Graphite reconnaissance, Petauke, Eastern Province, Zambia, June 2023

International Geoscience Research & Development Programme

Open Report OR/23/038

BRITISH GEOLOGICAL SURVEY

INTERNATIONAL GEOSCIENCE RESEARCH & DEVELOPMENT PROGRAMME

OPEN REPORT OR/23/038

Graphite reconnaissance, Petauke, Eastern Province, Zambia, June 2023

CJ Mitchell & D Currie

Contributors

E Chisakulo, C Mwansa, KK Maseka & NC Mwango

Keywords

Graphite; Zambia; Battery raw materials; Critical raw materials.

Front cover

Graphite polished pot, Manjolo village, Petauke District, Eastern Province, Zambia.

Bibliographical reference

CJ MITCHELL, D CURRIE, E CHISAKULO, C MWANSA, K MASEKA & NC MWANGO. 2023. Graphite reconnaissance, Petauke, Eastern Province, Zambia, June 2023. *British Geological Survey Open Report*, OR/23/038. 39pp.

Keyworth, Nottingham British Geological Survey 2024

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Nicker Hill, Keyworth,
Nottingham NG12 5GG

Tel 0115 936 3100

BGS Central Enquiries Desk

Tel 0115 936 3143
email enquiries@bgs.ac.uk

BGS Sales

Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP

Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road,
London SW7 5BD

Tel 020 7589 4090
Tel 020 7942 5344/45
email bgslondon@bgs.ac.uk

Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT

Tel 029 2167 4280

Maclean Building, Crowmarsh Gifford,
Wallingford OX10 8BB

Tel 01491 838800

Geological Survey of Northern Ireland, Department for the Economy, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB

Tel 0289 038 8462
www2.bgs.ac.uk/gsni/

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

UK Research and Innovation, Polaris House, Swindon SN2 1FL

Tel 01793 444000
www.ukri.org

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report summarises the visit from 19th to 30th June 2023 by Clive Mitchell, Industrial Minerals Geologist, and David Currie, Mineral Resources Petrologist, British Geological Survey (BGS) to Zambia as part of BGS research on African graphite resources for use as a battery raw material.

The main purpose of the visit was to refine a graphite reconnaissance field work methodology to identify graphite resources based on field work experiences in the Petauke District of Eastern Province in Zambia. In addition, meetings were held with the Zambian Geological Survey Department and the British High Commission in Lusaka.

The work formed part of the 'Graphite in Africa' research project which is part of the BGS International Geoscience Research and Development (IGRD) programme. This is funded by the BGS International NC programme 'Geoscience to tackle Global Environmental Challenges', NERC reference NE/X006255/1. This report is published by permission of the Director of the British Geological Survey.

Acknowledgements

The authors of this report would like to thank the following for their assistance and support in preparation for and during the visit:

- Dr Michael Watts, Anneli Evans, Lily Cullen Coates and Heather Churchill from the BGS,
- Gerald Mwila, Director, Geological Survey Department (GSD), Lusaka, Zambia.

Contents

FIGURES

TABLES

Summary

As a major producer of minerals, Zambia is keen to ensure that more of the economic benefits derived from exploitation of its indigenous mineral resources are retained in-country. Currently, Zambia produces coal, cobalt, copper, gemstones (mostly emeralds), gold, lead, manganese, nickel, silver, pyrites and zinc. In addition, there is production of construction materials (including sand and gravel, limestone for cement and lime, and clay for brick making) and industrial minerals such as dolostone for agricultural lime, and gypsum for cement, plaster and school chalk. There are also deposits of kaolin, silica sand and talc which are worked on a small-scale.

A key objective of the Zambian Government is to develop a critical and battery raw material supply chain. As part of this there is renewed interest in the undeveloped critical raw material resources of Zambia which includes graphite, lithium, and rare earth elements. The BGS International Geoscience Research and Development (IGRD) project 'Graphite in Africa' is collaborating with the Zambian Geological Survey Department (GSD) and the Copperbelt University (CBU) to develop a reconnaissance exploration methodology to assess the graphite resources of Zambia.

Graphite is known to occur in the Paleoproterozoic metasedimentary gneiss and schist that occurs in Central and Eastern Zambia. The Petauke District of Eastern Province was chosen as a focus for the current work as past studies indicated several deposits of flake graphite including those at Njoka, Nkonda and Mvuvye. Fieldwork was carried out in June 2023 by the BGS, GSD and CBU. The aim of the fieldwork was to refine a methodology for graphite reconnaissance exploration. Chief Mumbi of the Nsenga people in Petauke approved the fieldwork and provided logistical assistance via a local guide. The Provincial Government and Police Commissioner in Chipata were also officially notified.

Past graphite studies were used to identify locations where graphite was known to occur. One issue of the studies from the 1950s and 1960s was the lack of precise geographical location data. To address this, the location map diagrams in the past studies were scanned and geolocated using Google Earth. This enabled the location of past sampling points to be identified. These formed the basis for the reconnaissance target list. The field team attempted to find the locations and take samples of graphite where it was present.

Over three days of fieldwork in Petauke District, sites were visited at Mvuvye River, Kalobe, Dominico, Sichombwe-Changwe, and Nyakocha. The graphite samples collected included graphite-rich lateritic soil, graphite-rich saprolite, weathered graphitic gneiss, and graphitic gneiss. In addition, samples of pegmatitic granite were collected. Duplicate samples were taken for all the graphite sample sites with the first set retained in Zambia and the second set to be dispatched to BGS in the UK.

The graphite reconnaissance fieldwork carried out in Zambia demonstrated that a collaborative approach to the planning of the fieldwork yielded results, with graphite mineralisation successfully identified and that engagement with the local community was culturally respectful. Overall, the reconnaissance fieldwork was successful and will contribute to prospectivity analysis being undertaken to better understand the graphite critical raw material potential of Zambia.

1 Introduction

The development of a critical and battery raw material supply chain, crucial to achieve global decarbonisation and net zero, is a key focus of the Zambian Government. The current Government of Zambia, lead by President Hakainde Hichilema, has a clear focus on development of the Zambian mining sector and has created a more receptive and supportive environment for foreign direct investment. As part of this, the African Export-Import Bank and the United Nations Economic Commission for Africa have signed a framework agreement with the Democratic Republic of Congo and Zambia to establish special economic zones to produce electric vehicles and batteries (African Business, 2023).

Zambia is a major producer of minerals such as copper and cobalt and has resources of graphite, lithium, rare earth elements and other Critical Raw Materials. Despite over 100 years of mining legacy, Zambia is a country where a significant proportion of 'unexplored terrains' still exist. Only 58% of Zambia has been mapped to 'modern' geological standards by the Zambian Geological Survey Department (GSD). Many of the older geological maps from the 1950s and 1960s would benefit from updating. The most recent geophysical surveys of Zambia were carried out in the 1970s and 1980s, although the government is currently in the process of implementing the first phase of an anticipated nationwide airborne geophysical survey. In terms of geochemistry, most surveys undertaken on behalf of the Geological Survey date from the 1970s. A geochemical survey was undertaken in Mwinilunga, Northwestern Zambia by the Geological Survey Department and the British Geological Survey as part of a World Bank project from 1997 to 2001. Data collected using modern surveying techniques would greatly improve the prospectivity modelling carried out for mineral resource exploration.

Signs are encouraging that the current Government have recognised the value of the GSD to the continuing development of the mining sector. A key priority is strengthening the GSD capacity to carry out geological surveying, mineral resource assessments and mineral characterisation.

In May 2022 a small team from the BGS visited the Copperbelt University Africa Centre of Excellence for Sustainable Mining (CBU-ACESM) in Kitwe, Zambia as part of ongoing research collaboration and to explore the potential for a joint research project on graphite resources in Zambia (Hamilton *et al*., 2022). A follow-up visit in November 2022 was carried out to start planning a battery raw material research project on graphite resources in Zambia involving BGS, CBU & the GSD (Mitchell, 2022).

From 19th to 30th of June 2023, Clive Mitchell (BGS Industrial Minerals Geologist) and David Currie (BGS Mineral Resources Petrologist) participated in geological fieldwork to refine a reconnaissance methodology to identify graphite resources in the Petauke District of Eastern Province in Zambia (this report). The fieldwork was a collaboration between the BGS, CBU, and the GSD.

The graphite field reconnaissance team members are shown in Figure 1. From left to right:

- Dr Nelly Chunda Mwango, Project Manager, (CBU-ACESM)
- Professor Kakoma Maseka, Dean, School of Mathematics and Natural Sciences, CBU
- Clive Mitchell, Industrial Mineral Geologist, BGS
- Chisamba Mwansa – Geologist, GSD
- Dr Edward Chisakulo, Exploration Geologist / Head, Geology & Survey Department, CBU
- Dr David Currie, Mineral Resources Petrologist, BGS
- Enoch Mwandila, Driver, CBU
- Loeakay Siasimuna, Driver, CBU

Figure 1. Graphite reconnaissance team meeting at Zambian Geological Survey Department.

2 Visit itinerary

Table 1. Itinerary for visit to Zambia June 2023

Date	Activity
Monday 19th & Tuesday 20th June 2023	Travel from the UK to Lusaka, Zambia (2 flights; Birmingham to Dubai, United Arab Emirates (UAE); Dubai to Lusaka).
Wednesday 21st June 2023	AM: Meeting with the field team at the Geological Survey Department in Lusaka (Figure 1). PM: Meeting at the British High Commission in Lusaka.
Thursday 22nd June 2023	Travel from Lusaka to Petauke (400km; 7-hour drive).
Friday 23rd June 2023	AM: Travel from Petauke to Chipata to inform Provincial Government of research team activities and then travel back to Petauke (each way 175km; 2-hour drive). PM: Meeting with Chief Mumbi of the Nsenga people in Petauke.
Saturday 24th June 2023	First day of graphite reconnaissance fieldwork.
Sunday 25th June 2023	Rest day.
Monday 26th June 2023	Second day of graphite reconnaissance fieldwork.
Tuesday 27th June 2023	Third day of graphite reconnaissance fieldwork.
Wednesday 28th June 2023	Travel from Petauke to Lusaka (400km; 7-hour drive).
Thursday 29th June 2023	AM: Meeting with the British High Commission in Lusaka. PM: Meeting with the field team at the Geological Survey Department in Lusaka. Evening: Travel from Lusaka to Dubai, UAE.
Friday 30th June 2023	Travel from Dubai to the UK.

3 Meetings

3.1 ZAMBIAN GEOLOGICAL SURVEY DEPARTMENT

The graphite reconnaissance team held a meeting with Gerald Mwila, Director of the Geological Survey Department (GSD) of the Zambian Ministry of Mines and Minerals Development (MMMD). He was supportive of the graphite reconnaissance work and assigned a GSD geologist (Chisamba Mwansa) to support the field work. Discussions focused mainly on the international initiatives that are currently being developed to support the critical and battery raw material objectives of the Zambian Government.

During the visit, the BGS team met counterparts from BRGM (French Geological Survey) who were working at the GSD on geological and mining data digitisation, software and training as part of a project funded by the French Ministry for Europe and Foreign Affairs. A USGS (US Geological Survey) seismology team was also met.

3.2 BRITISH HIGH COMMISSION, ZAMBIA

Two meetings were held at the British High Commission in Lusaka to discuss initiatives on the responsible mining of critical minerals in support of the Zambian Government. Discussions focused on support for the development of a Critical Raw Materials (CRM) capability within the Geological Survey Department. The aim would be to work towards the assessment of mineral resources including geological mapping/ surveying and enhancing the understanding of the economic potential of CRM resources in Zambia.

3.3 CHIEF MUMBI OF THE NSENGA PEOPLE IN PETAUKE

The graphite reconnaissance team held a meeting with Chief Mumbi of the Nsenga people in Petauke (Figure 2). Chief Mumbi was supportive of the graphite reconnaissance work and arranged for a local guide (Roy Tembo) to work with the team. A local group of field assistants were recruited for the duration of the field visit to Petauke District (Figure 3).

Figure 2. Reconnaissance team meeting with Chief Mumbi of Nsenga people in Petauke. (Chief Mumbi in the centre)

Figure 3. Local guide and field assistants in Petauke District, Zambia.

(Clockwise from top left: Roy Tembo, Matthews Zulu, Wonderful Ngulube, Chisoni Lungu & Patrick Tembo)

4 Graphite reconnaissance methodology

4.1 METHODOLOGY DEVELOPMENT

The graphite reconnaissance methodology developed for this research was largely based on available geological information found in past reports and maps. The most detailed graphite studies carried out in Zambia date from the 1950s and 1960s (as detailed in section 5.1.2 of this report). Using this information, a GIS map was created that included all known graphite occurrences in Zambia. This enabled target areas to be identified as potential locations for reconnaissance fieldwork. Without these past studies the approach taken would rely on identification of the most likely geological formations to contain graphite mineralisation. At this stage the lack of appropriate geophysical or other survey data would have made the identification of prospective locations for graphite reconnaissance difficult.

Past studies indicate that deeply weathered and/ or regolith material is common across much of Central and Eastern Zambia which would make direct outcrop sampling difficult. Outcrops are more likely found in and along the banks of river courses. Field sampling for graphitic material is likely to consist of soil sampling and anthill sampling (Drysdall, 1960). Anthills are known sources of material brought to the surface from several meters depth and are a good target when sampling (Drysdall, 1960b). Graphite flakes are resistant to weathering and are likely to survive normal environmental conditions. When a graphite-bearing soil sample is gently placed in water, graphite will float on the water's surface.

The graphite reconnaissance field work required a field team to be assembled. The team for the Zambia work included mineral geologists to provide the necessary geological knowledge and experience, alongside logistical support and drivers for the two vehicles used. An initial field team meeting was held in Lusaka, before travelling to the field area, to discuss the approach to the graphite reconnaissance fieldwork, logistical arrangements for travel and field materials. Materials that were considered necessary for the reconnaissance work included notebooks, sample bags, spades, geological hammers, buckets for floating soils, handheld GPS, geological maps of the areas to be visited, and field reports of graphite occurrences.

After arriving in the field location, a one-day reconnaissance drive around the Petauke/ Mvuvye area, defined by Drysdall (1960a), was carried out to better understand the terrain and access to known graphite occurrences. This coincided with meeting the District Commissioner, local police, and Chief Mumbi to make them aware of our presence and seek permission to conduct fieldwork. These meetings were important for general safety and to ensure appropriate engagement with the local community. They assisted in sourcing local help and provided knowledge of graphite use in rural community pottery. Where possible it was planned to dig ~1 m trenches to try to sample 'cleaner' material. In addition, outcrop samples would be taken, when possible, to give clearer indication of graphite host rock.

4.2 PROSPECTIVITY MODELLING

Sample collection and the use of data is constantly evolving with technology. Data-driven predictive modelling of mineral prospectivity across a wider geographic area has gained considerable traction over the past three decades (e.g. Bonham-Carter, 1994; McCuaig and Horonsky, 2014; Carranza and Laborte, 2015). In sites where past exploration has taken place, data sets like soil and stream sediment geochemistry, geological mapping, satellite imaging, and geophysical surveys may already be available. Coupling these data sets with known and unknown mineral occurrence data can lead to potentially informative predictive modelling across a wide geographic area (Carranza and Laborte, 2015).

Prior to the reconnaissance work, precise GPS location data was not available for graphite occurrences across any of the study areas identified in Zambia. During this fieldwork, we aimed to ensure that we collected precise GPS data for each sample taken. This would allow us to feed all subsequent analytical data generated into a GIS-based system that would be used for all future study. Further, it was not known if geophysical, geochemical, satellite, geology, or any other regional to national scale data sets were available. The goal is to create a prospectivity modelling framework that can be used in the future to develop prospectivity models for Zambia and other countries which seek to better understand their (critical) raw material potential.

5 Graphite reconnaissance fieldwork

5.1 GEOLOGY AND GRAPHITE IN ZAMBIA

5.1.1 Geology of Zambia

Landlocked in central southern Africa with a population of ~20 million people, Zambia covers ~750 000 km^2 (CSO, 2020). In 2021, Zambia produced >800 000 tonnes of copper, the 8th largest producer globally (BGS, 2022). Zambian geology has been influenced by surrounding cratonic blocks of Kasai (DRC), Tanzania, Zimbabwe, and Kaapvaal (South Africa) (Money, 1986; Bosse, 1996) and contains major lithostratigraphic successions shared across these geographic areas. The Basement Supergroup (~3 Ga to ~2 Ga) is the oldest rock sequence in Zambia which includes graphite-bearing Paleoproterozoic metasedimentary Mkushi Gneiss and Mvuvye Gneiss. The Muva Supergroup (1800-1250 Ma) overlies the Basement Supergroup and contains meta-pelites, meta-quartzites, and continental sedimentary successions. Katanga Supergroup (1 Ga – 500 Ma), containing the Mine Series Group which is the primary host for copper-cobalt mineralisation of the Copperbelt, overlies the Basement and Muva Supergroups. Formed during the assembly and rifting of the Pangaean supercontinent, the Karoo Supergroup (late Carboniferous to early Jurassic) is the most widespread stratigraphic unit in Africa south of the Kalahari Desert and records an almost continuous sequence of marine glacial to terrestrial deposition over the course of ~120 Ma (Johnson *et al.*, 1996). The Karoo Supergroup is exposed in rifts through the Zambezi, Luangwa, Luano-Lukusashi and Kafue valleys, and outcrops in western Zambia. These consist of conglomerates, sandstones, carbonaceous siltstones, and mudstones. Although outcrops are plentiful, it is more common to encounter deeply weathered cover material to depths of >1m.

5.1.2 Graphite occurrences in Zambia

Graphite is a form of carbon, and geological deposits can be classified as one of three types (amorphous, flake, and vein). Flake graphite is the main graphite type that is used as a battery raw material (Lusty and Goodenough, 2022). Graphite forms where carbon-rich sedimentary rocks have been metamorphosed, with flake graphite being restricted to areas of relatively high temperature metamorphism (amphibolite facies and above). Areas of potential prospectivity for flake graphite are thus those where there is evidence of amphibolite facies metamorphism and where carbon-rich metamorphosed sedimentary rocks are mapped (Mitchell & Deady, 2021).

Relative to other natural resources like copper, graphite exploitation in Zambia has been limited despite multiple known occurrences (Kennedy and McKeown, 1934; Drysdall, 1959; 1960a; 1960b) (Figure 4). Flake graphite appears associated with Paleoproterozoic metasedimentary gneiss and schist. These units are variable across a substantial area in Central and Eastern Zambia, but typically are biotite-gneisses, pyroxene-granulites, calc-granulites, and limestones (Drysdall, 1960b).

The Njoka graphite deposit occurs approximately 53 km west-north-west of Lundazi on the lower part of the Lundazi River (Figure 4). The deposit is hosted in garnet-biotite gneiss containing bands of leucogranite. Flake graphite occurs in lenses of medium grained, dark graphitic gneiss up to 366 m in length by 8 m wide. Three deposits are recorded at this location that have graphite contents of up to 20 per cent and average 10 to 13 per cent. A further deposit, comprising flake graphite in gneiss (15 per cent graphite), occurs immediately north of the Lundazi River. Processing trials produced concentrates grading 77 to 95 per cent graphite with recoveries from 90 to 97 per cent (Mitchell, 1993). The non-compliant resource estimate is approximately 10 000 tonnes of graphite (Drysdall, 1960b).

The Nkonda graphite deposit occurs 12 km west of Petauke and 16 km west-southwest of Sasare (Figure 4). Flake graphite occurs in leucocratic granodiorite-gneiss that forms a series with paragneiss and subordinate crystalline limestone and amphibolite. Graphite flake size reaches up to 1.2 mm, with an average of about 1 mm, and the graphite content averages 6–7 per cent. Graphite rarely occurs in outcrop, although where associated with biotite it forms harder “reefs”. Mica minerals intergrown with graphite pose an issue, as separation is difficult, leading to low recovery and an impure final product (Drysdall, 1960b).

The Mvuvye graphite deposit, located in the basin of the Mvuvye River, south of Petauke, stretches over an area of 260 km^2. Flake graphite occurs in a variable sequence of biotite-gneiss and granulite. The flake size varies considerably with graphite contents ranging from approximately 6 to 12 per cent. The extreme north-east part of the Mvuvye paragneiss outcrop, south-east of Sasare, hosts a graphite deposit that is very similar to the rest of the Mvuvye graphite and has a graphite content of up to 17 per cent (Drysdall, 1960b).

Other published information on graphite deposits is as follows:

- Graphitic schist occurrence in Serenje, Central Province (Guernsey, 1952)
- Graphitic shale, described as a ‘minor’ occurrence and assaying 16 per cent graphite, on the east bank of the Lunga River, Northwestern Province (Coats *et al.*, 2000)
- Graphitic schist, in Walamba Siding, between Kapiri Mposhi and Ndola, Copperbelt Province. The occurrence comprises lenticular bodies of graphite schist in the Basement Complex that contain up to 25 per cent amorphous graphite (Drysdall, 1960a)
- Kayumba (Kajumba) graphite, 34 km north-east of Chama, Eastern Province. “Massive” graphite occurs in a grey gneissic granite. It takes the form of a lenticular body, estimated to contain 3 000 tonnes with a graphite content of 40 per cent (Coats, *et al.*, 2000).

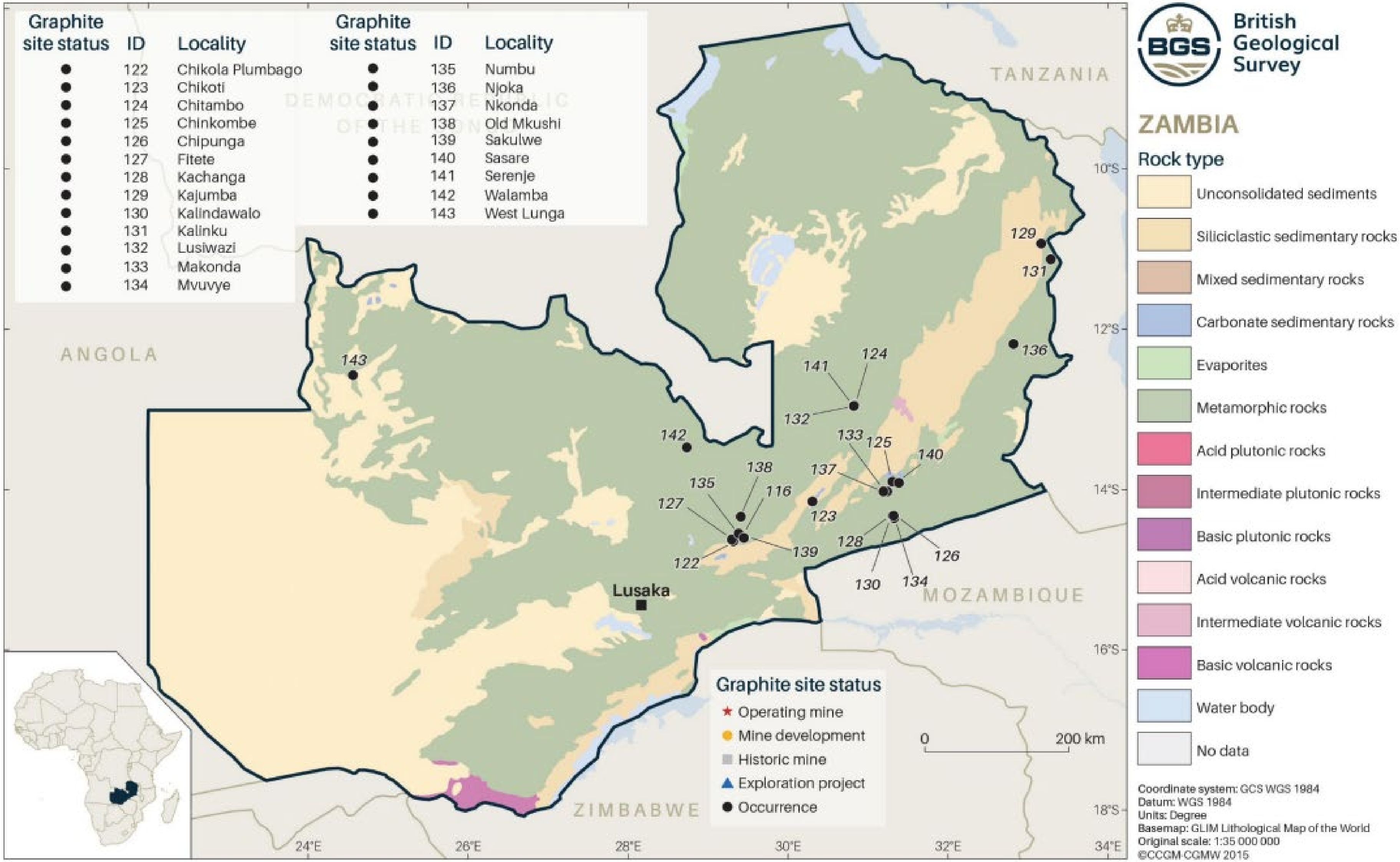

Figure 4. Geological map and graphite occurrences across Zambia (Mitchell, 2022).

5.2 FIELDWORK DAY ONE: MVUVYE RIVER AND KALOBE

The first location was visited to identify graphite occurrences that were sampled in previous graphite studies (Drysdall, 1960a & b). The site was adjacent to the bridge over the Mvuvye River on the gravel road approximately 5 miles north of Mumbi. Four samples were taken although no visible graphite was observed: SP35/01 (S14°23’19.2” E031°09.1”), SP35/02 (S14°23’18.6” E031°19’05.9”), SP/03 and SP35/04 (both at S14°23’19.7” E031°19’08.4”) (Figures 11, 12 and 13) In addition, two samples of weathered granitic soil were collected in Mumbi village: MB/01 & MB/02 (S14°27’53.9” E031°18’38.8”) (Figure 14).

The reconnaissance team visited Manjolo village (S14°25’55.7” E031°18’52.0”) where a potter was encountered using graphite to polish earthenware ceramic pots. A graphite-rich sand is used to decorate air dried clay pots then fired at a relatively low temperature to create a metallic polished surface. Firing of pots coated with graphite is carried out in reducing conditions at temperatures between 700-1000°C. Care must be taken as graphite oxidises readily at high temperatures, if the pot is exposed to the atmosphere when still hot the coating would quickly burn off (Kreiter *et al.*, 2014). Using graphite to decorate pots is a traditional practice that is only carried out by older members of the community relying on their knowledge of local resources. The graphite-rich sand used to polish the pots was sourced from the nearby area of Kalobe.

Kalobe is an agricultural area, largely cotton plantations, underlain by lateritic soil (Figure 15). The mapped geology at depth was indicated to be semipelitic gneiss of the Mvuvye Group (Phillips, 1965).

A trench was used to excavate to a saprolitic rocky horizon (Figures 5, 16 and 17; S14°25’45.9 E031°20’08.7”). Three samples were taken: KL/01 at the surface, KL/02 at 30cm depth and KL/03 at 45cm depth. Solid bedrock was not reached. Several bags of graphite rich material were taken to the potter in Manjolo village to thank them for their assistance.

Figure 5. Trenching graphite occurrence, Kalobe, Petauke, Zambia.

5.3 FIELDWORK DAY TWO: DOMINICO AND SICHOMBWE-CHANGWE

5.3.1 Dominico

The reconnaissance team visited Dominico village (S14°25'54.5" E031°16'05.6") where graphite outcrops were discovered in the centre of the village (Figures 6, 18, 19 and 20); no samples were taken in the community dwelling areas. The mapped geology at depth was indicated to be semipelitic gneiss of the Mvuvye Group (Phillips, 1965).

Graphite outcrops were discovered on the track leading northwards from the village; two rock samples were taken: DM/01 (S14°25'53.7" E031°16'04.1") and DM/02 (S14°25'51.3" E031°16'03.1"). Samples were weathered graphitic gneiss with coarse-grained (several mm) graphite flakes. NB no sample was taken at DM/03.

Figure 6. Graphite occurrence and close-up, Dominico village, Petauke, Zambia.

A trench was dug in the dried out dambo (seasonal flood plain) to the north of Dominico village (S14°25'50.2" E031°16'02.2"). Four samples of lateritic soil were taken: DM/04/10 (10cm depth), DM/04/20 (20cm depth), DM/04/30 (30cm depth) and DM/04/40 (40cm depth) (Figure 21). Sub-samples were sieved using 600μm and 250μm aperture sieves (Table 2).

Table 2. Particle size distribution of graphitic soil, Dominico, Petauke, Zambia

Size fraction	**DM/04/10**	**DM/04/20**	**DM/04/30**	**DM/04/40**
>600 μm	132.6g (60%)	91.1g (59%)	69.9g (58%)	65.5g (61%)
-600+250μm	60.3g (27%)	41.9g (27%)	38.9g (32%)	31.6g (30%)
<250 μm	27.6g (13%)	20.9g (14%)	12.4g (10%)	10.0g (9%)
Total	220.5g (100%)	153.9g (100%)	121.2g (100%)	107.1g (100%)

5.3.2 Sichombwe-Changwe

The reconnaissance team visited a small roadside quarry between the villages of Sichombwe and Changwe where a graphite occurrence was discovered (S14º24'45.6" E031º14'41.4"). The mapped geology at depth was indicated to be semipelitic gneiss of the Mvuvye Group (Phillips, 1965).

Rock samples of feldspathic pegmatite were taken from a surface outcrop above a contact with a graphite-bearing biotite-feldspar-quartz gneiss(Figures 22, 23, 24, 25 and 26). Graphite is in flake form and varies in grainsize from less than 1 mm to up to 10 mm. A trial pit revealed further graphite mineralisation extending to at least 1 m depth below surface. Bedrock became increasingly difficult to trench using hand tools by this point, thus depth of graphite mineralisation at this location is unknown.

Five samples were taken from this graphite occurrence:

- SC/01/01 zone 1 above contact
- SC/01/02 zone 2 Trial pit location
- SC/01/03 zone 3 between trial pit and contact
- SC/01 Trial pit, rock sample (as shown in Figure 7)
- SC/01 Trial pit, channel sample (as shown in Figure 7)

Figure 7. Graphite occurrence and sample, Sichombwe-Changwe, Petauke, Zambia.

5.4 FIELDWORK DAY THREE: NYAKOCHA

The reconnaissance team visited Nyakocha village to locate previously studied graphite occurrences (Figures 8, 27, 28, 29, 30 and 31). Little evidence of graphite was found. The mapped geology at depth was indicated to be semipelitic gneiss of the Mvuvye Group (Phillips, 1965). However, elevated areas encountered when walking northeast from Nyakocha village were granitic to pegmatitic. This suggests that a more detailed mapping exercise would be of use across the region.

Four samples of pegmatitic granite were collected:

- NY/01 (S14º25'33.5" E031º15'51.5")
- NY/02 (S14º25'27.5.6" E031º15'53.9")
- NY/03 (S14º25'11.7" E031º15'43.6")
- NY/04 (S14º25'24.6" E031º15'36.2")

Figure 8. Looking southwest from granite hill towards Nyakocha village, Petauke, Zambia.

The reconnaissance team visited the Lusowe area but could not proceed further as the Mvuvye River was too high to cross (S14º21'00.00" E031º16'46.0"). This marked the end of the fieldwork.

5.5 GRAPHITE SAMPLES

The graphite samples collected were split equally between the BGS and CBU-GSD. The set of samples for the BGS were left with the GSD (Figures 9 and 10). The sample list is shown in Appendix 1. Photos of the samples are shown in Appendix 2. It was agreed that the GSD would arrange for the samples to be despatched to the UK.

Upon return to the UK, samples will be processed for thin sectioning followed by petrographic analysis by optical microscopy and scanning electron microscopy (SEM). This will allow a better understanding of the host rock mineralogy as well as flake morphology, size, and distribution within the host rock. Subsequent crushing and mineral separation will generate fractions of material for X-ray diffraction and total graphitic carbon analysis.

Figure 9. Graphite samples from Petauke District, Zambia.

Figure 10. BGS staff (Clive Mitchell & David Currie) going through graphite samples collected from Petauke District, Zambia.

6 Conclusions

The graphite reconnaissance fieldwork carried out in Zambia demonstrated that a patient and collaborative approach can yield results with graphite mineralisation successfully identified and sampled. The involvement of GSD and CBU allowed BGS staff to communicate effectively and in a culturally respectful manner with people local to the area and the district chief which subsequently enhanced community engagement.

The availability of modern geological information and maps are crucial to studies such as this. The maps used in this work date from the late 1950's to mid-1960's and were found to be partially inaccurate with some geological linework misplaced. This led the field team to locations where no graphite was found. Looking forward, to survey an area of this size and other nearby graphite occurrences like Nkonda and Njoka could take several more weeks or months. Colleagues at GSD-CBU can carry out such work following this collaborative trip but to do so they would require funding for fieldwork and for a strengthening of analytical capabilities and technical expertise in Zambia. For example, neither organisation has the means to manufacture thin sections and even if they did, they have below industry standard analytical capabilities to assess the graphite sample material collected.

The methodology used to undertake this work, primarily an attempt to place GPS co-ordinates on previously reported graphite occurrences across the Mvuvye-Petauke region, was successful. GPS data can now be included in a data-driven prospectivity modelling framework that could be used in the future to create powerful models for Zambia and any other country which seeks to create national-scale models to better understand its (critical) raw material potential. This work will be ongoing in collaboration with GSD-CBU. Material collected will be processed and characterised by optical and scanning electron microscopy at BGS. X-ray diffraction and total graphite content analysis will also be carried out at BGS in what will become a standardised and systematic approach to graphite reconnaissance work. A 50-50 split of material between BGS and GSD-CBU was agreed prior to fieldwork to allow for research and training to be carried out in Zambia.

Recommendations for future work:

- Development of methodologies, strengthening of laboratory capacity and staff training for graphite resource mapping, characterisation and mineral processing in Zambia.
- Targeted geological mapping to improve the geological understanding and linework for areas identified with graphite potential.
- Continuation of the collaboration between the BGS, GSD and CBU could be extended to carry out reconnaissance for graphite and critical raw materials in other parts of Zambia.
- Greater engagement with local communities and acknowledgement of the value of local knowledge, such as that of the potters making graphite polished pots.
- Engagement with mineral industry stakeholders and international organisations that are actively supporting critical raw material development in Zambia.

The reconnaissance fieldwork highlighted the need for more data, for clear roles and lines of communication between team members, the need for a systematic approach, and the value of planning in advance of fieldwork. Overall, the reconnaissance fieldwork was successful and will contribute to prospectivity modelling to better understand the critical raw material potential of Zambia. The collaboration between the BGS, CSD and CBU is probably the main achievement of this work with the strengths and experience of the teams contributing to a highly effective graphite reconnaissance mission.

Appendix 1 Sample list

Sample No.	**Location**		**Description** (weight)
	Latitude	Longitude	
Mvuvye River			
SP35/01	S14°23’19.2”	E031°19’09.1”	Weathered biotite gneiss (291g)
SP35/02	S14°23’18.6”	E031°19’05.9”	Weathered biotite gneiss (838.7g)
SP35/03	S14°23’19.7”	E031°19’08.4”	Weathered biotite gneiss, 15cm depth, sand (742.9)
SP35/04	S14°23’19.7”	E031°19’08.4”	Weathered biotite gneiss, 30cm depth, sand (931.8g)
Mumbi village			
MB/01	S14°27’53.9”	E031°18’38.8”	Sand (441.5g)
MB/02	S14°27’53.9”	E031°18’38.8”	Sand (40.3g)
Kalobe			
KL/01	S14°25’45.9”	E031°20’08.7”	Weathered graphitic gneiss, surface (592.0g)
KL/02	S14°25’45.9”	E031°20’08.7”	Weathered graphitic gneiss, 30cm depth (634.3g)
KL/02	S14°25’45.9”	E031°20’08.7”	Weathered graphitic gneiss, 45cm depth (234.4g)
KL/03	S14°25’45.9”	E031°20’08.7”	Weathered graphitic gneiss, 45cm depth, rock (1800.9g)
KL/03	S14°25’45.9”	E031°20’08.7”	Weathered graphitic gneiss, 45cm depth, sand (2372.5g)
Dominico village			
DM/01	S14°25’54.5”	E031°16’05.6”	Weathered graphitic gneiss (751.2g)
DM/02	S14°25’53.7”	E031°16’04.1”	Weathered graphitic gneiss (702.3g)
DM/03	S14°25’51.3”	E031°16’03.1”	Graphite gneiss outcrop, no sample
DM/04/10	S14°25’50.2”	E031°16’02.2”	Graphite-rich laterite soil, 10cm depth (588.8g)
DM/04/20	S14°25’50.2”	E031°16’02.2”	Graphite-rich laterite soil, 20cm depth (741.7g)
DM/04/30	S14°25’50.2”	E031°16’02.2”	Graphite-rich laterite soil, 30cm depth (1063.2g)
DM/04/40	S14°25’50.2”	E031°16’02.2”	Graphite-rich laterite soil, 40cm depth (1079.0g)
DM/04	S14°25’50.2”	E031°16’02.2”	Size fractions (total weight 602.7g)

Sample No.	**Location**		**Description** (weight)
	Latitude	Longitude	
Sichombwe-Changwe			
SC/01/01	S14°24’45.6”	E031^{0}14’41.4”	Graphite gneiss, above contact (978.7g)
SC/01/02	S14°24’45.6”	E031^{0}14’41.4”	Graphite gneiss, trial pit location (260.1g)
SC/01/03	S14°24’45.6”	E031^{0}14’41.4”	Graphite gneiss, between trial pit and contact (522.4g)
SC/01	S14°24’45.6”	E031^{0}14’41.4”	Graphite gneiss, trial pit, rock sample (508.3g)
SC/01	S14°24’45.6”	E031^{0}14’41.4”	Graphite gneiss, trial pit, channel sample (2.27kg)
Nyakocha			
NY/01	S14°25’33.5”	E031°15’51.5”	Pegmatitic granite, rock (416.7g)
NY/02	S14°25’27.5.6”	E031°15’53.9”	Pegmatitic granite, rock (556.7g)
NY/03	S14°25’11.7”	E031°15’43.6”	Pegmatitic granite, rock (774.1)
NY/04	S14°25’24.6”	E031°15’36.2”	Pegmatitic granite, rock (1022.0g)

Appendix 2 Sample photographs

Figure 11. SP35/01 – weathered biotite gneiss near Mvuvye Bridge, Chivunga.

Figure 12. SP35/02 – weathered biotite gneiss near Mvuvye Bridge, Chivunga.

Figure 13. SP35/03 + SP35/04 – sand sampling near Mvuvye Bridge (in background), Chivunga.

Figure 14. MB/01 + 02 – sand sampling near Mumbi village. Left image shows outcrop of granitic rock. Right image is of sand material sampled.

Figure 15. Kalobe cotton farming area en route to Kalobe sampling site.

Figure 16. Kalobe sampling site where samples KL/01-04 were collected. Image shows initial trenching.

Figure 17. Kalobe sampling site where samples KL/01-04 were collected.

Image shows glistening flakes of graphite within saprolitic material.

Figure 18. DM/01 Dominico Village where flake graphite outcrops in weathered biotite-gneiss occur.

Figure 19. Dominico Village where flake graphite outcrops in weathered biotite-gneiss occur.

No samples taken from this location as it was in centre of village.

Figure 20. DM/03 moving west of Dominico Village towards DM/04 location.

Pegmatitic material with minor flakes of graphite and biotite.

Figure 21. DM/04 moving west of Dominico Village into dambo location.

Sampling of weathered material to depth of 40 cm. Splits were taken at 10, 20, 30, and 40 cm depth. This image is of a 40 cm split with glistening graphite flakes seen throughout the sample.

Figure 22. Sichombwe/ Changwe outcrop.

1: Upper contact between feldspathic pegmatite & band of graphite-bearing gneiss. Sample SC01/01 taken here. 2: Trial pit location where SC/01 & SC01/02 taken. 3: Contact zone between upper pegmatitic material, a band of graphite-bearing gneiss, & lower contact which extends from at least 1 m into trial pit. Sample SC/01/03 graphite-bearing gneiss taken here.

Figure 23. SC/01/01 Sichombwe/Changwe location 1 in figure 22.

Feldspathic pegmatite with minor biotite and graphite.

Figure 24. SC/01/03 Sichombwe/Changwe location 3 in figure 22.

Contact zone between pegmatite and friable graphite-biotite gneiss.

Figure 25. SC/01/03 Sichombwe/Changwe location 3 in figure 22.

Image zoom in of notebook area in figure 23 above. Metallic flake graphite mineralisation evident on top edge of sample in foreground.

Figure 26. Sichombwe/Changwe location 2 in figure 22.

Channel samples SC/01/02 and hand sample SC/01 taken from this pit.

Figure 27. Nyakocha location.

Raised hill areas were granitic to pegmatitic in composition. NY/01 taken from where photo was taken.

Figure 28. Nyakocha location sample NY/01 taken from this outcrop.

Figure 29. Nyakocha location sample NY/02 taken from this outcrop.

Figure 30. Nyakocha location sample NY/03 taken from outcrop Clive Mitchell is standing on.

Figure 31. Nyakocha location sample NY/04 taken outcrop beside prominent tree in foreground.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://of-ukrinerc.olib.oclc.org/folio/.

African Business. 2023. DRC and Zambia to establish SEZs for electric vehicle production. https://african.business/2023/04/long-reads/drc-and-zambia-to-establish-sezs-for-electric-vehicle-production

British Geological Survey. 2022. World Mineral Production statistics, https://nora.nerc.ac.uk/id/eprint/534316/

Bosse, HR. 1996) Zambia in Limestone and dolomite resources of Africa, Geologisches Jahrbuch, Reihe D, p. 495-512.

Carranza, EJM & Laborte, AG. 2015. Random forest predictive modelling of mineral prospectivity with small number of prospects and data with missing values in Abra (Philippines). *Computers & Geosciences*. 74. http://dx.doi.org/10.1016/j.cageo.2014.10.004

Coats, JS, Mosley, PN, Mankelow, JM, Mwale, M, Chikambwe, EM, Muibeya, B, Ndhlovu, KC & Nzabara, F, 2001. The geology and mineral resources of Zambia. Memoir No. 6, Geological Survey Department, Ministry of Mines and Minerals Development.

Central Statistical Office, 2020. https://www.zamstats.gov.zm/

Drysdall, AR. 1959. Preliminary investigation of an occurrence of graphite near Sasare Mine, Easter Province. Technical report No. 62TR. Department of Geological Survey, Northern Rhodesia.

Drysdall, AR. 1960a. A new occurrence of graphite in the Eastern Province, with notes on some other graphite deposits in Northern Rhodesia. Records of the Geological Survey for the year ending 31st December 1958. Ministry of Labour and Mines, Geological Survey, Government Printer, Lusaka.

Drysdall, AR. 1960b. Graphite of the Petauke District, Eastern Province. Geological Report No. 14. Ministry of Labour and Mines, Geological Survey, Government Printer, Lusaka.

Guernsey, TD. 1952. A prospector's guide to mineral occurrences in Northern Rhodesia. The British South Africa Company. 87pp.

Hamilton, E.M., Mitchell, C.J. & Maseka, K.K. 2022. BGS/CBU-ACESM Exchange Visit, Zambia. Nottingham, UK, British Geological Survey, 22pp. OR/22/048. https://nora.nerc.ac.uk/id/eprint/532904/

Johnson, MR, VanVuuren, CJ,Hegenberger, WF, Key, R, & Shoko,U.,1996.Stratigraphy of the Karoo Supergroup in southern Africa: an overview.J.Afr.EarthSci.23(1),3–15.

Kreiter, Attila & Czifra, Szabolcs & Bendő, Zsolt & Imre, Janosne & Pánczél, Péter & Váczi, Gábor. 2014. Shine like metal: An experimental approach to understand prehistoric graphite coated pottery technology. *Journal of Archaeological Science*. 52. 129-142. http://dx.doi.org/10.1016/j.jas.2014.07.020

Lusty, P. and Goodenough, K. 2022. The potential for graphite in the UK. British Geological Survey, 6pp. (Minerals for the UK's Net Zero Transition, CR/22/119N) https://nora.nerc.ac.uk/id/eprint/535252/1/CR22119N.pdf

Money, NJ. 1986. An outline of the geography and geology of Zambia. Geological Survey Department of Zambia.

Mitchell, CJ. 1992. Industrial Minerals Laboratory Manual: Flake graphite. Nottingham, UK, British Geological Survey Technical Report WG/92/030, 35pp. https://nora.nerc.ac.uk/id/eprint/9015/

Mitchell, CJ. 1993. Characterisation of some industrial minerals from Zambia. In: Zambian J. Appl. Earth Sci,. Special Publication No. 2, 1-34.

Mitchell, CJ & Deady, E. 2021 Graphite resources, and their potential to support battery supply chains, in Africa. *British Geological Survey Open Report* **OR/21/039**. 27pp. http://nora.nerc.ac.uk/id/eprint/531119/

Mitchell, C.J. 2022 Visit to Zambia and the United Arab Emirates, 30/10 to 17/11 2022. Nottingham, UK, British Geological Survey, 15pp. OR/22/068. https://nora.nerc.ac.uk/id/eprint/534051/

Nachalwe-Mbao, N. 2022. Significance of Zambia-DRC cooperation agreements. page 9, Monday May 16, 2022, Times of Zambia.

Phillips, K.A., 1965. The Geology of the Petauke and Mwanjawantu Areas: Explanation of Degree Sheet 1431, NW. Quarter and Part of SW. Quarter. Government Printer, South Africa.

Simpson, JG AND Drysdall, AR. 1965. The Njoka graphite deposit, Lundazi District. Economic Unit Report No. 4., Ministry of Mines, Geological Survey Department, Government Printer, Lusaka.