Summary

The rise in molybdenum prices since the start of this decade has been nothing less than spectacular, and market prices appear to have stabilized at much higher levels than those seen in the 1990s. The situation is clearly very favourable for molybdenum exploration, which has been relatively neglected in Quebec.

Most of the world’s molybdenum is produced as a by-product from porphyry copper deposits with the balance coming from porphyry molybdenum deposits. In Québec, there are many known deposits of the former type, notably in the Appalachian Mountains (including the Gaspé Copper mine, a former Mo producer), and in the Superior Province. A number of porphyry-type molybdenum occurrences are also known, and although no such deposit has ever been mined in Quebec, the discovery potential is promising for several regions.

This document provides a brief summary of the molybdenum market, the metallogeny of molybdenum, exploration methods, and target regions in Quebec.

The mission of SIDEX is to invest in companies engaged in mineral exploration in Quebec in order to diversify the province’s mineral base and open new territories to exploration.

ECONOMICS

Molybdenum (Mo) is an alloy metal particularly effective in the manufacture of steel to which it confers enhanced mechanical strength, hardenability, weldability, high-temperature resistance, and corrosion resistance (www.moly.imoa.info). The steel industry consumes about 80% of the annual Mo production to make stainless steel, cast iron, and other types. Some of the many applications of Mo in steel and alloys include high-pressure pipelines for long-distance oil and gas transportation, offshore petroleum production, desalination factories, nuclear power plants, the aeronautics industry, military armour, etc. Molybdenum is also used in pigments, lubricants, and as a desulphurizing agent for petroleum products (to produce low-sulphur diesel fuel, for example). Many of these applications are showing strong growth (http://www.sprott.com/pdf/Structural%20Changes%20in%20Moly%20Demand.pdf).
As a result, molybdenum prices have exploded since the start of the decade, with the price of a kilogram of oxide jumping from 5.20 USD in 2001 to more than 70 USD in 2005 — an increase of more than 1000%. The average price for 2006 was 53.10 USD, which is still far above historical values, and makes the mining of some molybdenum deposits highly profitable.

Average annual price for molybdenum concentrate since 1955 in U.S. dollars. Data sources: “Metal Prices in the United States through 1998” (U.S. Geological Survey) and “Mineral Commodity Summaries” (USGS).

Weekly prices for molybdenum concentrate since 2000 in U.S. dollars. Data source: CIBC World Markets. Ferromolybdenum is another product that is currently trading.
The high prices of the last few years can be explained by several factors beyond the increased demand for steel from China. These factors include a capacity problem for roasters in the United States (roasting is the process by which MoS$_2$ is transformed into oxide; http://www.moly.imoa.info/Default.asp?page=62), and problems with production in the Huludao region in China during 2005 and 2006 (the Huludao region represents two-thirds of China’s ferromolybdenum production according to the American Metal Market; http://www.amm.com). China produces about 20% of the world’s Mo according to the USGS, and the most recent rumours are that the Chinese government may impose export quotas, which would have the effect of further reducing China’s Mo exports.


The biggest molybdenum producer in the world is Corporación Nacional del Cobre de Chile (Codelco) with approximately 80 million pounds of molybdenum in 2005 (production was lower in 2006). The second-largest producer is Phelps Dodge Corporation, based in the United States (now Freeport-McMoRan), with 68.2 million pounds in 2006. Other significant producing countries are China, Peru, and Canada. Codelco’s molybdenum production comes entirely from porphyry copper deposits, whereas the majority of the Phelps Dodge production is from the Henderson mine in a rift-type porphyry molybdenum deposit. At the global scale, porphyry copper deposits account for 65% of the approximate 400 million pounds produced every year, with the balance from porphyry molybdenum deposits (primary producers) and a negligible contribution from other deposit types.


METALLGENGY-EXPLORATION

Porphyry copper deposits represent a well-known type compared to porphyry molybdenum deposits, so this bulletin will concentrate on the metallogeny of the latter with additional comments about other deposit types.

Porphyry molybdenum deposits

In terms of primary producers, historical production is mainly from rift-type porphyry molybdenum deposits, which are richer than arc-type porphyry molybdenum deposits. However, arc-type deposits contain more copper and are just as interesting given the current prices for the two metals. These two types of molybdenum deposits differ not only in their Mo and Cu grades, but also in tectonic context, the geochemistry of their associated intrusions, and their metal associations.
### Classification of porphyry molybdenum deposits

<table>
<thead>
<tr>
<th></th>
<th>RIFT-TYPE</th>
<th>ARC-TYPE</th>
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</thead>
<tbody>
<tr>
<td>Average grades</td>
<td>0.25-1.0 % MoS$_2$</td>
<td>&lt;0.25 % MoS$_2$</td>
</tr>
<tr>
<td>Metal association</td>
<td>Cu practically absent, but significant W, U, Nb</td>
<td>Presence of Cu</td>
</tr>
<tr>
<td>Fluorine content</td>
<td>Fluorine-rich (fluorite, topaz, micas)</td>
<td>Fluorine-poor</td>
</tr>
<tr>
<td>Intrusion geochemistry</td>
<td>Multiple rhyolitic intrusions (&gt;75 % SiO$_2$), commonly alkaline</td>
<td>Calc-alkaline intrusions: monzogranite - quartz monzonite</td>
</tr>
<tr>
<td>Geological environment</td>
<td>Long-term regional intraplate magmatism – association with calderas, felsic volcanism</td>
<td>Magmatic arcs</td>
</tr>
<tr>
<td>Tectonic setting</td>
<td>Intraplate extension</td>
<td>Subduction zones</td>
</tr>
<tr>
<td>Examples</td>
<td>Climax (Colorado), Henderson (Colorado), Questa (New Mexico)</td>
<td>Endako (British Columbia), Quartz Hill (Alaska)</td>
</tr>
</tbody>
</table>

Sources: Sillitoe (1980); Carten et al. (1993).

All porphyry-type deposits are formed at shallow crustal depths (probably 3–4 km or less). In the case of porphyry Mo deposits, most ore bodies lie just above or within the summit of an intrusive porphyritic or aplitic cupola. If the intrusion crops out over a large area, it is probable that the deposit has been eroded (that is, if the geologic strata were not tilted prior to erosion). The ideal level of erosion for porphyry-type deposits is several hundred metres above the pluton.

In cases where the rock sequences have been only slightly tilted, buried plutons represent more interesting exploration targets than outcropping plutons. Buried plutons can be located by the geophysical anomalies they generate, or by felsic dyke density maps (ex., Doyon, 1995). In sedimentary rocks that are unmetamorphosed or only slightly metamorphosed, it is also possible to map clay minerals or illite crystallinity to reveal a paleo-heat flux (ex., William-Jones and Duba, 1985). This is notably the case for areas of the Gaspésie region that are underlain by rocks of low metamorphic grade (the Gaspé Belt).
### Detailed comparison of rift- and arc-type Mo porphyries, compiled by Rowe (2005)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>RIFT-TYPE RIFT</th>
<th>ARC-TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Intrusion</td>
<td>Granite porphyry</td>
<td>Quartz monzonite porphyry</td>
</tr>
<tr>
<td>Geochemistry</td>
<td>High silica, peralkaline, F-rich (&gt;0.1% F), Rb, Y, and Nb are high; Ba, Sr, and Zr are low</td>
<td>Calc-alkaline, low F content (&lt;0.1% F)</td>
</tr>
<tr>
<td>Deposition</td>
<td>Multiple intrusions of granite</td>
<td>Composite intrusions of diorite to quartz monzonite in orogenic belts</td>
</tr>
<tr>
<td>Age range</td>
<td>Palaeozoic to Tertiary, but mainly Mid-Tertiary</td>
<td>Archean to Tertiary, but most commonly Mesozoic and Tertiary</td>
</tr>
<tr>
<td>Tectonic Setting</td>
<td>Rift zones in areas of thick cratonic crust</td>
<td>Subduction zones related to arc-continent or continental collision</td>
</tr>
<tr>
<td>Associated ore deposit types</td>
<td>Ag-base-metal veins and polymetallic replacement deposits, possibly molybdo-hosted Sn deposits and porphyry W deposits; possibly Mo, Sn, and W greisen systems</td>
<td>Porphyry Cu-Mo, Cu skarn, volcanic-hosted Cu-As-Sb deposits</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>Molybdenite, quartz, K-feldspar, fluorite, fluorine-rich biotite and topaz, pyrite, calcite, rutile, anhydrite, sylvite, clays, wolframite, cassiterite, molybdenite, sphalerite, galena</td>
<td>Molybdenite, pyrite, scheelite, chalcopyrite, argentian tetrahedrite, quartz, K-feldspar, biotite, calcite, sylvite, clays, galena</td>
</tr>
<tr>
<td>Alteration</td>
<td>Intense silification and potassic alteration, upper zones of phyllic propylitic alteration, quartz- sylvite-pyrite alteration, minor greisen below orebody</td>
<td>Potassic outward to propylitic, phyllic and propylitic overprint, minor peripheral argillic</td>
</tr>
<tr>
<td>Texture</td>
<td>Predominantly in veinlets and fractures; minor disseminations; breccias</td>
<td>Disseminated and in veinlets and fractures; breccias</td>
</tr>
<tr>
<td>Ore controls</td>
<td>Stockwork ore zone draped over small stocks; multiple stages of intrusion and mineralization</td>
<td>Stockwork in felsic porphyry and surrounding country rock; multiple stages of mineralization are common</td>
</tr>
<tr>
<td>Geochemical signature</td>
<td>Mo, Sn, W and Nb anomalies near ore zones; Pb, Zn, F, and U anomalies in periphery up to 2 km</td>
<td>Mo, Cu, W, and F anomalies near ore zones; Pb, Zn, Au and Ag anomalies in periphery up to several km</td>
</tr>
<tr>
<td>Average ore grade</td>
<td>0.3-0.45% MoS₂</td>
<td>0.1-0.2% MoS₂</td>
</tr>
<tr>
<td>Cu:Mo ratio</td>
<td>1:100 to 1:50</td>
<td>1:30 to 1:1</td>
</tr>
</tbody>
</table>

### Diagram

Diagram showing the ideal erosional level for rift-type Mo porphyries from an exploration perspective.

The "inverted teacup" mineralization lies just above the cupola of a porphyry or porphyritic aplite.
Historical exploration for porphyry deposits was mainly restricted to relatively young belts because of their shallow level of erosion. Nevertheless, examples of porphyry-style mineralization are known in rocks of all ages, including Archean. Among the characteristics shared by all porphyry deposit types, the abundance of pyrite and the presence of propylitic alteration beyond economic zones are interesting features from an exploration point of view. Specifically in terms of porphyry Mo deposits, the following are important additional exploration criteria for either type:

- Yellow ferrimolybdite — the product of molybdenite oxidation — may be present at the surface;
- Ag-Pb-Zn veins are sometimes present around the deposits; and
- In regions covered by glacial deposits, like most of Quebec, basal till can be sampled and analyzed for its Mo content; lake bottom sediment geochemistry can also be considered (Trudel, 1980, p. 14).

The metallogenic parameters and exploration criteria specific to each type of porphyry molybdenum deposit will now be presented.

Rift-type porphyry Mo deposits

Rift-type porphyry Mo deposits constitute a relatively well-understood deposit type in terms of their characteristics and genetic model. Deposits of this type are clearly associated with highly differentiated intrusions (more than 75% SiO₂), are rich in fluorine, and were emplaced within an extensional intraplate context. The molybdenum in the intrusion was concentrated by magmatic processes (differentiation, etc.), and transported by magmatic-hydrothermal fluids (eventually diluted by meteoric water) towards the summit of the intrusive cupola and into the country rock. The nature of the country rock around the intrusion seems to have little significance (granites at Henderson, andesites at Questa, etc.).

Climax-type deposits are a sub-type of rift-type porphyry Mo deposits in the classification of Carten et al. (1993). The typical ore body for these deposits is a convex-shaped stockwork of quartz-molybdenite veinlets (MoS₂) at the summit of a porphyritic or aplitic cupola. Unidirectional solidification textures, sometimes forming a rock called “brain rock,” are found at the summit of the intrusive cupola. At the Henderson mine, Carten et al. (1988) demonstrated the lateral and vertical superposition of more than ten mineralized bodies, each associated with an intrusive cupola. It is this superposition that creates such rich and large orebodies (800 Mt @ 0.28% MoS₂; Carten et al., 1988). At Climax, several mineralized bodies are vertically superposed to collectively form a convex shape (White et al., 1981).
In deposits that do not belong to the Climax sub-type, unidirectional solidification textures may be absent, and mineralization may not have the typical convex shape. The Questa deposit (277 Mt @ ~0.25% MoS₂; Carten et al., 1993) is one such example where a well-developed structural control generated a series of horizontally elongated mineralized bodies. In longitudinal section, two large hydrothermally altered breccia zones are also evident just above the contact with the porphyry intrusions (“Southwest Zone porphyry”). These breccias are crosscut by a fairly classic quartz-molybdenite stockwork.
Longitudinal section at Questa, after Ross et al. (2002). Mineralization is indicated by the red line (cut-off grade of 0.2% MoS$_2$).

The Pine Grove deposit in Utah (125 Mt @ 0.3% MoS$_2$; Sillitoe, 1980) illustrates the relationship between felsic volcanism and rift-type porphyry Mo deposits (see also Sillitoe and Bonham, 1984). A schematic section — reconstructed to take into account the erosion of the upper part of the system — reveals a volcanic conduit that was responsible for the eruption of the Pine Grove felsic tuff. This same conduit served as a pathway during the emplacement of the rhyolite domes and the formation of the deeper porphyritic intrusions associated with the deposit.

Schematic section of the Pine Grove volcanic conduit and the associated extrusive units, modified after Keith et al. (1986). The same conduit was used during the felsic tuff eruption, as well as the emplacement of the rhyolite domes and the mineralizing porphyritic intrusions. All rocks are part of the same magmatic series according to Keith et al. (1986).

To summarize, the favourable geological, geochemical, and geophysical parameters include the following:

- Thick continental crust (not always necessary);
• Fluorine-rich, highly evolved porphyritic or aplitic intrusions (>75% SiO$_2$, Rb/Sr >>1) emplaced in an extensional context;

• In a general manner, intraplate felsic volcanic manifestations like calderas, rhyolite domes;

• Stream sediment anomalies in Mo, Sn, W (F, Cu, Pb, Zn);

• Silicification and potassic alteration. In U.S. deposits, these are the types of alteration closest to mineralization, and such alteration should survive metamorphism;

• Mo, Sn, W, Rb, Mn and F may be anomalous in rocks near the mineralized zones; Pb, Zn, F and U anomalies sometimes occur in rocks up to several kilometres from the deposits;

• Fluorine-rich minerals; and

• Possible magnetic lows due to the absence of magnetite in intrusions associated with the mineralized bodies (partly drawn from http://www.em.gov.bc.ca/mining/Geolsurv/metallicminerals/MineralDepositProfiles/PROFILES/L08.htm).

Arc-type porphyry Mo deposits

Arc-type porphyry molybdenum deposits have a lot in common with porphyry copper (Cu-Mo) deposits. They are found in magmatic arc environments and are associated with calc-alkaline intrusions like diorites and quartz monzonites. Therefore, they represent less-evolved magmas than those of rift-type porphyry Mo deposits. Alteration resembles that of the porphyry copper deposits (potassic core, then phyllitic and propylitic alteration near the margins). Typical grades are 0.1–0.2% MoS$_2$ and tonnages can reach several hundred million metric tons. British Columbia has many examples, such as Endako (336 Mt), Glacier Gulch (125 Mt), Kitsault (108 Mt), and Adanac (94 Mt). The largest arc-type porphyry Mo deposit is Quartz Hill in Alaska (793 Mt).

When exploring for arc-type porphyry Mo deposits, the target geological context is different than that of rift-type deposits. Favourable indicators include the following:

• Arc magmatism, with porphyritic calc-alkaline intrusions;

• Stream sediment Mo, W, F, Cu, Pb, Zn and Ag anomalies;

• Potassic and phyllic alteration (which may be possible to locate using radiometric surveys);

• Pyrite concentrations just beyond the Mo zones, detectable by induced polarization and resistivity surveys; and
• Possible anomalies in Mo, Cu, W and F in rocks near the mineralized zones; Pb-Zn-Ag anomalies are sometimes found kilometres away from the intrusions (http://www.em.gov.bc.ca/mining/Geolsurv/metalllicminerals/MineralDepositProfiles/PROFILES/L05.htm).

Other deposit types

Other than porphyry Cu-Mo and Mo — the two main sources of molybdenum — some tungsten porphyries also contain molybdenum, such as Mount Pleasant in New Brunswick or Logtung in the Yukon. Although these non-porphyritic deposits account for only a negligible fraction of global molybdenum production, they are included here for completeness. They include the following:

• Mo skarns [in carbonate sequences at the contact with intrusions; tonnages of up to 2 Mt; see http://www.empr.gov.bc.ca/Mining/Geolsurv/MetallicMinerals/MineralDepositProfiles/PROFILES/K07.htm]. In Quebec, certain showings in the Mont-Laurier belt may belong to this type;

• Ni-Zn-Mo-PGE deposits in shale [thin horizons of black shale enriched with pyrite, vaesite (NiS$_2$), jordisite (amorphous MoS$_2$), and sphalerite, in post-Archean orogenic belts]. These deposits are currently uneconomical; see http://www.empr.gov.bc.ca/Mining/Geolsurv/MetallicMinerals/MineralDepositProfiles/Profiles/E16.htm for more details and a list of references for Chinese deposits;

• Pegmatites and aplite dykes [small deposits with irregular grades; the type example is from the Abitibi Subprovince where they also contain bismuth; see “Quebec’s Potential”]; and

• Quartz-molybdenite veins [may be associated with porphyry-type deposits, like at Questa].

QUEBEC’S POTENTIAL

From World War II to 1965, Quebec was the biggest Canadian producer of molybdenum thanks to mines in three pegmatite-type deposits in the Abitibi region, and to the Mines Gaspé operations that started up in 1963 (Trudel, 1980). British Columbia has since taken the lead with its porphyry copper and arc-type porphyry Mo deposits like Endako.

Quebec’s Ministère des Ressources naturelles et de la Faune (MRNF) has compiled 122 mineralized showings, deposits and closed mines for which molybdenum is or was a main substance, and 103 for which Mo is or was a secondary substance. Their locations are shown on the map on the next page, and an emphasis is placed on porphyry-type mineralization since this deposit type currently produces almost all of the world’s molybdenum and the deposits are large tonnage. It should be noted that several of the MRNF’s deposit files list the typology as “undetermined,” and thus it is possible that some represent porphyry-type mineralization. The Appalachian and Superior provinces have the best potential for porphyry deposits in Quebec.
Simplified geological map of Quebec (modified from DV 2002-06) showing the locations of known Mo deposits and showings (tonnages and grades from MRNF deposit files). The Mo grades have been converted into MoS$_2$ by dividing by 0.599.
Appalachians

In the Appalachians, the areas that stand out for their Cu-Mo or Mo porphyry-type mineralization are the Gaspésie and Estrie-Beauce regions. The main mining operation in Gaspésie was the Gaspé Copper mine near Murdochville, where a number of Cu-Mo skarns and porphyries (Allcock, 1982; Wares and Berger, 1995) were mined for several decades by Mines Gaspé. At Gaspé Copper, the Mo grade increased with depth (Hollister et al., 1974), and some Mo bodies still remain unexploited, like Mont Porphyre, for example. These deposits are associated with Devonian granitoids that do not crop out, or only very little, but they do produce a positive magnetic anomaly on maps of the total magnetic field. Wares and William-Jones (1993a) have demonstrated that the main intrusion at depth is a porphyritic biotite granodiorite that is syn-tectonic with respect to Acadian deformation.

Map of molybdenum contents in stream sediments from the Gaspé region (interpolation, 200-m cells, search radius of 4 km). The 99th percentile corresponds to Mo grades of 6 ppm, whereas the 95th percentile is between 2 and 3 ppm. Note the isolated anomalies in the centre of the Gaspé region, the train of anomalies stretching to the SE starting from the Mines Gaspé mineralized system (an intrusion of Devonian age), the anomalies in the southern part of the Lemieux Dome sector, and anomalies along the Grand Pabos Fault. The white area to the southwest of the dome represents a gap in the geochemical coverage (lack of analyzed samples), not a positive anomaly.
Devonian intrusions are also present elsewhere in Gaspésie; for example, the Lemieux dome area (Pilote, 2005) and the McGerrigle Mountains. The Lemieux Dome consists of a circular structure — possibly an ancient caldera — containing sedimentary rocks that are older than the surrounding volcanics. This configuration led many to believe it represents a non-outcropping Devonian intrusion that forced rock layers upward (Bellehumeur and Valiquette, 1993). Molybdenum anomalies were detected in stream sediments south of the dome.

The 1.5- to 3-km wide metamorphic aureole surrounding the McGerrigle Massif was originally formed at a depth of about 6 km (de Römer, 1977). The Madeleine mine, located within this aureole, exploited molybdenum-free copper mineralization from 1969 to 1982 (Wares and William-Jones, 1993b). Also notable is the strong Mo anomaly in stream sediments directly above the granitic massif and also to the south.

In addition, Exploratech Ltd (1979) considered the Grand Pabos Fault in the southern Gaspé region as a potentially interesting area for Mo due to the presence of rhyolitic dykes and “small masses.” Trudel (1980) also noted porphyritic intrusions in the sector. Furthermore, several occurrences of Ag-Pb-Zn vein-type mineralization were discovered along this fault, like the Reboul deposit (Savard, 1985; not shown on the map). These types of veins may be the distal expression of porphyry Mo deposits.

Several Devonian granitoids also crop out much farther south in the Lac Mégantic area (Cheve, 1990). Many of these intrusions are considered mesozonal, with crystallization depths of about 8 km and surrounding contact metamorphic aureoles up to 4 km wide (Gauthier et al., 1989). Nevertheless, Mo mineralization has been noted in two areas bordering the Sainte-Cécile/Saint-Sébastien intrusion: the Copper Stream-Frontenac deposit to the north (the “Gayhurst” property of Globex Mining), and the Sainte-Cécile showings to the south (property belonging to Ressources Appalaches).

At the Copper Stream-Frontenac deposit, two large mineralized zones — North (300 x 140 x 180 m) and South (300 x 110 x 200 m) — graded more than 0.2% MoS$_2$ and were briefly mined during World War II. Probable reserves (pre-43-101) were on the order of 0.6 Mt @ 0.54% Mo (deposit file: Cogite 21E/15-1000). Other occurrences in the same sector, including the Sainte-Cécile showings, collectively form a NE-trending “molybdenum trend” more than 20 km long and centred on the Sainte-Cécile/Saint-Sébastien intrusion. A parallel “tungsten trend,” which includes the St-Robert deposit, exists about 15 km farther east (Gauthier et al., 1989).

The New Sainte-Cécile showing (“Nouvel Indice Sainte-Cécile”; Maheu property) is characterized by locally quartz porphyritic felsic dykes (aplates and granites) and quartz veins (deposit file: Cogite 21E/10-0015). Mineralization is preferentially concentrated in these dykes and veins, but may also be present in the hornfels (deposit file: Cogite 21E/10-0014). At the Old Sainte-Cécile showing (“Vieil Indice Sainte-Cécile”), probable reserves (pre-43-101) of 2 Mt @ 0.52% MoS$_2$ were defined. Kelly (1975) presented the results of a public geochemistry program in the surficial deposits (mainly stream sediments) of the region. According to Trudel (1980), this program revealed Mo anomalies along the eastern contact of the Sainte-Cécile/Saint-Sébastien intrusion.
At the St-Robert Metals deposit, Zn-Pb-W-Cu±Mo±Au mineralization is hosted by quartz-calcite-sericite veins and porphyritic dykes, all of which are enclosed in biotite hornfels. The hornfels can be located by its magnetic signature, and may reflect the presence of an intrusion at depth.

On a somewhat more speculative note, molybdenum occurrences may be associated with Ordovician or Silurian intrusions in the Estrie-Beauce region. In fact, the Standard Asbestos showing (no SIGÉOM deposit file; not shown on map) is a quartz-molybdenite stockwork “crosscutting the granitoids that form part of a Chain Lakes-type tectonic wedge of gneiss in the Saint-Daniel mélange” (translated from Gauthier et al., 1989). The stockwork fills a fault and is at most 30 cm wide. The interest in this showing resides in the fact that it bears a certain resemblance to the Catheart Mountain and Sally Mountain Cu-Mo porphyry deposits in northwest Maine. At Catheart Mountain, mineralization is associated with an early Silurian porphyritic granodiorite that cuts the Ordovician Attean granodiorite within the Chain Lakes Massif (Hollister et al., 1974; Schmidt and Ayuso, 1993).

Superior Province

Abitibi: porphyry-type mineralization

In the Abitibi Subprovince, several areas show potential for porphyry-type deposits, notably the regions of Chibougamau, Val d’Or, and Rouyn-Noranda (Don Rouyn mine). Labbé et al. (2006) presented mineral potential maps for this deposit type in the Abitibi.

The Chibougamau region appears to be the most promising according to several authors (ex., Morin et al., 1999). Many of the deposits and showings display features reminiscent of porphyritic mineralization. For example,

- The Queylus prospect on the south flank of the Chibougamau anticline (widespread alteration, hydrothermal breccias, stockwork, and disseminated mineralization; Pilote et al., 1996; Pilote and Guha, 1998; Furic, 2006);

- The Devlin deposit in the Chibougamau Pluton (extensive alteration and veins partially hosted by breccia zones; Pilote et al., 1996); and

- The Clark deposit on the north flank of the Lac Doré Complex (porphyritic and aphanitic dykes, quartz-molybdenite veinlets in the core of mineralized zones, and several types of breccia; Pilote et al., 1998).
Potential for Cu-Au-Mo porphyritic-type deposits in the Abitibi according to a fuzzy logic model (see Labbé et al., 2006; image modified from http://www.quebecexploration.qc.ca/pdf/session1_10h30_labbejean-yves.pdf). The known occurrences on this map do not necessarily contain Mo as the main substance.

In his review of Mo mineralization in Quebec, Trudel (1980) also mentioned the Grandroy mine, the Radar Dome, and the Rio Tinto zone, and he cited several factors that demonstrate a similarity between the Chibougamau sector and younger porphyry deposits: the presence of acid intrusive complexes characterized by several intrusive phases, an epizonal character marked by intrusive breccias, mineralization associated with quartzo-feldspathic porphyritic intrusions, intense hydrothermal alteration, and the emplacement of mineralization within a fracture network (stockwork-type).

Explorategth Ltd (1979) considered the area around the Lavoie-Simard showing near Senneterre to be a first-priority target. Quartz veins containing molybdenite, chalcopyrite, and sphalerite were found in a “band of altered tuff” that may represent a “sheared and altered porphyry dyke” according to Trudel (1980). The mineralization is near a granitic batholith.

And finally, Jébrak and Doucet (2002) described the Au-Mo porphyritic mineralization known as the Messaguay showing, which is linked to the Launay Pluton. The alteration is sodic, potassic, and magnetite-bearing. The property has belonged to Osisko Exploration since 2005.
Abitibi: other types

Mo-Bi pegmatites and quartz veins, along with beryl, colombo-tantalite or spodumene pegmatites, are associated with the Preissac-La Corne Batholith in the southern part of the Abitibi (Ste-Croix and Doucet, 2001). Of note are two small Mo-Bi deposits that were mined in the Preissac Pluton during the 1960s (Boily, 1995):

- the Cadillac Molybdenite mine, with a production of 2 Mt @ 0.36% MoS$_2$ and reserves (pre-43-101) of 0.51 Mt @ 0.19% MoS$_2$ and 0.03 % Bi; and

- the Preissac Molybdenite mine, with pre-production reserves of 1.25 Mt @ 0.53% MoS$_2$.

The Moly Hill deposit in the pluton of the same name has reserves (pre-43-101) of 0.27 (?) Mt @ 0.21% MoS$_2$ and 0.08% Bi (Boily, 1995), but was never exploited (Trudel, 1980). In addition, Molybdenite Corporation’s Morono mine in the La Corne Pluton extracted Mo and Bi from quartz and potassic quartz-muscovite-feldspar veins (pre-43-101 reserves of 0.2 Mt @ 0.07% Mo and 0.019% Bi; Trudel, 1980).

According to Ste-Croix and Doucet (2001), molybdenum pegmatites associated with the Preissac-La Corne Batholith are restricted to hydrothermal veins along the internal boundary of the muscovite-garnet facies (especially in the case of the Preissac and Moly Hill plutons). The molybdenite is mainly concentrated in albitite dykes and quartz veins associated with spodumene pegmatites in the country rock. Golden Valley mines acquired several properties in the area in 2005.

Although these deposits accounted for part of Quebec’s historical molybdenum production, Mo pegmatites do not present much exploration interest compared to porphyritic deposits due to the small size of their deposits and their highly variable grades.

Elsewhere in the Superior Province

A potential for porphyry mineralization also exists in the rest of the Superior Province. This potential is particularly well illustrated by the Troilus mine located 175 km north of Chibougamau (Inmet Mining Corp.). Troilus is a copper-gold porphyry deposit (without Mo) that produced about 56 Mt @ 0.1% Cu and 1.1 g/t Au since 1995 (Goodman et al., 2005; MRNF poster at the 2007 PDAC convention).

A number of Mo-bearing porphyry-type showings and deposits have been documented along the Eastmain River. Western Troy’s McLeod deposit contains 23.7 Mt @ 0.52% Cu, 0.08% Mo, 0.5 g/t Au and 4.0 g/t Ag in indicated resources (43-101 compliant), and 3.8 Mt of inferred resources for the main zone. This deposit is of Proterozoic age, around 2.0 Ga (GM 62037).

Another interesting area in the James Bay region is that of Tilly Lake (Sirios). It consists of a polymetallic porphyritic system (Mo-Cu; locally with Cu-Au-Ag-Bi-Te) most likely of
Archean age. It is characterized by a grouping of wide hydraulic hydrothermal breccias and zones of conjugate veins (N100°–040°–140°) in a tonalite with quartz-biotite phenocrysts (GM 58969).

The James Bay region and the Far North thus represent the new frontier for molybdenum exploration in Quebec.

REFERENCES


