as well as for, graphite and lithium, also possibly in small-scale. However, some large-scale projects on tin and lithium have already been announced that have the potential to produce the critical raw material tantalum as by-product. In 2018, Prospect Resources Ltd. of Australia was granted a mining license for the Arcadia lithium mine. The mine is expected to produce 212,000 t/yr of spodumene concentrates, 216,000 t/yr of petalite concentrates, and 85 t/yr of tantalum concentrate. Chinese companies are also investing in lithium mining projects in Zimbabwe. In some occasions, it can be expected that local ASM operations will supply Chinese processing plants with lithium ores.

In this context, the UK-based company Galileo Resources plans to reactivate the Kamitivi tin mine that was closed in 1994 as a multi-element tailings project producing tin, lithium and tantalum. This decision comes after conducting brownfield exploration activities; the still available resources in the tailings are estimated to 26.3Mt at 0.58% Li2O, 493 ppm SnO2, 41 ppm Ta2O5 & 65 ppm Nb2O5 for the Kamativi tailings project (Market Screener 2023). The Kamitivi mine is located in a pegmatite deposit containing also a significant amount of wolframite ore that is not related to the formation of the pegmatite.

The critical element tungsten has been mined in the past at a small scale by companies and mining syndicates at the so-called RHA mine in Hwange District of the Matabeleland North province of Zimbabwe where tungsten is associated to wolframite minerals in quartz veins. In 2015, production was started at the RHA Tungsten Mine at a bigger scale by RHA Tungsten (Pvt) Limited, but reliable information about the tungsten output is not yet available. The nominal annual tungsten output (as $WO_3$) of the mine is projected to be about 60 – 80 t/a. The lifelong production of the mine shall accumulate to about 1,550 t $WO_3$.

The tungsten containing mineral scheelite has been produced in the region of Bulawayan in the past as a by-product of gold mining (BGR 1993). Therefore, it seems possible the ASM activities could focus on the reprocessing of gold tailings to extract any not yet recovered scheelite.

With regard to tantalum, Roskill pointed out that Zimbabwe has a long history of artisanal miners that exploit numerous deposits of microlite, columbite-tantalite and simpsonite, and sell their output to local traders. Production is centered around Kamativi, about 420 km southwest of Harare and the Sutswe, Rusambo and Shamva areas, 100 – 180 km northeast of Harare.

Presently there is no mining of copper in Zimbabwe (with exception of small amounts of by-product copper from nickel mining) despite the existence of many deposits that have previously produced. However, there are many copper deposits that have remained unexploited as they are too small to have their own processing plants, presenting an untapped resource for ASM activities. The copper deposits generally are clustered e.g., Mutandahwe and there are hydrothermal deposits around Kadoma (Mugabate 2014).

Graphite in crystalline flake form was also mined at small industrial scale by Lynx Graphite Mine, at Karoi by the Zimbabwe German Graphite Mines (Private) Ltd., which was a joint venture of the Kropmühl division of AMG Advanced Metallurgical Group N.V., 50%, and Zimbabwe Mining Development Corp. 50%]. The joint venture ended in 2017. The production capacity was about 6,000 t/a of concentrate but the low graphite prices in 2017 resulted in the closure of the mine that is now under care and maintenance. In the western district of Hwange there are some occurrences of graphite, that have been considered in the past as too small for industrial mining but could perhaps support ASM activities.

## 19.4 Artisanal ECRM mining and processing

Despite their negative impact on the environment, mercury and cyanide are still being used for gold processing in artisanal and small-scale gold mining (IPIS 2018). ASM mining of ECRM is done in low grade mechanized open pit and underground mines. In the case of facing high rock strength, compressed air and pick hammers are used to extract ore from open pit benches or from underground stopes. The ASM miners in Zimbabwe are also experienced in the use of rock blasting techniques, both underground and in open pit mines. In the case of lithium ore, the artisanal miners in general use only handpicking to produce an upgraded run of mine ore that is sold locally to private traders or processing plants.

Pegmatite ores in Zimbabwe, like in other African countries, are expected to be processed by the miners using simple gravitational processing techniques (sluice box and washing pans) in order to produce mixed pre-concentrates of tin and tantalum that can be sold to intermediate buyers. Wolframite ore from quartz veins has to be crushed first and can then be concentrated by gravitational processing methods.

## 19.5 Production and trade patterns

Besides gold and chromite, official figures for Zimbabwe's ASM production and the trade patterns for its ECMR are not officially disclosed. Roskill reported for the period 2011 – 2019 in five years exports of tantalum ores and concentrates that are sold to China. The span of the exported volume was between 10 and 47 t $Ta_2O_5$ and Roskill assumes that a part of these exports' stems from the by-products of the Bikita mine (Roskill 2021). For the years 2020 and 2021 the UN Comtrade Database reported tantalum concentrate exports in a range of 16 – 24 t.

With regard to tungsten the UN Comtrade Database reported for the period from 2017 – 2021 average annual exports of tungsten concentrates from Zimbabwe of about 30 t/a with a maximum in 2019 of 78 t. However, the production and trade of Sn, Ta and W ores from ASM in Zimbabwe can be considered as not very significant.

## 19.6 Potential future ASM ECRM production opportunities

ASM activities in Zimbabwe could play a role for the European supply with critical raw materials in two ways. One way is by performing exploratory pioneer mining in small ECRM deposits since such small-scale mining areas in Zimbabwe are often indicators for possibly significant mineralization. Nearly all of Zimbabwe's large mines were initially operated as small mines. However, the partitioning of ore bodies by small-scale mining claims belonging to different owners presents challenges to large size exploration (Mugumbate 2014).

The other way is by developing the ASM sector in Zimbabwe for critical raw materials when the price levels continue to increase and new ASM projects are starting up. In this case an investor engagement in ASM has the advantage of a short lead time and reaction time to the market. On the opposite side of the balance are the ESG challenges that could be caused by the development of the sector. However, at present, the contribution for the supply of the EU is still insignificant.

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Business opportunities to produce ECRM in the ASM sector of Zimbabwe could be associated with the production of lithium ores from the great number of pegmatites in Zimbabwe. In this case the European companies partnering with ASM should support developing processing plants to produce Li-containing concentrates and the required extraction permits from the government.

Another business opportunity with ASM could be the reprocessing of tailings from the numerous abandoned and closed gold mines that contain the tungsten mineral scheelite. The ASM miners could produce a pre-concentrate by simple ASM technique that would be further upgraded by milling and flotation in an industrial plant operated by a European company.

The untapped copper resource for ASM could be put in production when there are investments for the construction of centralized facilities for processing the copper ore and concentrates (Mugabate 2014).

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