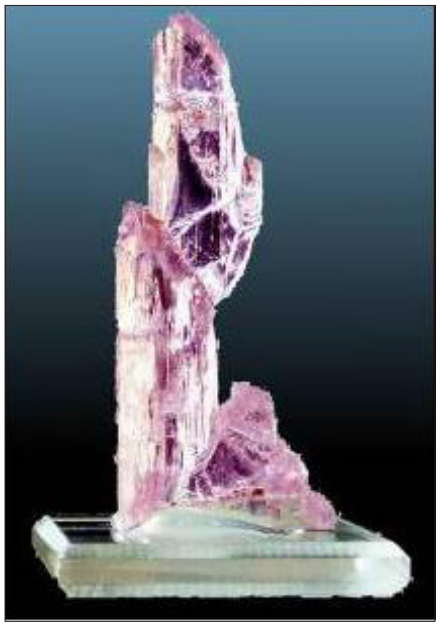
HARD ROCK LITHIUM PROCESSING

LITHIUM EXTRACTION FROM SPODUMENE

SGS Minerals Services has experience with complete flowsheet development to recover high grade lithium products from hard rock lithium minerals. SGS offers a multi-disciplinary team that is involved from the initial stages of the characterization of the lithium deposit to the production of a market sample of a high grade lithium product.

SGS provides the comprehensive range of testwork capabilities required to extract lithium. These capabilities include:

- Comprehensive high definition mineralogy
- Extensive grindability test suite
- Mineral separation (gravity, heavy liquid and heavy media)
- Flotation
- Pyrometallury (concentrate roasting and acid roasting)
- Hydrometallurgy
- Pilot plant testing
- Environmental testing.



Spodumene, Galileia, Brazil
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INTRODUCTION

Lithium is found in very low concentration in igneous rocks. The largest concentrations of lithium-containing minerals are found in granitic pegmatites. The most important of these minerals are spodumene (Li_2O, Al_2O_3. $4SiO_2$) and petalite (Li_2O, Al_2O_3. $8SiO_2$). Spodumene has a theoretical Li2O content of 8.03%. Due to its high lithium content, spodumene is considered the most important lithium ore mineral. A typical run of mine ore can contain 1-2% Li_2O, while a typical spodumene concentrate suitable for lithium carbonate production contains 6-7% Li_2O (75% - 87% spodumene). Higher grade concentrates with 7.6% Li_2O and low iron content are used in ceramics and more demanding industries.

MINERALOGICAL ANALYSIS OF A TYPICAL PEGMATITE DEPOSIT

A typical pegmatite deposit can contain quartz, sodium-feldspar, spodumene, lepidolite, petalite, lithiophilite, microcline, and variable amounts of muscovite (1-5%). One can also find trace amounts of Ta-Nb phases, commonly columbite, tantalite, and other accessory phases such as spessartine, biotite, pollucite, amphibole and other minerals (Fe-Ti oxides, tourmaline, chlorite, apatite) (Grammatikopoulos et al., 2009).

SGS experts in High Definition Mineralogy use the QEMSCAN® to identify and map textural features of coarsely crushed samples. A typical assemblage includes sodium feldspar, microcline, spodumene and minor muscovite. False-coloured images provide textural information on the occurrence of spodumene and associated minerals.

Liberation data are very important because they indicate the potential recovery of a mineral of interest (e.g., spodumene and mica). Association data illustrate the potential impurities in a concentrate or product. The liberation and association for each sample are calculated for each size fraction of the entire sample based on the modal analysis of each fraction. Normally liberation increases from the coarse to the fine fraction. Metallurgical results show that a high grade lithium concentrate (>7%) can be achieved.

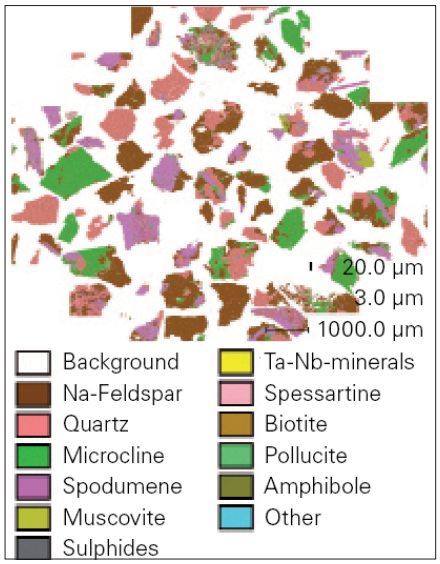
GRINDABILITY TESTS

SGS supports the minerals and chemical industries in the design and operation of efficient crushing and grinding circuits using both power and model-based methods. We can design bankable circuits and provide operating advice to maximize milling efficiency, considering both steel and power consumption. Our practical experience also ensures that we recommend effective circuit configurations that offer ease of operation and maximum flexibility.

SGS performs the following grindability tests:

- SPI test
- SMC test
- Bond Ball Mill Grindability Test
- Bond Impact Test
- Abrasion Test
- JK Drop-Weight Test
- MacPherson Autogenous Grindability Test
- MacPherson 18" Mill Test.

Well-instrumented pilot-scale autogenous grinding circuits, ball and rod mill circuits, and crushing circuits also facilitate testing and circuit design. After production starts, in-plant audits allow modeling and simulation to optimize existing plants.



False-coloured image of a crushed spodumene pegmatite sample

MINERAL SEPARATION

Separation of lithium minerals can be efficiently achieved by taking advantage of their physical, electrical and magnetic properties. Physical separations are performed by wet and dry screening, tabling and magnetic, electromagnetic, electrostatic, magnetohydrostatic bullet and heavy media separation. Gravity separation is feasible only if the spodumene is coarsely grained. SGS delivers on all physical separation techniques, both at the laboratory scale and pilot plant scale. Depending on your objective, the flotation concentrate can then be further processed by high-temperature techniques (pyrometallurgy) or chemical techniques (hydrometallurgy) to produce lithium carbonate or other desirable lithium compounds.

FLOTATION

Flotation is used to generate a high grade spodumene concentrate (75-85% spodumene) suitable for lithium extraction.
SGS' expertise in flotation ensures you can:

- Generate a high grade concentrate with high lithium recovery suitable for downstream roasting and hydrometallurgy
- Maximize recovery
- Minimize acid-consuming contaminants
- Minimize the cost of roasting.

CONCENTRATE ROASTING AND ACID ROASTING

Lithium can be extracted from spodumene concentrates after roasting and acid roasting operations. A concentrate with at least 6% Li_2O (approximately 75% spodumene) is suitable for roasting. Roasting is performed at about 1050°C, during which spodumene will go through a phase transformation from α-spodumene to β-spodumene. The α-spodumene is virtually refractory to hot acids.

As a result of the phase transformation, the spodumene crystal structure expands by about 30% and becomes amenable to hot sulphuric acid attack. Due to this expansion, the specific gravity of the spodumene decreases from 3.1 g/cm^3 (natural α-spodumene) to around 2.4 g/cm^3 (β-spodumene).

After roasting, the material is cooled and then mixed with sulphuric acid (95-97%). The mixture is roasted again at about 200°C. An exothermic reaction starts at 170°C and lithium is extracted from β-spodumene to form lithium sulphate, which is soluble in water.

Petalite

After Crushing

Spodumene Flotation

Spodumene Concentrate

Roasted Concentrate

After Acid Roasted Concentrate

HYDROMETALLURGY

Working with the lithium concentrate, SGS' team uses a standardized flowsheet to produce high grade lithium products such as lithium carbonate or lithium hydroxide. These are reagents for the lithium battery industry. The multi-step process involves atmospheric leaching, liquid-solid separation and impurity removal via precipitation and ion-exchange. Our team expertise can deliver:

- High grade market samples of lithium products using a standardized flowsheet
- Process optimization based on the unique properties of your material
- Process data in support of pre-feasibility and feasibility studies
- Capital and operating expense modeling
- Piloting of the optimized flowsheet.

A sample of high grade lithium carbonate

PILOT PLANT TESTING

Pilot testing is the best way to reduce technical risk associated with a new flowsheet or flowsheet changes. It will generate the data needed to design the full scale plant. As well, existing operations can be simulated at the pilot scale to evaluate new technologies or address problems without interrupting production. In a pilot plant, the actual process is constructed from appropriately sized equipment and the testing allows us to address virtually all of the issues that a full processing plant will face. As a result of many years of experience, our staff can quickly provide workable alternatives.

ENVIRONMENTAL TESTING

Environmental responsibility is a fact of life in today's industry. Corporations are constantly confronted with new laws and regulations so must spend a great deal of time and money meeting environmental requirements. This can include adapting extraction processes, investing in emission-reducing and energy saving technologies and conducting ongoing environmental investigations. SGS offers the following environmental services to help you meet these ongoing challenges:

- Acid rock drainage testing
- Water treatment services
- Laboratory testing
- On-site laboratories
- Mine site reclamation and closure planning
- Health & safety audits

RECENT PUBLICATIONS

1. Aghamirian, M., Mackie, S., Raabe, H., Lang, D., Grammatikopolous, T., Pearce, G., Todd, I., Imeson, D. (2010). Lithium Extraction from Spodumene. Hydroprocess 2010 III International Workshop on Process Hydrometallurgy, August 11 – 13, 2010, Santiago, Chile.
2. Grammatikopolous, T., Gunning, C., Pearse, G., Gelcich, S. (2009). Quantitative characterization of spodumene ore by automated mineralogy from the Moblan Pegmatite Deposit, Quebec, Canada. Proceedings of 48th Conference of Metallurgists, COM 2009, August 23-26, Laurentian University, Sudbury, ON Canada, pp. 65-76.

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