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graphite petrography

Introduction

Industrial minerals such as graphite have recently become the focus of attention for many listed exploration companies, particularly due to developments in battery technologies and new product opportunities such as graphene. Consequently the race has been on to report larger tonnage exploration targets and resources, with certain projects being described, for example, as world class or highest grade.

Although resource tonnes and graphitic carbon content (grade) are important metrics, the evaluation of graphite projects (as with other industrial minerals) is more complex; key attributes in addition to deposit size and grade, are product flake size distribution and purity (Scogings, 2014; Scogings and Chesters, 2014).

Graphite purity is particularly important for the higher value end uses like lithium-ion batteries and is a key determinant in saleability of the product. Producing high purity graphite may also adversely affect the cost of production, as additional processing to make the product saleable will increase the operating cost.

Graphite flake size distribution is one of the more debated project factors. However a number of facts about flake size are currently true; firstly, the larger the flake the higher the purity of the graphite product is likely to be and secondly, the larger and purer the flake size the higher is the selling the price.

Graphite prices related to flake size and purity

Graphite type	Purity (% Carbon)	Size (mesh)	Size (Microns)	Low (US$, CIF)	High (US$, CIF)
Flake	94 to 97	+80	+180	1,050	1,150
Flake	94 to 97	+100 -80	+150 -180	900	1,000
Flake	94 to 97	-100	-150 + 200	750	800
Flake	90	+80	+180	750	850
Flake	90	+100 -80	+150 -180	700	800
Flake	90	-100	-150 + 200	600	650
Flake	85 to 87	+100 -80	+150 -180	550	600
Amorphous	80 to 85	-200	-75	430	480
Amorphous	70 to 75			500 (ex-works)	550

SOURCE: Industrial Minerals Magazine 30th April 2015 www.indmin.com

SAMREC 2009 Table 1, Section 5.5 Treatment / Processing

ASSESSMENT CRITERION: T 5.5 Treatment / Processing
EXPLORATION RESULTS (A)
(i) Describe any obvious processing factors that could have a significant effect on the prospects of any possible exploration target or deposit
MINERAL RESOURCES (B)
(i) Discuss the level of study, possible processing methods and any processing factors that could have a material effect on the likelihood of eventual economic extraction.
(ii) The basis for assumptions or predictions regarding metallurgical amenability and any preliminary metallurgical test work should already be carried out.
(iii) It may not be possible to make assumptions regarding metallurgical processes and parameters when reporting Mineral Resources. Where no assumptions have been made, this should be explained.

Source: The SAMREC Code 2007, as amended July 2009

The current edition of the SAMREC Code for public reporting of Exploration Results, Mineral Resources and Ore Reserves includes Table 1 which is a high-level checklist of assessment and reporting criteria. Although not prescriptive, it is important for the Competent Person ("CP") to "report all matters that might materially affect a reader's understanding or interpretation of the results or estimates being reported" (SAMREC, page 28). The Code goes further and states that the CP has the responsibility to consider all criteria listed and which additional criteria should apply to the particular project.

The author's intention is to address some of the criteria listed under 'Treatment / Processing' of Section 5.5 of SAMREC Table 1 and to provide examples from graphite exploration projects related to the issue of flake size and liberation characteristics. These criteria include the description of any "obvious processing factors that could have a significant effect on the prospects of any possible exploration target or deposit" and "the basis for assumptions or predictions regarding metallurgical amenability and any preliminary metallurgical test work".

Given that industrial minerals such as graphite are normally produced and sold according to size, purity and / or performance specifications, the responsibility falls on the CP to ensure that samples are tested for appropriate parameters such as flake size and purity, in addition to basic assay tests for graphitic carbon content. In this regard, the question is often raised about how to test graphite flake size across a deposit; given that relatively costly and time-consuming lab flotation procedures are usually required to separate graphite from gangue minerals.

The author suggests that petrographic examination of polished thin sections is a relatively affordable and quick option to estimate the *in-situ* graphite flake size distribution and likely liberation characteristics.

Back to basics – take a look at the rocks

The microscopic investigation of rocks in transmitted and reflected light is one of the classic mineralogical methods of analysis. Polarized-light microscopy provides a non-destructive way to identify minerals, as they can be studied within their textural framework. This method provides clues to the history of formation of the material, using specific textural characteristics such as structural fabric, mineral assemblages and relationships and has distinct advantages over bulk-analytical methods that use sample powders for mineral identification or chemical composition such as XRD and XRF. It is recommended that polarized-light microscopy, complemented by methods such as SEM (Scanning Electron Microscope), QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) and MLA (Mineral Liberation

Maggie Lambert-Newman
Dinosaurs

Analyser, or automated SEM) should be used when evaluating a graphite project.

Graphite explorers are encouraged to 'get back to basics' and use thin section petrography as a primary tool to evaluate and compare prospective targets (Scogings, 2015). Thin section petrography helps with the geometallurgical domaining of graphite deposits and selection of composites for metallurgical testing, in addition to explaining subsequent metallurgical test results.

Geometallurgy is multi-disciplinary approach that combines geology and mineralogy with extractive metallurgy, to create a predictive model that assists with selecting appropriate mineral processing for a deposit. It is used to reduce risk during mineral processing plant design and can also assist with production scheduling. Mining and processing based solely on grade (e.g. graphite content) may not be sufficient, as seemingly low grade mineralisation may result in a high quality concentrate if processed appropriately.

There are several steps that may be used in developing a geometallurgical model for a graphite deposit, including:

- Petrographic studies to define geological domains (e.g. lithologies, mineralogy and textural characteristics);
- Selection of samples according to geological domains, for metallurgical testwork;
- Laboratory-scale test work to determine the response to mineral processing methods;

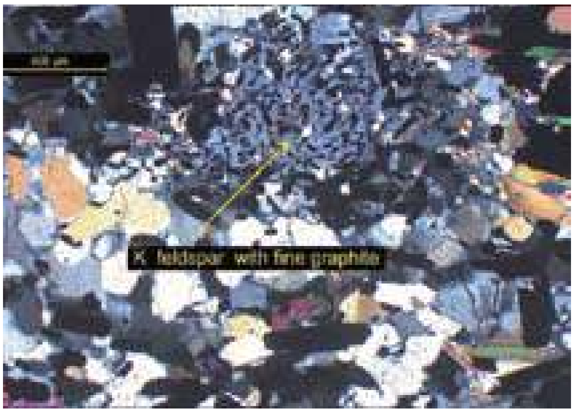
In order to define geometallurgical domains, a suite of samples may be prepared, representing the main lithologies from which two thin sections can be made for each sample, one perpendicular to the graphite flakes and a second approximately parallel to the flakes. In the case of RC chips, these can be cast into resin and made into polished thin sections in which case the sample orientation is random.

Graphite populations

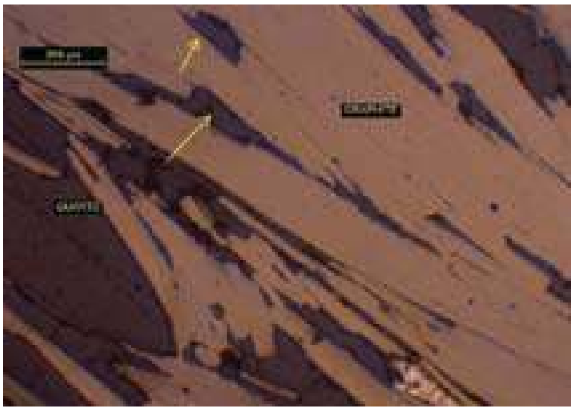
An example of how thin section microscopy can help understand metallurgical results is where graphite recoveries are lower than anticipated. Thin section examination highlighted that there were two graphite populations, with the majority as coarse flakes but with a second population of very small flakes within large crystals (porphyroblasts) of K feldspar. The small flakes

Core samples representative of rock types on a specific project. Approximate graphite contents indicated as percentages.

Polished thin sections made from core or outcrop (two samples on the left) and RC chips (two samples on the right)



Photomicrograph illustrating two graphite populations within one sample: large flakes in the general rock matrix, compared with fine flakes within K feldspar

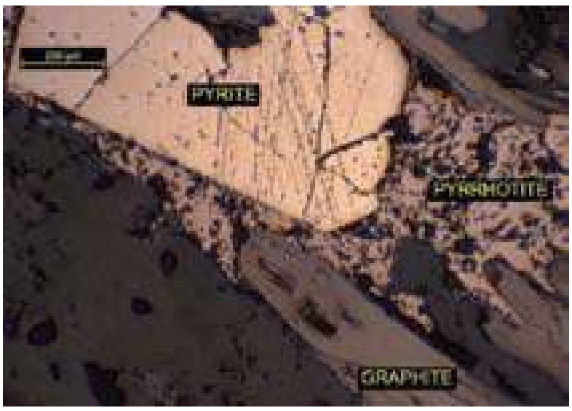


Photomicrograph of large 'clean' graphite flakes with one minor sulphide inclusion

were not being liberated at the coarse crushing size used to liberate large flakes, hence were not being recovered.

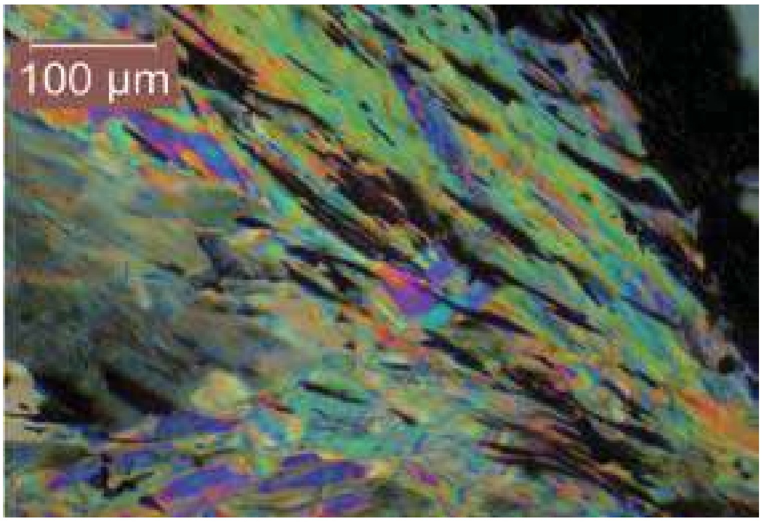
Mineral impurities

Sulphide minerals such as pyrite and pyrrhotite are common impurities in graphite deposits and thin section petrography can help define areas or specific lithologies where sulphides may be absent, present as discrete grains or interleaved within graphite flakes and thus more difficult to liberate.

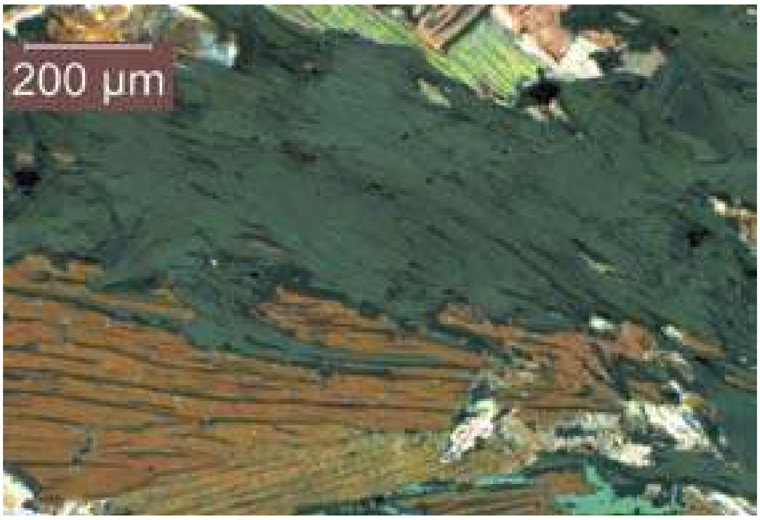


Photomicrograph of graphite flakes with discrete pyrite crystals and pyrrhotite blebs

Photomicrograph of pyrrhotite interleaved along cleavage planes in graphite



Photomicrograph of small graphite flakes generally less than 75 microns in length, intergrown with sericite



Photomicrograph of coarse graphite flake more than 1mm in length, associated with biotite

Flake size

A second example of the benefits of thin section petrography may be where flake size varies across an individual deposit, or between prospects within a region and where the explorer wishes to select an appropriate target. In this particular case, the explorer identified one target as having a population of very small flakes in a retrograde sericitic assemblage and a second target as containing coarse flakes in a medium to high grade metamorphic assemblage and elected to follow up on the second target.

Conclusions and recommendations

- Graphite explorers are urged to 'get back to basics' and use thin section petrography as a basic tool to help address treatment / processing aspects of industrial mineral resources according to SAMREC 2009 requirements.

- It is suggested that petrographic examination of polished thin sections be done early on in the project and during the subsequent resource drilling phase. Polished thin sections are relatively inexpensive and can be used to estimate the size and shape of *in-situ* graphite flake populations, relationships with other minerals including contaminants such as sulphide minerals, and for estimating likely liberation size. However it should be borne in mind that *in situ* flake size estimations don't necessarily translate directly to flake sizes produced by metallurgical processes such as gravity separation or froth flotation.

- Core drilling is the preferred technique for graphite exploration, as this provides undisturbed samples for thin sections and for metallurgical tests. Reverse Circulation (RC) drill chips may also be used to make thin sections; however RC chips are not suitable for metallurgical tests due to the grinding action of the drill bit, which reduces flake size. Caution should be exercised when selecting RC chips, as there may have been preferential grinding of softer (possibly graphite-rich) rocks.

- Once appropriate metallurgical samples have been selected, some cost-effective and fairly quick tests such as i) assay by size and ii) heavy liquid separation

(SG 2.3) may be considered as precursors to more detailed flotation tests.

- Knowing this type of information means being smarter early on in the project and can guide to more intelligent and informed selection of composite drill samples for metallurgical testing, in addition to benefitting mine planning and metallurgical processing further down the line.

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