Graphite exploration – the importance of planning

Graphite has become the focus for dozens of exploration companies since the mineral's investment boom of 2011-2012. *Andrew Scogings, Industrial Minerals Consultant**, looks at the different exploration and testing methods and reporting conventions used by the graphite industry.

Graphite exploration follows a similar path to other minerals, often from discovery of an outcrop, which is then explored by methods such as field mapping, trenching, geophysics, drilling, assaying of the graphite content and mineralogical and metallurgical testing.

Data generated in this way, if successful, can lead to the estimation of a mineral resource. At the bare minimum, this defines the geometry, tonnage and the graphite content of the deposit.

Most of the recent exploration activity has focused on flake graphite deposits which generally occur in tabular or lens-like bodies; these may vary greatly in thickness and range from sub-horizontal to steep-dipping. The purpose of this article is to provide an overview of a road-map to success, based on some fundamental steps through the exploration process for flake graphite deposits.

Table 1: Minerals likely to interfere or mask graphite assay by LOI method

Mineral	Decomposition	Temperature (°C)	Weight loss (%)
Calcite	Decarbonation	920-975	44.0
Kaolinite	Dehydroxilation	450-700	13.0
Goethite	Dehydroxilation	250-360	10.1
Talc	Dehydroxilation	850-1000	4.8

Source: Mitchell, 1993 (BGS)

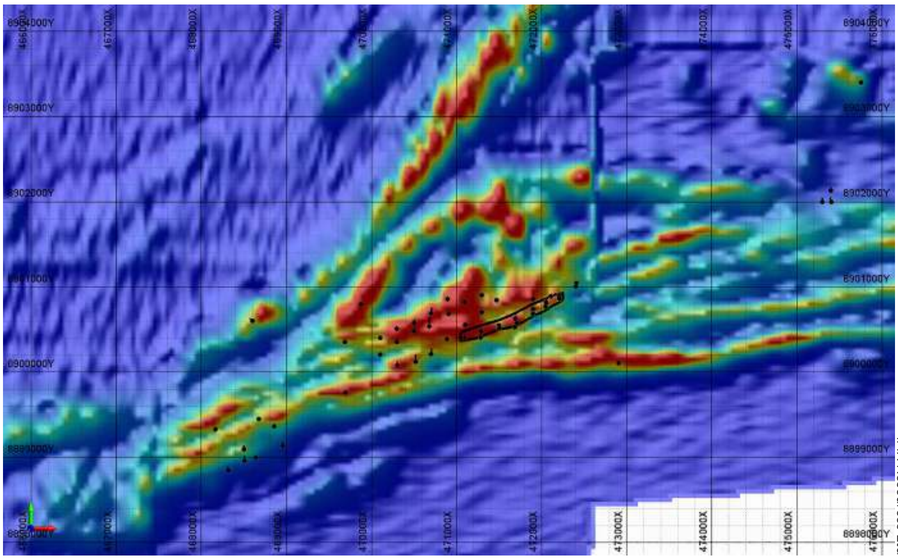

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Figure 1: Map showing VTEM anomalies, collar positions and the Chilalo mineral resource under development by IMX Resources Ltd (outlined in black). Map grid = 1,000 metres

Exploration geophysics

Geophysical techniques are an indirect way of tracing geological and/or mineralisation trends across an exploration project. Given that graphite and associated metal sulphide minerals – for example pyrite and pyrrhotite – are conductors, various electromagnetic (EM) methods can be highly effective exploration tools for graphite mineralisation. EM surveys can be carried out on the ground, downhole or from the air.

Ground surveys can be performed by several methods, including fixed loop (FLEM) or moving loop. Downhole EM surveys (DHEM) can be used to locate conductive targets that may have been missed by a drill hole. Airborne EM surveys, such as versatile time-domain electromagnetics (VTEM), are commonly used during the early stages of exploration as large areas can be covered quickly and relatively cost-effectively.

An example of VTEM anomalies that have been successfully explored by drilling is given in *Figure 1*.

Exploration trenching and drilling

Outcrops of weathered graphite schist may be sampled by excavating trenches, or by cutting channels across un-weathered outcrops, using a portable disk grinder (*Figure 2*). These methods provide a reasonably inexpensive way to trace mineralisation across a property before drilling.

There are two main methods of drilling for graphite, namely reverse circulation (RC) and diamond core drilling (DD), each of which has its own advantages and disadvantages. Auger drilling may occasionally be used to explore highly-weathered clayey mineralisation.

RC is a type of percussion drilling that uses a hammer to pulverise the rock into powder and chips, which are brought to the surface by compressed air (*Figure 3*). RC is a useful way of infill drilling between DD section lines to demonstrate geological and grade continuity, as it is quicker and less costly than DD.

DD is however the preferred method of exploration drilling for graphite, as the graphite flakes and host rock are relatively undisturbed when retrieved as core (*Figure 4*). Many exploration companies employ both RC and DD methods to optimise drilling density.

Quality assurance and quality control

The old computing adage of "garbage in, garbage out" is highly appropriate in the mining industry, which relies on miniscule sample sizes (such as drill cores) to make important decisions regarding the set-up of a mining project.

Quality assurance (QA) is put in place to prevent problems, while quality control (QC) aims to detect them in the event that they occur. It is necessary to insert samples known as standards, blanks and duplicates into the sample sequence that is submitted to a laboratory. A set of samples should also be submitted to another (external) laboratory for check, or umpire assays.

QC data may be visualised in a number of ways including tables, control charts (*Figure 5*), histograms, scatterplots or quantile-quantile (QQ) plots.

Twinned holes are traditionally drilled for verification of historic data or confirmation of drill hole data during geological due diligence studies. When drilling out a resource, a selection of RC holes must be twinned with DD holes, as the soft and low density graphite may be lost as fine dust from RC samples and cause an assay bias.

Bulk density

Bulk density is a measure of mass per unit volume of rock. In the mining industry, this is generally referred to as metric tonnes per cubic metre, or pounds per cubic foot.

Graphite resources are typically modelled as volumes in three-dimensional space, after which the estimated volume is converted to mass using density values. Density can be expected to vary across a graphite deposit, from low density weathered mineralisation near surface through a denser transitional zone and finally into the densest fresh (un-weathered) rock.

Determining bulk density from small samples is something often faced by geologists, who might only have drill core samples to use for density measurement. There are several methods available to determine volume of a sample, including

Ardiden Ltd

Figure 2: Channel sampling of a graphitic outcrop in Canada

Kibaran Resources Ltd

Figure 3: RC chip samples at Kibaran Resources Ltd's Epanko graphite project, Tanzania

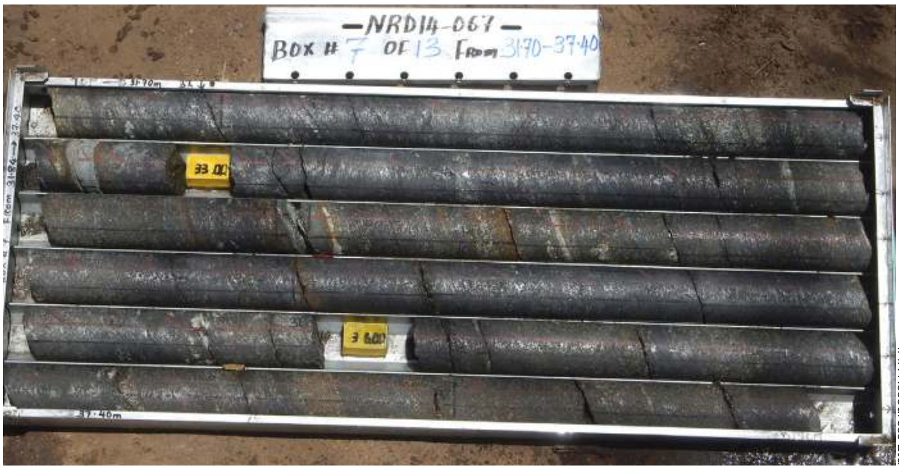

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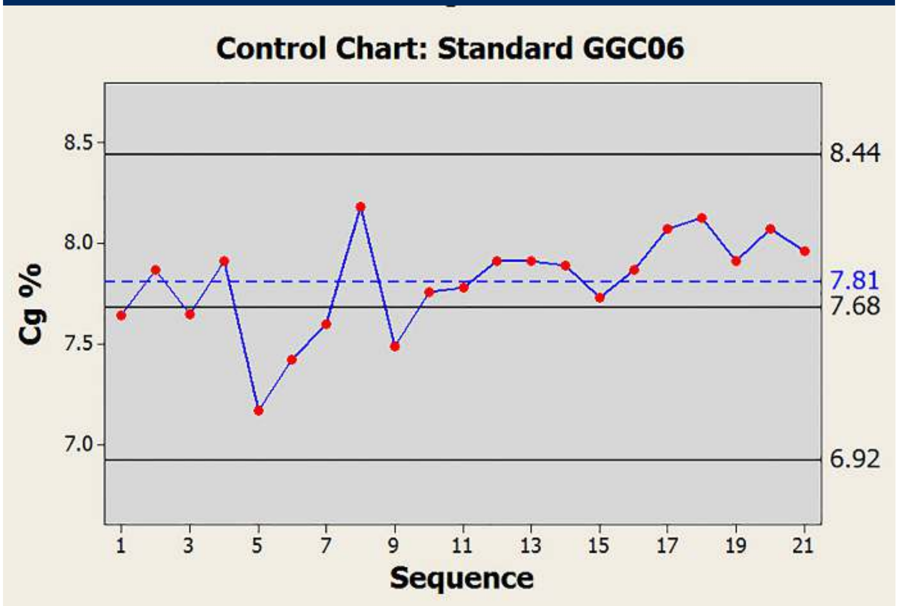
Figure 4: DD core samples of high-grade flake graphite mineralisation in a core tray

Table 2: Mineral resource classification based on the JORC Code 2012

Criteria	Inferred resource	Indicated resource	Measured resource
Does the resource estimate support the application of modifying factors?	Must not be converted to an ore reserve.	Supports mine planning and economic evaluation. Can be converted to probable ore reserve.	Supports detailed mine planning and final economic evaluation. Can be converted to a proved or probable ore reserve.
Quality of information	Limited geological and sampling evidence.	Adequately detailed and reliable geological and sampling evidence.	Detailed and reliable geological and sampling evidence.
Geological and grade continuity between points	Sufficient to imply but not verify.	Sufficient to assume.	Sufficient to confirm.

Source: Jacqui Coombes (pers. comm.); IMR Natural Graphite Report

Figure 5: Graphite standard GGC06 submitted with drill samples**



** Expected value = 7.68% graphitic carbon; sample mean = 7.81 % graphitic carbon

Source: Scogings and Coombes, 2014

Lamboo Resources Ltd; CSA Global Pty Ltd

Figure 6: Polished thin sections. DD core on the left, RC chips on the right

water displacement (the "Archimedes" method) or the caliper method, in which core diameter and length are measured and from which the volume can be derived.

Highly weathered drill core presents a challenge, as it may not be possible to remove the core intact from the core tray for volume measurement. In this case, an entire tray with core can be weighed, from which the weight of an empty tray is subtracted to give the weight of core. The core volume is then determined using the calliper method.

Assaying for graphitic carbon

Carbon may be present in rocks in several different forms, including organic carbon, carbonates or graphitic carbon. Depending on the method used, carbon in rocks may be reported as total carbon (organic carbon + carbon in carbonate minerals + carbon as graphite) or as total graphitic carbon (TGC) (total carbon – (organic + carbonate carbon)).

The simplest way to analyse a sample for graphite is by loss on ignition (LOI), in which case a sample is heated to 1,000°C and the graphite content is determined as the percentage weight loss. However, other minerals – such as calcite that contain carbon dioxide (CO_2), or clay and mica that contain structural water – will contribute to weight loss, resulting in apparently higher graphite content than anticipated (*Table 1*).

Therefore, when TGC is reported, organic carbon and carbon in carbonate minerals such as calcite should be removed before assaying TGC. Different laboratories use different procedures for measuring graphitic carbon, which is the reason for inserting standards into the sample stream and also for sending a set of samples to an external, or umpire laboratory.

Mineralogical examination

Samples may be analysed for graphitic carbon and other elements, in addition to examining thin sections under a petrographic microscope. Petrographic examination of polished thin sections (*Figure 6*) using an optical microscope is a relatively affordable and quick way of estimating the in situ graphite flake size distribution and likely liberation characteristics.

Polarised-light microscopy is usually complemented by methods such as X-ray diffraction (XRD), QEMSCAN (quantitative evaluation of minerals by scanning electron microscopy) and mineral liberation analyser (MLA, or automated SEM).

Mineralogical examination helps with geometallurgical domaining of graphite deposits and selection of composites for metallurgical testing. Sulphide minerals such as pyrite are common impurities in graphite deposits. Thin section petrography can help define areas or specific lithologies where sulphides are interleaved within graphite flakes and therefore may be difficult to liberate (*Figure 7*).

Graphite deposits may be weathered near surface, in which case sulphide minerals may be replaced by sulphates, or silicate minerals such as sillimanite may be replaced by kaolinite. The volume increase brought about during the kaolinisation process may cause graphite flakes to split (*Figure 8*).

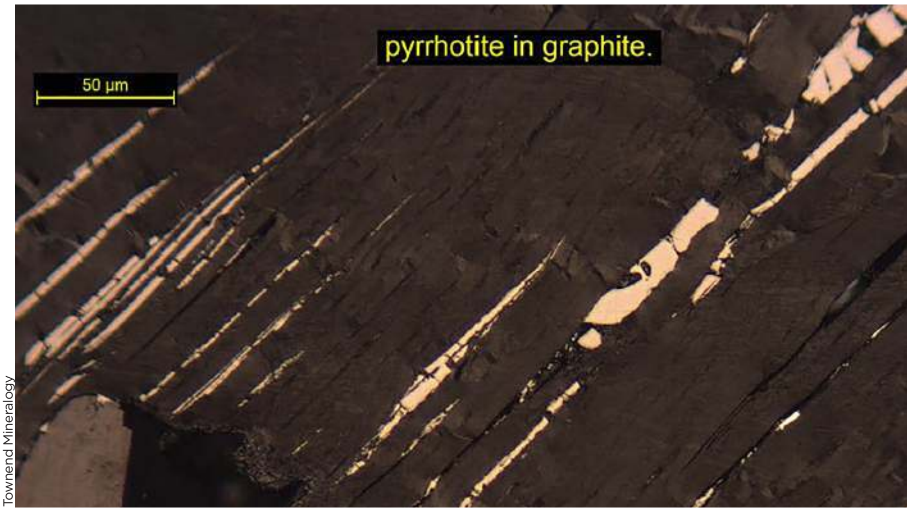


Figure 7: Photomicrograph of pyrrhotite interleaved along cleavage planes in graphite

Extractive metallurgy

Assaying for graphitic carbon quantifies the amount of graphite contained within a deposit, but does not indicate the amount of graphite that may be recoverable; the purity of such graphite; the particle size distribution of recovered (liberated) graphite; the process required to liberate and produce a graphite concentrate; or likely markets for that product.

Therefore, it is essential to test representative samples of mineralisation from a deposit to confirm appropriate metallurgical processes and likely product mix. Samples should be taken to a specialist laboratory, which would typically run mineralogical, crushing, assay by size and other characterisation tests before embarking on flotation or gravity tests (*Figure 9*).

Mineral resource estimation

The next step in the exploration process is to estimate a mineral resource, which is usually done after importing a validated geological and assay database into 3D modelling software. During this process, the resource geologist (someone specialised in modelling resources) models the limits of mineralisation taking into account structural controls such as folding or faulting, spatial distribution of graphite grades, lithological variations or other attributes. The model should be domained where possible according to grade (graphite content), flake size, lithology and weathering which can all have an impact on mining and processing methods.

The final outcome should be a block model (*Figure 10*) from which a mineral resource may be estimated; this is typically reported in terms of tonnes and grade (% graphite).

Mineral resource classification

Publicly-listed companies should report mineral resources (and reserves) according to accepted codes such as JORC (Australia); SAMREC (South Africa); NI 43-101 (Canada); SME Guide (US); PERC (Europe); NAEN (Russia); or CRIRSCO (international).

The different categories of mineral resource classification reflect increasing geological confidence (*Table 2*) and the link to economic viability and the importance of continuity of both geology and grade (or product quality) as is emphasised, for example, in the 2012 edition of the JORC Code.

Reporting of industrial mineral resources

Industrial mineral resources such as graphite should be reported in terms of product specifications, as noted by the JORC Code (2012) which requires that industrial mineral resources or reserves must be reported in terms of mineral specifications.

The code states that: “For minerals that are defined by a specification, the mineral

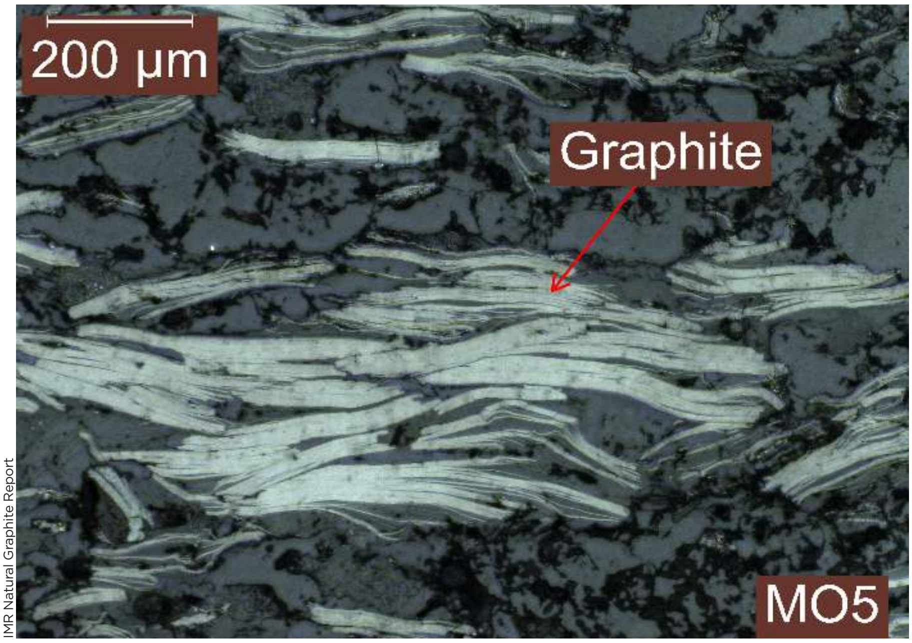


Figure 8: Photomicrograph of kaolin interleaved with split graphite flakes

Figure 9: Graphite flotation test

resource or ore reserve estimation must be reported in terms of the mineral or minerals on which the project is to be based and must include the specification of those minerals."

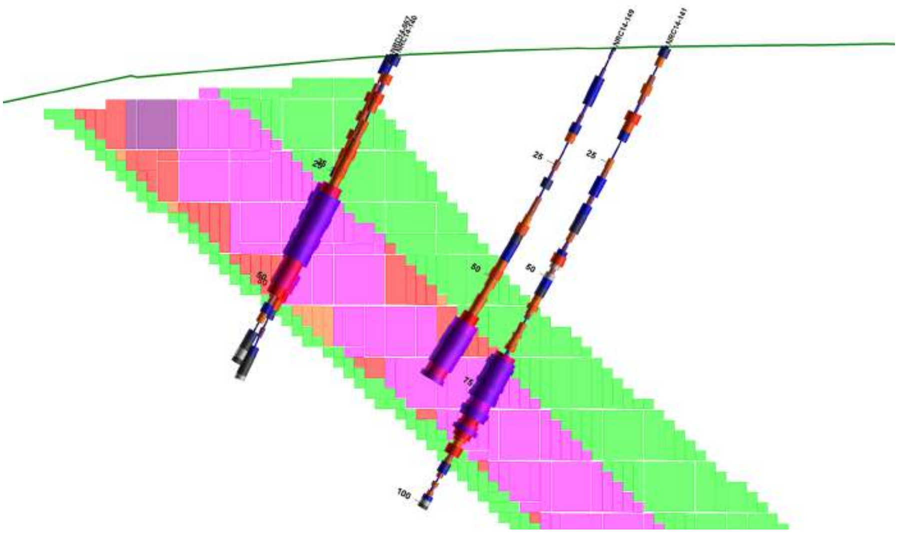
Conclusion

Exploration for graphite is likely to follow a similar track to exploration for other minerals, for example:

- Discovery of a mineralised outcrop
- Field mapping and trenching
- Geophysical survey
- Drilling and assaying for graphite content
- Mineralogical and metallurgical testing

Successful exploration following the above steps should result in the definition of a mineral resource, which may be classified according to geological confidence and must take account of product specifications and markets.

Figure 10: Graphite mineral resource block model in cross section



Source: IMX Resources Ltd

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