New Models for Mineral Exploration in British Columbia: Is There a Continuum between Porphyry Molybdenum Deposits and Intrusion-Hosted Gold Deposits?

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Introduction

There has been little research into, or exploration for, Mo deposits in Canada or elsewhere since the early 1980s, but that is likely to change, particularly if the price of Mo stays at or anything near current levels. There are numerous poorly understood, relatively underexplored Mo deposits and occurrences in the Canadian Cordillera that are likely to be explored over the next several years, and it would be of great benefit to the exploration community if more was known about Mo deposits of high- (climax-type) and low- (quartz-monzonite–type) fluorine type in the province.

In addition, there are geochemical similarities between porphyry Mo deposits and 'intrusion-hosted' Au deposits (e.g., Tombstone Belt; Figure 1), suggesting a possible genetic link. The Adanac Mo deposit belongs to an important class of mineral occurrences within the Atlin gold camp. The Adanac deposit contains no Au itself, but placer gold is still being mined on the lower reaches of Ruby Creek below the deposit. Historically, it has always been assumed that the Mo deposit postdates Au mineralization, which occurs in quartz-carbonate shears in Cache Creek Group volcanic strata and as placer gold. Isotope work by Mihalynuk et al. (1992), however, suggests that some of the placer gold in the Atlin area may have been derived from the Surprise Lake batholith. This is consistent with the presence of Au- and W-bearing quartz veins in drainage areas immediately south of the Adanac Mo deposit, because, in general, wolframite is commonly associated with porphyry Mo deposits, peripheral to the molybdenite zone (Wallace et al., 1968). Thus, the presence of Au in those wolframite veins raises the question of a potential linkage between Au-depleted Mo and Au-bearing W 'intrusion-related' deposits. Understanding the association, or lack thereof, is an important step toward focusing further exploration in the province for both of these deposit types.

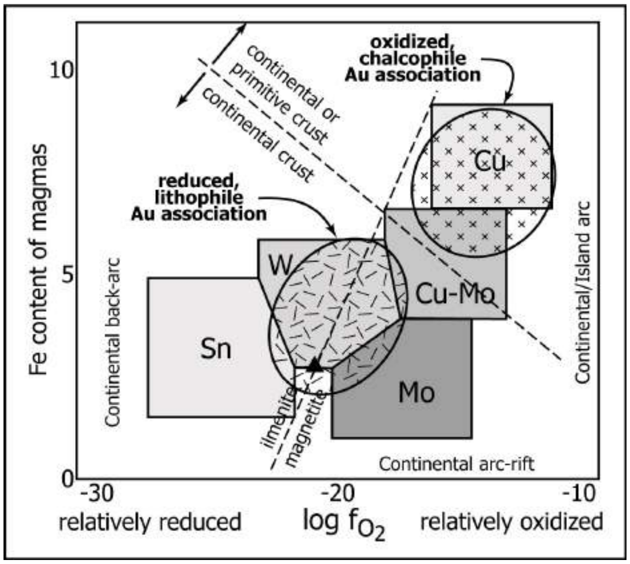

Figure 1. Plot of Fe content vs. oxidation state for plutons and associated 'porphyry' mineral deposits (fields *from* Thompson et al., 1999); note that Au is found in both oxidized (porphyry Cu) and reduced (porphyry Sn-W-Mo) environments; Surprise Lake batholith plots approximately at the solid triangle.

Geological Background

The Adanac Mo deposit is located in the northwestern corner of British Columbia, near the town of Atlin (Figure 2). The geology of the Atlin area was mapped by Aitken (1959), and the regional setting of the deposit was discussed by Christopher and Pinsent (1982). The Atlin area (Figure 3) is underlain by deformed and weakly metamorphosed ophiolitic rocks of the Pennsylvanian and/or Permian Cache Creek Group (Monger, 1975). These rocks, which include serpentinite and basalt, as well as limestone, chert and shale, have long been thought to be the source of much of the placer gold found in the Atlin area. The sedimentary and volcanic rocks are cut by two younger batholiths: a Jurassic granodiorite to diorite intrusion

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Keywords: *porphyry, molybdenum, isotope geochemistry, whole-rock geochemistry, Atlin*

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(Fourth of July batholith) north of Pine Creek and a Cretaceous granite to quartz monzonite intrusion (Surprise Lake batholith) north and south of Surprise Lake. The rocks are locally strongly faulted and the Adanac deposit is located near the intersection of two major syn- to post-mineralization fault systems.

The deposit area was described by Sutherland Brown (1970), White et al. (1976), Christopher and Pinsent (1982) and Pinsent and Christopher (1995). The Adanac Mo deposit underlies the valley floor near the head of Ruby Creek. It is largely buried and has very little surface expression. There is little outcrop in the lower part of the valley and molybdenite is only rarely found in float and/or veins in outcrop in the bed of the creek. The geology underlying the valley floor is largely derived from drill data (Figure 4). Although the geology of the Adanac deposit is moderately well understood, it has had almost no detailed research. It was reported to resemble a quartz-monzonite–type low-fluorine stockwork deposit (Westra and Keith, 1981) with a single flat-lying to steeply dipping shell of mineralization over a main porphyry intrusion, as described by White et al. (1976) and Pinsent and Christopher (1995).

The deposit is near the western margin of the Surprise Lake batholith, a composite, highly evolved, U-rich granite. The deposit occurs in the Mount Leonard stock, a satellite body of the batholith. The deposit is entirely within plutonic rock. There are three stages of intrusion: an early, generally coarse-grained stage that was deformed prior to the intrusion of second-stage 'porphyry domes', and a late, fine-grained phase that was injected into the first two phases at about the same time as mineralization. The deposit itself is a disrupted, blanket-shaped deposit that formed late in the development of the plutonic suite. The deposit is partially controlled and offset by the Adera fault system, which trends approximately northeast and defines much of the southern boundary of the pre-ore Fourth of July batholith. The approximately north-trending Boulder Creek fault system appears to have localized emplacement of the late, third-stage porphyritic and aplitic plutonic rocks.

Figure 5 shows most of the main rock types in the deposit. They are listed, with hand-sample photographs, in order from oldest to youngest. Coarse-grained quartz monzonite (CGQM) is the main unit in the deposit. Most other rock types cut this unit or are a textural variation of it. Mafic quartz-monzonite porphyry (MQMP) is an intrusion that postdates CGQM and occurs to the east and south of the deposit. The contact between the two units is a roughly north-trending fault. Coarse-grained quartz monzonite is interpreted to grade into transitional and hybrid varieties (CGQM-T and CGQM-H), which both represent increasing matrix content. These units occur as dikes, and also as mappable phases on the southwestern end of the deposit and in the north section of the deposit. The north section of the deposit is the 'cap' of the system that has been dropped down and separated from the rest of the deposit by the Adera fault, a northeast-trending normal fault. This area also contains crowded and sparse quartz-feldspar porphyry (CQFP and SQFP), which represent the temporal end-members of the CGQM evolution. The series CGQM, CGQM-T, CGQM-H, CQFP and SQFP coarsens inward, with SQFP being at the top of the stock and having the greatest matrix content, and CGQM being at the deepest parts and having a coarse-grained texture. Intruding the CGQM is the crowded and sparse quartz-monzonite porphyry (CQMP and SQMP) on the east end of the deposit, in the central pit area. This intrusion disappears to the southwest; whether this is the result of a fault or simply a steep contact is not known. On the southwest end, there is a younger intrusion of medium-grained equigranular quartz monzonite (MEQM). Also occurring at this end of the de-

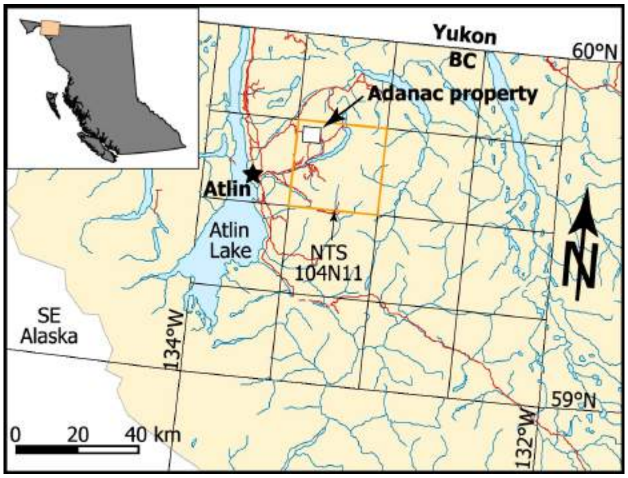


Figure 2. Location of the Adanac Mo deposit; white box is the approximate location of Figure 3.

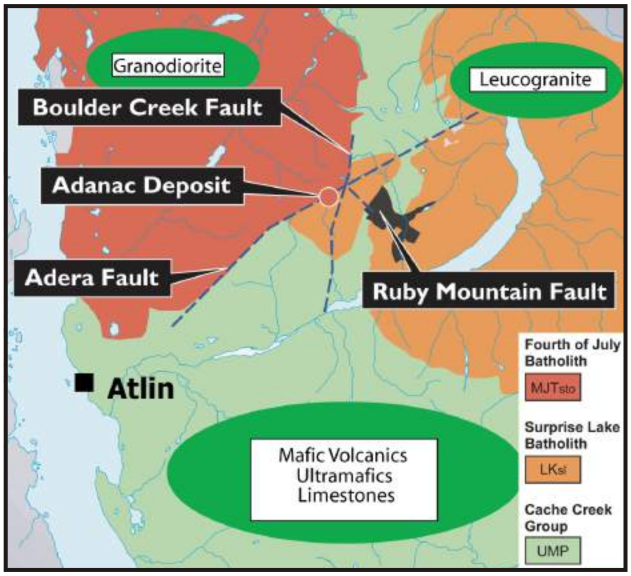


Figure 3. General geology of the Adanac deposit area (*modified from* Aitken, 1959).

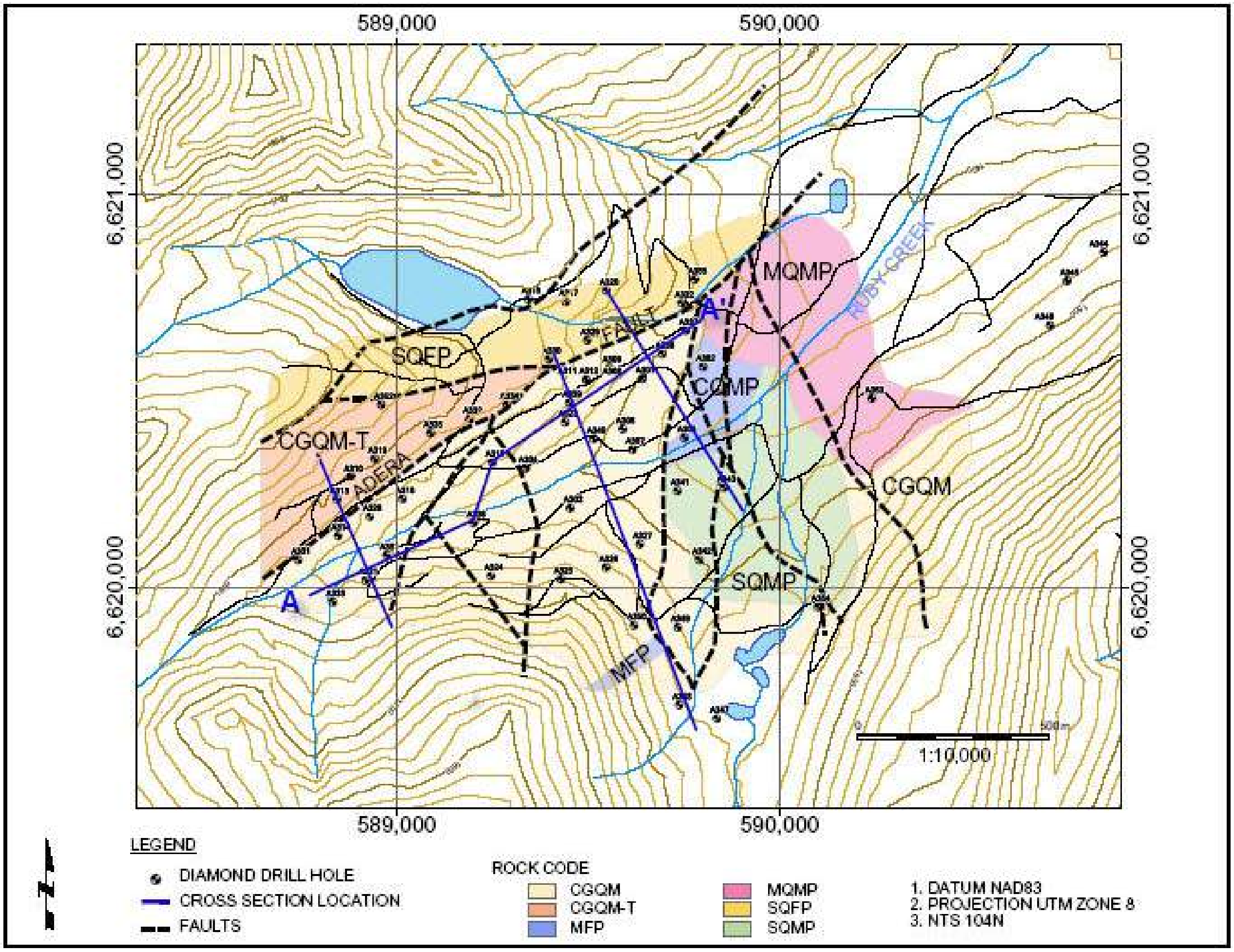


Figure 4. Surface geology of the Adanac Mo deposit (*modified from* unpublished company reports), showing a cross section of diamond-drill holes from which samples were collected for geochemical analysis.

posit in the form of a dike is megacrystic feldspar porphyry (MFP). Throughout the deposit, there are numerous fine-grained dikes (FGQM) that cut all other rock types.

Molybdenite mineralization postdates all rock types and appears in drillcore to postdate hydrothermal alteration. Mineralization is in the form of quartz-vein stockwork. Based on visual estimates in drillcore and confirmed by a downhole geophysical study done by Aurora Geophysical Consultants in Whitehorse, Yukon, most veins are subhorizontal, and there is a second set of veins that is subvertical and trending east. There appears to be multiple mineralization events. A broad generalization can be made that ductile (sheared, interpreted as forming at high temperatures within hostrock), smoky quartz veins are early, and that subhorizontal, lower grade, white quartz veins with brittle, sharp contacts with the hostrock are relatively late. There are also some rare veins that contain other minerals such as pyrite, galena, huebnerite and chalcopyrite. Without precise dates for each event, it is difficult to determine how many mineralization events occurred and whether or not there was a significant, if any, time lapse between them.

Alteration is not pervasive or incredibly strong in the deposit, at least relative to climax-type molybdenite deposits. Early primary hydrothermal alteration exists in the form of silicified zones and K-feldspar envelopes around veins, K-feldspar floods and secondary biotite, which is characterized by large (3–5 cm) biotite crystals. Early primary alteration is more pronounced at the southwest end of the deposit. Late primary alteration in the deposit is mainly seen as clay alteration and late 1 mm veins or fractures containing small amounts of pyrite and commonly coated with calcite and/or stilbite. Most clay alteration appears to be green to black chlorite, judging from hand sample, and is prominent in faults. There is also sometimes an apple-green sericite alteration that occurs as rims on feldspars or pervasively alters feldspars. This usually occurs for a few tens of feet above and below faults, and reflects fault focusing of fluids. A pyrite-rich halo does not occur in the area of the proposed central pit, but it can be seen in higher elevations that surround the deposit, still within the CGQM-T, or the cap of the system. Conveniently for mining, glaciation has removed this halo from directly above the deposit and the proposed pit area.

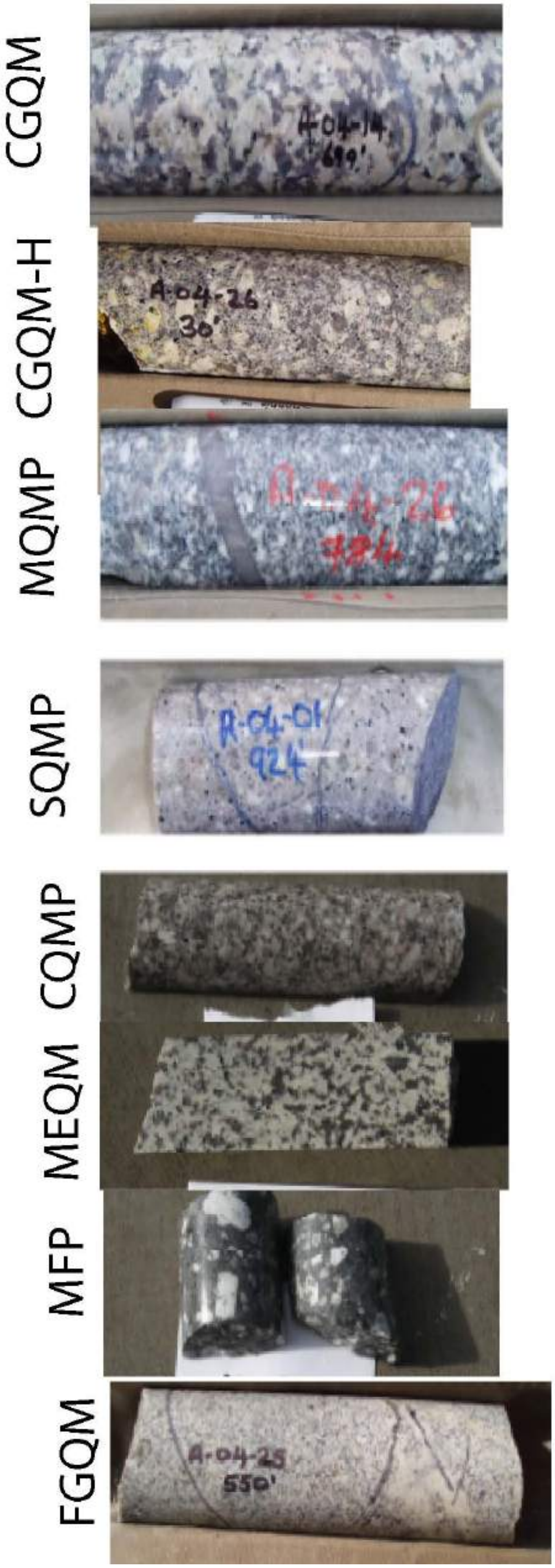


Figure 5. Photographs of rock types from drillcore, in order from oldest (at the top) to youngest (at the bottom).

Research Objectives

The goal of this research is twofold. The first goal is to determine the place of the Adanac deposit within the spectrum of molybdenite deposits (i.e., a climax type or quartz-monzonite type, or a transitional type between these two end members) based on new drillhole and geochemical information acquired in the last five years. Part of this goal has been obtained by studying the trace-element and whole-rock geochemistry at Adanac. Additional work to further this goal, such as an alteration study and a study of various aspects of geochronology at Adanac, is planned for the academic year of 2007–2008. The second goal of the research is to compare the Adanac Mo deposit to intrusion-hosted Au deposits in the North American Cordillera and to determine whether there are geochemical similarities between Adanac and these deposits.

Results of Work Completed in 2006–2007

Rock Descriptions

Each rock type in the deposit was described according to hand sample and thin section analyses. These analyses were done in order to complement the whole-rock geochemical data and for comparison to other molybdenite deposits. Rock types are roughly listed in order from oldest to youngest, based on crosscutting relationships. Because crosscutting relationships are absent between a few rock types, some relationships are uncertain.

Coarse-grained quartz monzonite (CGQM) is the oldest and most common rock in the Mount Leonard stock (Figure 3). It is a weakly to moderately deformed pink or grey, equigranular, coarse-grained (0.5–3.0 cm) granite to quartz monzonite. It contains roughly equal amounts of K-feldspar, plagioclase and quartz. Minor biotite is present. Two samples of fresh CGQM were selected for thin section examination. Quartz is the dominant mineral in both sections, at 45–50%, with K-feldspar and plagioclase having roughly equal amounts at about 20–25% each. Biotite comprises 3–10% of the rock. Other minerals noted (secondary) were chlorite replacing biotite, sericite and kaolinite replacing feldspars, euhedral topaz (less than 0.1 mm), euhedral pyrite replacing or overprinting chlorite, cogenetic pyrrhotite and magnetite replacing chlorite, and the presence of calcite. Total secondary minerals comprise from 1 to 5% of the rock. Minor myrmekitic textures were noted of quartz and feldspar (0.2 mm). Feldspar commonly has perthitic texture.

Transitional and hybrid coarse-grained quartz monzonite (CGQM-T and CGQM-H) are varieties of CGQM that contains increased groundmass, 25% in transitional and 50% in the hybrid type. The groundmass is 2–4 mm in size. This phase occurs at contacts where CGQM grades into FGQM. It is presumed to be a volatile-rich residual phase preparing for the release of hydrothermal fluids, as this rock type has some features that are not clearly magmatic or hydrothermal, such as graphic intergrowths and myrmekitic textures. This phase sometimes occurs as early dikes that are cut by mineralized quartz veins. The composition is the same as CGQM. Thin section examination showed that CGQM-H is 50% quartz, and 20% each of alkali feldspar and plagioclase. Also noted were calcite, biotite (fresh and altered), pyrite, magnetite, sericite and chlorite (alteration product of biotite). Pyrite and calcite are associated and occur in the groundmass as 5–6 mm crystals. Pyrite also occurs replacing chlorite along cleavage planes and replacing magnetite. Magnetite occurs in close proximity to biotite and replacing chlorite. Sericite occurs as fine crystals on feldspars. In one sample, a 1 mm fluorite grain was noted alongside calcite inside a plagioclase crystal. Calcite was noted to postdate pyrite and magnetite.

Mafic quartz-monzonite porphyry (MQMP) is a grey rock unit characterized by an increase in biotite. This unit cuts CGQM, but is cut by the two main porphyry units (listed next). The MQMP unit contains fine biotite crystals (1 mm), plagioclase crystals (phenocrysts and groundmass) that are chalky white in colour and 5–7 mm in size, and quartz phenocrysts are 6–10 mm in diameter, on average smaller than plagioclase crystals. The matrix comprises a mixture of biotite, quartz and feldspar. From thin section analysis, this rock was noted to have slightly more feldspar content than CGQM. Quartz comprises 40% of the rock, while plagioclase and alkali feldspar makes up 50%, with slightly more plagioclase than alkali feldspar. Biotite makes up the other 10% of the rock, with secondary minerals and zircon all making up less than 1%. Pyrite and magnetite are both present replacing biotite and chlorite, while chlorite exclusively replaces biotite. Pyrite is more euhedral than magnetite, and both are about 0.4 mm in size. Kaolinite and sericite were noted as fine dustings on feldspars. Anhedral calcite was noted near the pyrite- and magnetite-altered biotite. Graphic intergrowth texture was noted in one 0.5 mm sized area. Texture appears to be made up of feldspar and quartz ‘liquid like’ streaks.

Sparse and crowded quartz-monzonite porphyry (SQMP and CQMP) are younger than CGQM and MQMP. They both consist of white plagioclase, pink orthoclase, quartz and biotite phenocrysts that are 2–6 mm in size, in a light brownish to pinkish aphanitic matrix. In the sparse variety, phenocrysts make up 10–30% of the rock and in the crowded variety, about 60–80%. The SQMP may be slightly younger, as it is seen to sometimes cut the crowded version. The thin section analysis determined that quartz makes up about 45% of the rock with plagioclase and alkali feldspar at about 25% each. Biotite is about 4% in some of the samples, and opaque minerals such as pyrite, magnetite and molybdenite comprise the rest. One zircon crystal was noted, with a brownish to orange damage halo at about 0.5 mm in size. Chlorite is commonly seen to replace biotite, and feldspars have dustings of clays (which appear to be kaolinite and sericite) clustered in the centres of crystals. In two samples, it was noted that molybdenite does not occur in veins but in cleavage planes of altered biotite (to chlorite). Molybdenite crystals are large (1 mm) and euhedral. Clustering around the molybdenite and appearing to postdate it are small amounts of subhedral, 0.3 mm sized sphalerite and galena grains. Some larger, subhedral, 1 mm sized pyrite crystals were noted, and nearby in the same field of view, small magnetite crystals (0.2 mm, euhedral) with a chalcopyrite grain (0.1 mm, euhedral) were noted next to the magnetite. These sulphides were not in veins but occurred near chlorite. In one sample, galena was clearly seen to be replacing pyrite. One small area (0.3 mm) exhibited graphic intergrowth textures, as mentioned above.

Medium-grained equigranular quartz monzonite (MEQM) is a rock type that is not widespread in the deposit. It is possibly a transition between CGQM and FGQM, but may also be a separate intrusion at the southwest end of the deposit. It has a mosaic texture that is equigranular, and consists of equal amounts of quartz, plagioclase and alkali feldspar grains that are about 1–2 cm. Biotite is present as well, with crystals about half this size. In thin section, it was noted that biotite is more abundant than in CGQM or FGQM. Biotite makes up 15% of the rock. Quartz, plagioclase and alkali feldspar comprise roughly equal amounts at 25% each. Other minerals are zircon, clay dustings on feldspars, calcite, chlorite, pyrite and magnetite. Pyrite is replacing feldspar and magnetite is replacing chlorite.

Megacrystic feldspar porphyry (MFP) is noticeably different from other rock types in the deposit. It consists of a dark blue matrix, is very fine grained and contains small biotite crystals (1 mm). Phenocrysts are rounded, 6 mm smoky quartz eyes, and larger, 1–4 cm plagioclase and alkali feldspar crystals that are euhedral. It is not widespread and usually occurs as dikes or sills (cutting CGQM and MQMP) on the southwest end of the deposit. The rock sometimes exhibits mylonitic texture. In thin section, quartz is 40% of the rock, biotite is 15% and plagioclase and alkali feldspar are 20% each, roughly. The matrix is mostly extremely microcrystalline quartz and feldspar (<1/30 mm) with intergrown biotite. Feldspars are moderately to strongly altered to kaolinite and/or sericite. Feldspars sometimes exhibit poikilitic textures, with plagioclase (1 mm) inside larger alkali feldspar. The rock has an increased amount of opaque minerals, mostly pyrite and magnetite with minor chalcopyrite and pyrrhotite, comprising up to 7% of the rock. Opaque minerals occur with ‘veins’ of microcrystalline quartz that are not visible to the naked eye and may be flow textures. Magnetite replaces chlorite.

Fine-grained quartz monzonite (FGQM) is probably the youngest rock type in the deposit, as it is seen to cut all other units. This unit occurs as both dikes and sills throughout the deposit. It is also noted in drillcore to postdate hydrothermal alteration such as silicification. It is a brownish to pinkish rock type that is equigranular and appears to be a mixture of white and pink feldspar, quartz and trace biotite. The grain size ranges from less than 1 mm to about 3 mm. In thin section, FGQM is noted to contain roughly equal amounts of quartz, plagioclase and alkali feldspar, usually at about 90% of the rock. Biotite makes up 5–10%, with secondary minerals comprising the rest. The secondary minerals include chlorite replacing biotite, clays and calcite replacing feldspars, and small grains (0.2 mm) of pyrite or magnetite, euhedral to subhedral, either in the matrix or replacing biotite or chlorite. There is an elevated amount of graphic intergrowth textures (quartz and feldspar) in one thin section where FGQM is a dike cutting CGQM. Where this small dike (1–2 cm) comes into contact with CGQM, CGQM has increased clay alteration of feldspars. In one thin section, there appears to be two mixing phases of FGQM, one with very fine grains (less than 0.1 mm) and another with grain sizes of about 0.2 mm. In one sample where FGQM is completely ‘by itself’ (i.e., not in contact with other phases or quartz veins), the rock is noticeably fresh (no clay).

Whole-Rock Geochemistry

Major element geochemistry was determined for 10 samples of fresh rock, one from each major rock type in the deposit. The analyses were done at ACME Analytical Laboratories Ltd. in Vancouver, BC, using inductively coupled plasma–emission spectroscopy. The rock types include CGQM and its transitional varieties (CGQM-T and CGQM-H), the feldspar porphyries (CQFP and SQFP), which represent the cap of the system, MQMP, the two porphyry intrusions (SQMP and CQMP), MFP and MEQM. Normative mineral amounts were calculated using the CIPW (Cross et al., 1903) method. According to the International Union of Geological Sciences (IUGS) system of classification (Streckeisen, 1973), all rocks in the suite are granite. The rocks have an average of 35% normative quartz. Alkali/total feldspar ratios in each rock type were about 50. An alkali-lime index at 50 wt% SiO_2 was calculated, meaning the rocks are further classified as alkaline. It was also determined that the suite is peraluminous, and a series of Harker diagrams was also made. With increasing silica, Al_2O_3, Fe_2O_3, MgO, CaO, TiO_2, P_2O_5, MnO, Ba, Sr and Zr decrease; Rb, Na_2O and Cr_2O_3 remain constant; and K_2O increases.

Published literature on porphyry Mo deposits broadly outlines two basic types of deposits: the granite and quartz-monzonite types (Sutherland Brown, 1969; White et al., 1981; Wallace, 1995). Westra and Keith (1981) recognized that these two basic types can be separated based on the K_2O value at 57.5 SiO_2 wt%. A natural dividing line occurs between those deposits with a K_2O value of less than 2.5% and those with values above that. If the value is less than 2.5%, the Mo deposits are classified as the ‘calcalkaline’ quartz-monzonite type with low F values. These deposits typically have lower molybdenite grades, little Sn, and W is present as scheelite. Source plutons have between 100 and 350 ppm Rb, and between 100 and 800 ppm Sr (Figure 6). Those deposits with values above 2.5% are broadly referred to as the climax type of Mo deposit. These deposits are associated with alkali-calcic to alkalic granite, and are enriched in F and Sn. Rubidium content of the source plutons is typically 200–800 ppm, with less than 125 ppm Sr (Figure 6). The molybdenum grades are typically higher and W is present as wolframite. Using the Westra and Keith (1981) classification scheme of porphyry Mo deposits, the K_2O value at 57.5 wt% SiO_2 ($K_2O_{57.5}$) was calculated at >2.5% for the rocks of Adanac. All of the rocks at Adanac contain between 70 and 76% silica, so the K_2O value had to be extrapolated considerably. Figure 6 illustrates how the $K_2O_{57.5}$ value is consistent with the Rb vs. Sr data in dividing porphyry molybdenite deposits based on geochemistry. Since granite and quartz-monzonite Mo deposits have these different and predictable geochemical characteristics, they should be useful in delineating the nature of the system at Adanac. Fresh rock types at Adanac group well with other climax-type deposits based on Rb and Sr ratios, as well as on the basis of the $K_2O_{57.5}$ value.

Trace Element Zonation

A series of cross sections in the deposit were completed in order to show trace-element zonation in comparison with deposit geology. Four examples of the main (A–A’, refer to Figure 4 for cross-section location) cross sections are shown in Figures 7–10. Figure 7 shows Mo values contoured against a black-and-white background of geology. High Mo values (670–1430 ppm) occur as a blanket over the main porphyry intrusion and the blanket steeply dips off to the west, where it is above the apex of another intrusion, the MEQM. High F values (Figure 8, 1000–3300 ppm) occur geographically above and peripheral to the Mo highs. Transitional phases of CGQM (CGQM-T, CGQM-H and the feldspar porphyries) typically have higher F values, while CGQM itself has relatively lower values. In drillholes 333 and 321 (at the southwest end of the section, Figure 8), the CGQM exhibits increased matrix content (CGQM-T) and has high F values. The Adera fault is parallel and north of the cross section of Figures 7–10. This fault has dropped the cap of the system, and the SQFP and CQFP are in the hangingwall. The highest F values in the deposit occur here in the SQFP and CQFP.

The average background values of W, Pb and Zn in an alkaline granite are 16 ppm, 15 ppm and 108 ppm, respectively

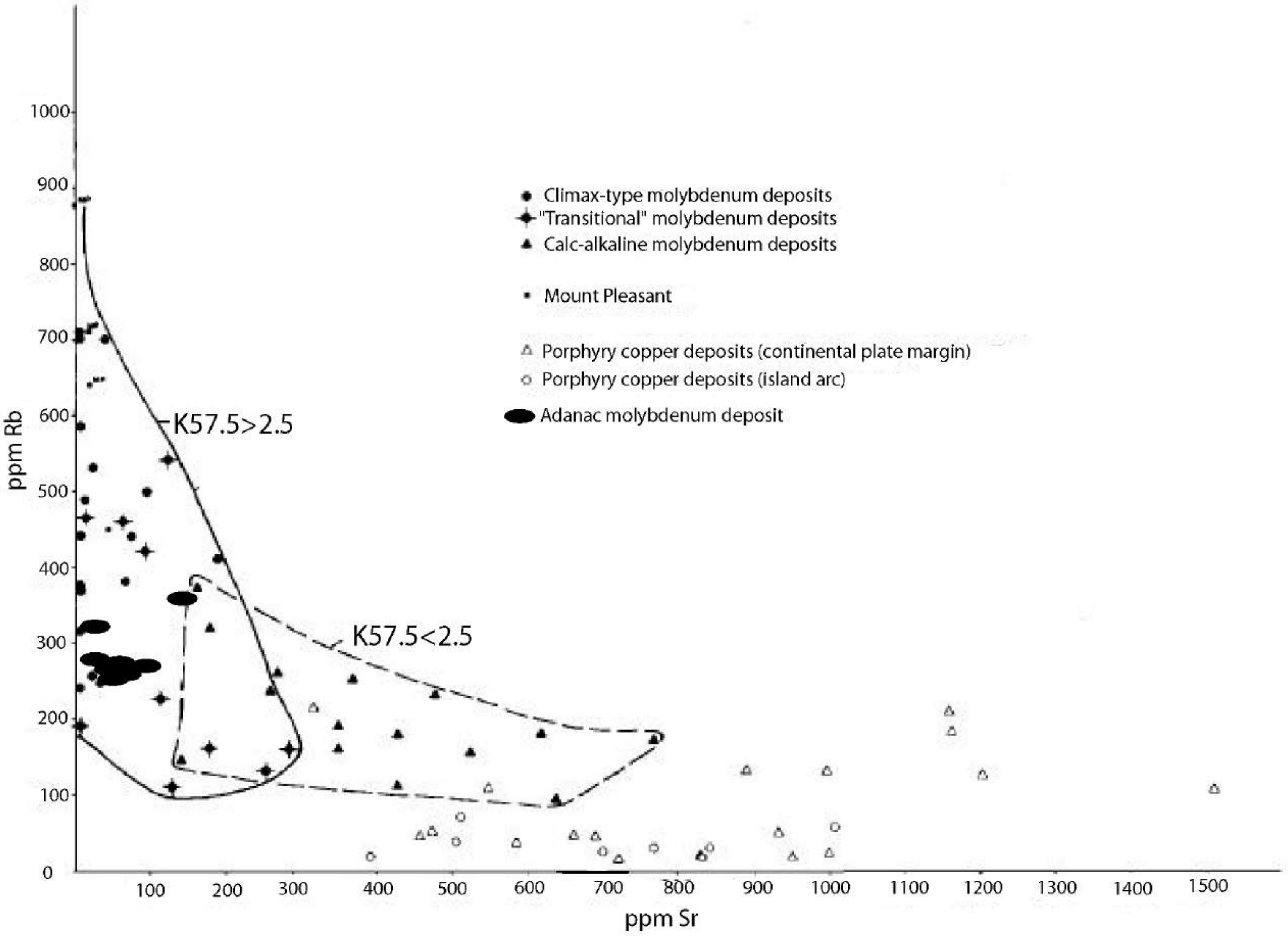
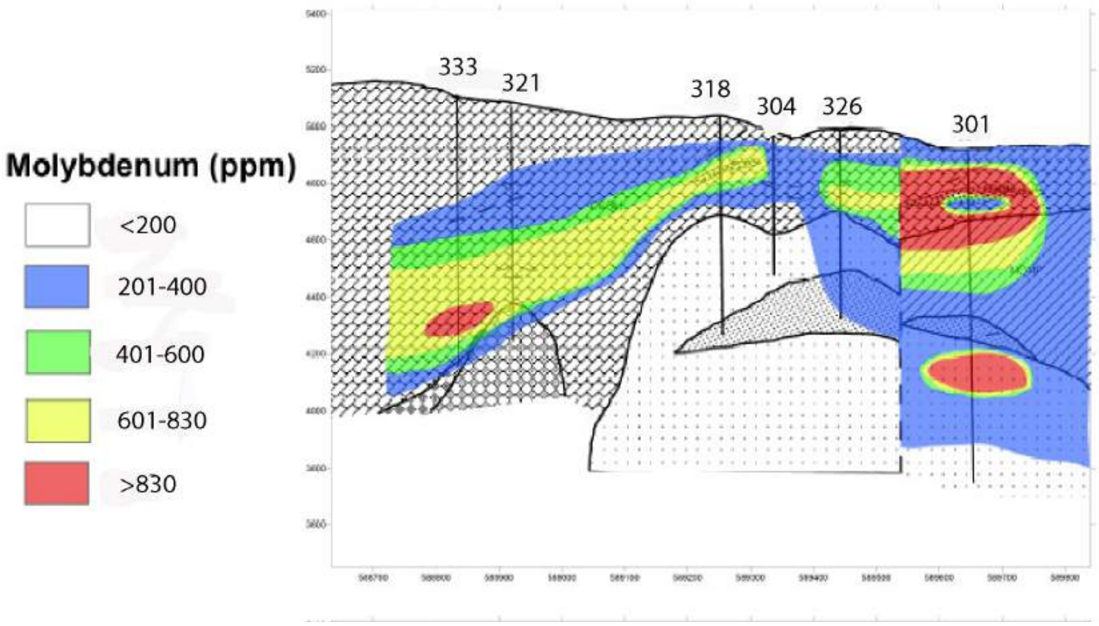


Figure 6. Graph showing Rb and Sr values for various types of porphyry deposits, including Cu porphyry and a W-Mo porphyry (Mt. Pleasant). The $K_2O_{57.5}$ value fields are superimposed on the graph. As their $K_2O_{57.5}$ value would indicate, rocks at Adanac fall within the field of climax-type deposits.



(Robb, 2005). Both W and Pb are elevated (100–200 ppm) in the central pit area (Figures 9–10). While the higher values for Zn in the central pit area (also around 100–200 ppm) are not anomalous for an alkaline granite, they are elevated relative to the pervasive low values (~10 ppm) elsewhere in the deposit. Tungsten highs occur as thin blankets coincident with the high-Mo zones. Elevated Pb and Zn occur only near faults within the molybdenite zone. Copper and Sn have values of 10 ppm or less in the central pit. Outside of the central pit area (and thus outside of the main molybdenite mineralization zone), higher values of Cu, Pb and Zn (200–1000 ppm) may be present at faults and in silicification zones. There is less than 0.1 ppm Au throughout the deposit.

A correlation matrix was calculated for a suite of 41 trace metals plus F. Molybdenum correlates with no other element in the deposit. Zinc correlates with Cu, Pb, Ag, Sn and Cd. These correlation coefficients are near 0.5 for all except Cd, which is 0.8. Copper correlates with Sn and Mn (correlation coefficient ~0.5). Lead correlates with Ag, Mn, Cd and Sb (coefficient ~0.5). Arsenic also correlates with Sb (0.7). Tungsten does not correlate with any other element. Tin correlates with Cd (0.6). Fluorine correlates with Th (0.5), Y (0.6) and Zr and Hf (0.7). The implications of these correlations are still being considered.

2007 Summer Field Season and Future Work

The 2007 summer field season was spent logging core and preparing various current deposit maps as required. Maps were prepared showing updated drillhole locations, including the 2007 drill program. Also updated were fault locations, various structures such as joints, and the current understanding of surface rock type. Another main focus of the summer was sampling and preparation for the 2007–2008 academic year goals. The goals for the coming academic year are outlined below. An accompanying schematic diagram (Figure 11) illustrates some important sample locations.

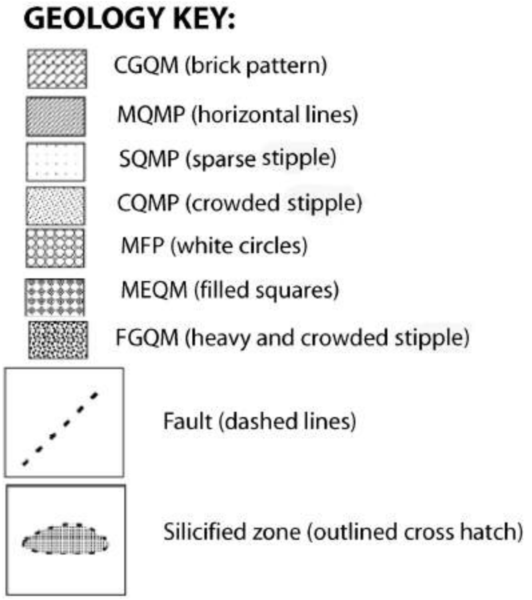


Figure 7. Cross section A-A', showing geology (rock type occurrences, faults and some silicification zones) in black and white, and Mo (in ppm) contoured against the black-and-white background.

Alteration Study

The first aspect of the alteration study is the creation of a series of cross sections of the deposit with a focus on megascopic alteration patterns. Because of the lack of surface exposure, the distribution of alteration types has been

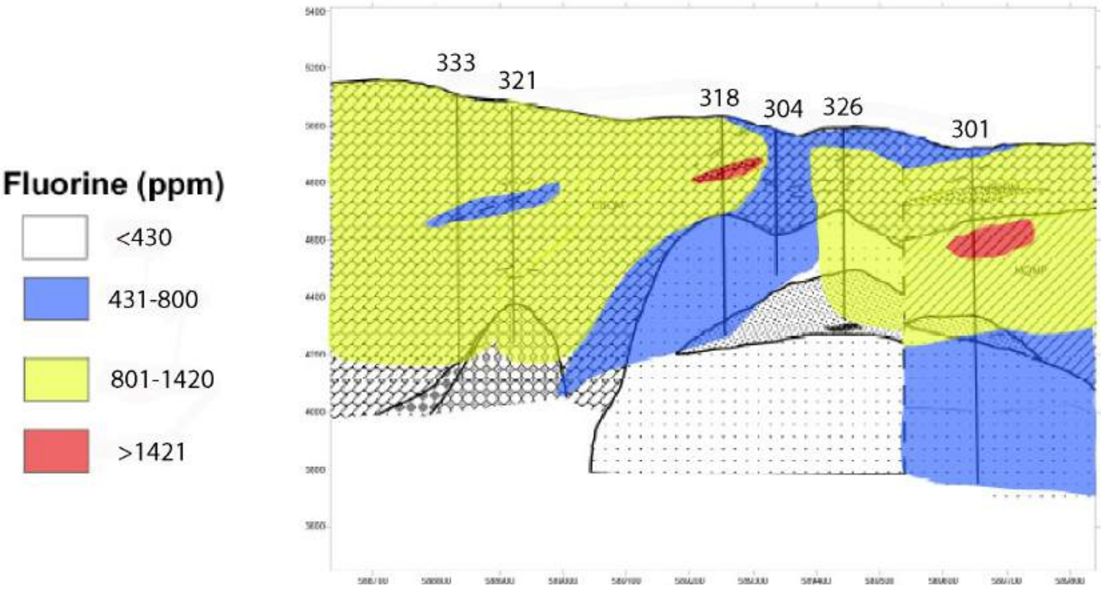


Figure 8. Cross section A-A', showing geology (rock type occurrences, faults and some silicification zones) in black and white, and F (in ppm) contoured against the black-and-white background; key as in Figure 7.

determined based primarily on drill logs. All the holes from which the cross sections were created were relogged over the summer with a focus on alteration. These data are being plotted on the same cross sections as the trace-element data and will be utilized to outline the locations of early primary hydrothermal alteration, such as silicification and K-feldspar flooding, and some late primary alteration, such as zeolite and calcite veins (propylitic).

An x-ray diffraction (XRD) study of the distribution of clay types in the deposit will be undertaken to further refine the alteration zoning. Samples of clay alteration were taken from strategic areas of the deposit to provide three-dimensional spatial coverage. Based on drillcore observations, most clay alteration occurs at faults; however, within the faults, there may be zoning patterns outward from high-grade areas and feeder zones, presumably representing variations in fluid chemistry and temperature. In addition, because different faults display different characteristics, such as dark green gouge, or recemented white sheared faults, some paragenetic information may also be gleaned from these clay studies. These data will be utilized to compare patterns between Adanac and other molybdenite deposits worldwide.

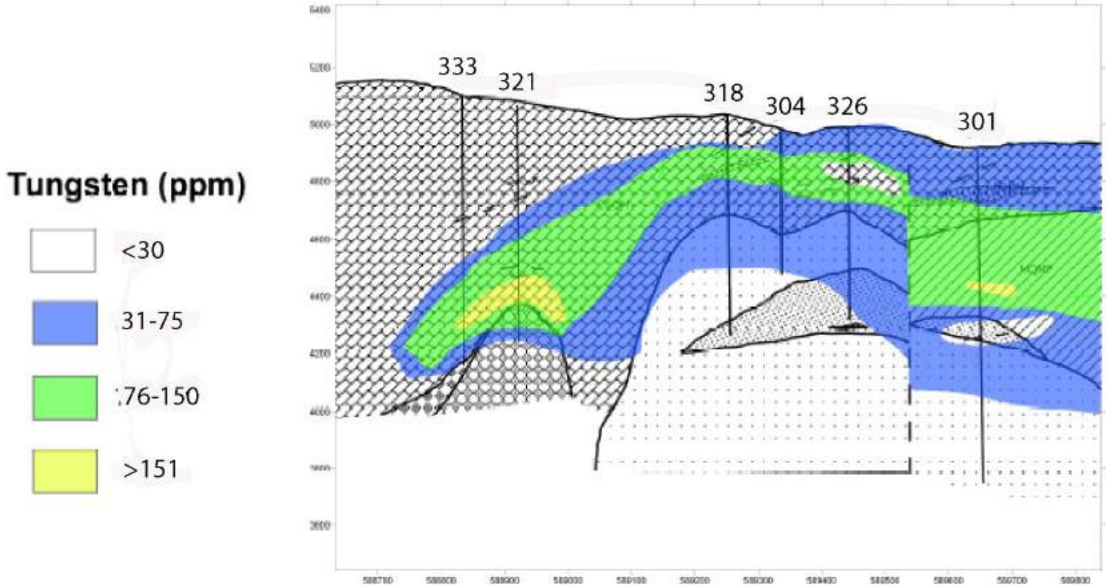


Figure 9. Cross section A-A', showing geology (rock type occurrences, faults and some silicification zones) in black and white, and W (in ppm) contoured against the black-and-white background; key as in Figure 7.

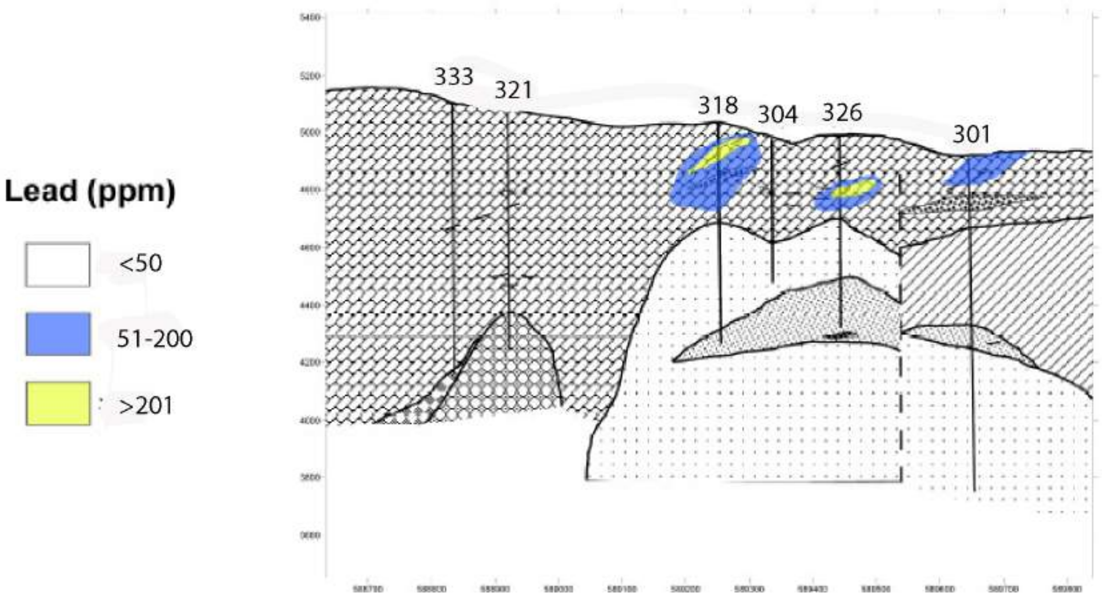


Figure 10. Cross section A-A', showing geology (rock type occurrences, faults and some silicification zones) in black and white, and Pb (in ppm) contoured against the black-and-white background; key as in Figure 7.

In conjunction with the XRD work, representative thin-section petrography of each alteration type in the deposit is planned. Forty-five thin sections are currently being made. These sections will be utilized to assess the relationship(s) between various clay species and their precursors, thus allowing a better understanding of water-rock interaction during mineralization.

Geochronology

The sampling completed over the 2007 summer field season was designed to allow us to determine precise ages for mineralization; to determine if there are multiple stages of mineralization; and to compare and possibly correlate mineralizing events with magmatic events. This geochronological study also aims to determine the duration of the mineralizing event or events that occurred at Adanac.

The first aspect of the geochronological study is the dating of mineralization events using Re-Os isotopes in molybdenite from various samples, as shown schematically in Figure 6. Twenty samples have been collected for possible analysis. The sample locations are based on hypothesized centres of mineralization and observed paragenesis as described below:

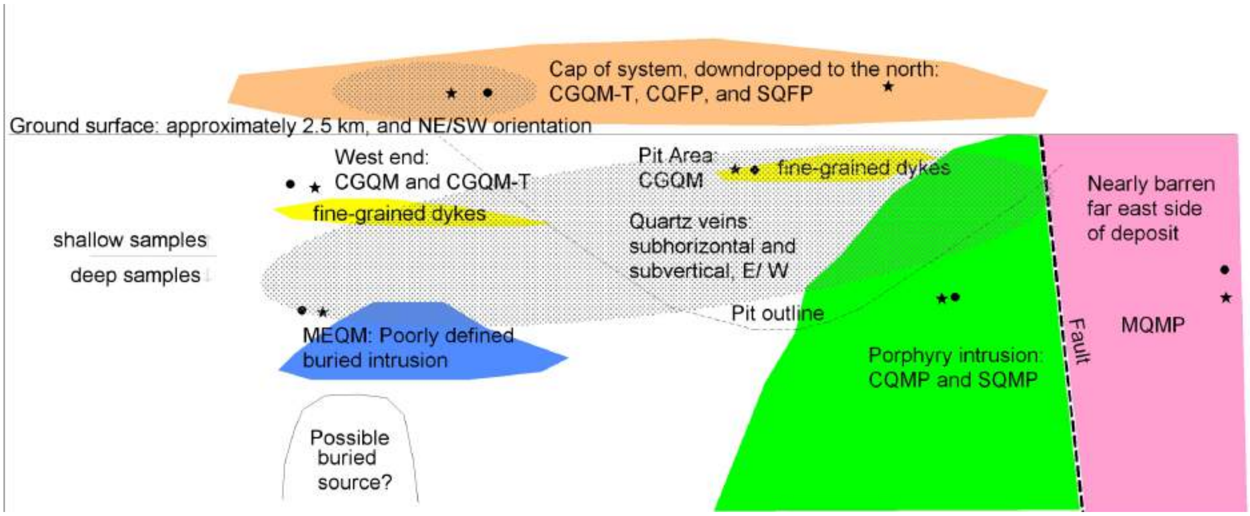


Figure 11. Schematic diagram representing sample locations throughout the deposit. The cross section follows the same orientation as A–A'. Biotite samples (black circles) are for microprobe analysis, in order to determine changes in trace-element content in early fluids. Molybdenite samples (black stars) are for Re-Os isotope geochronology and for an x-ray diffraction (XRD) determination of polytype. A sample of fresh rock for U-Pb zircon age dating was taken within 30.5 m (100 ft) of each molybdenite sample. An attempt was made to collect samples from distinctive areas in the deposit, e.g., feeder zones, lateral distance from feeder zones and the 'cap' of the system. These areas are labelled on the map, along with their associated rock types. Shaded areas represent high-grade zones.

- Feeder zone: the southwest portion of the system, as presently understood, displays an increased amount of early primary hydrothermal alteration. It also contains the most myrmekitic and unidirectional solidification textures, suggesting a volatile-rich area of the deposit. This area is where the proposed earliest stage of mineralization is located.
- Proximal to the feeder zone: samples from the main pit area and the southern and far eastern ends of the deposit are believed to be late-stage mineralization, based on the large lateral distance from the feeder zone.
- Cap areas and upper portions of drillholes: the analysis of samples from larger vertical, as well as lateral, distances away from the feeder zones may be later stages of mineralization, or may represent an evolution from the fluids passing through the feeder zone.
- Samples included different types of molybdenite veins: in addition to spatial variation, there are clearly two types of molybdenite veins, namely 'fine molybdenite in ductile veins' and 'coarse molybdenite in brittle veins' (i.e., veins have a sharp contact with host). Based on crosscutting relationships observed in drillcore, the molybdenite veins that are 'ductile' and contain fine molybdenite are older. A precise date will indicate the time lapse between these two mineralization events.
- Vein paragenesis: samples included molybdenite from veins with different associated minerals. There is molybdenite in veins by itself, in veins with pyrite and also in veins with other sulphides (chalcopyrite, galena). Unfortunately, these different types of veins are seen so rarely that temporal relationships between them cannot be determined. Therefore, geochronological analyses may yield insights into the paragenetic sequence of vein types.

In conjunction with the dating of mineralization, the timing of magmatic events will be determined using U-Pb isotope ratios in zircons. Samples of each rock type in the deposit were taken for age comparison. These included certain transitional phases present of each rock type, such as the transitional variety of the coarse-grained quartz monzonite, and aplite dikes, which are typically associated with a main rock type, such as CGQM. Ages of intrusion based on the zircon data will be compared to the timing of mineralization based on the Re-Os. Sampling locations for zircon are primarily based on locations of molybdenite Re-Os samples, i.e., a sample for each rock type was taken in proximity (within 30.5 m, or 100 ft) of a molybdenite sample. In addition, there was an extra sample taken of FGQM near the west end of the property, as opposed to the central pit area, to see if there is an age difference that may reflect local thermal variations. It is hypothesized that that deeper rock types on the southwest end (MEQM) will yield ages closest to mineralization, and thus may indicate a genetic relationship.

Two other types of studies will be carried out in parallel with the geochronological work. The first of these is a microprobe study of biotites to determine trace-element content, particularly F, S and Se. Understanding the temporal evolution of volatiles in the magmatic system, as reflected in biotite, may provide insights into molybdenite mineralization in the context of the evolution of the magmatic system. Primary magmatic biotite samples were collected from feeder zones of the deposit and laterally in various rock units. Secondary biotite from feldspar flood zones was collected as well, moving laterally from the feeder zone and into the central pit, and out to the far south and east ends of the deposit.

The second ancillary study comprises an x-ray diffraction study of molybdenite to determine polytype. The same samples used for Re-Os geochronology are a good representation of each type of mineralization from each distinct area of the deposit and will be used for the polytype study. There are two polytypes of molybdenite: the hexagonal 2H and the rhombohedral 3R. The 2H type is far more common than the exotic 3R, with the formation of the latter largely dependent upon impurities (commonly Re) in the molybdenite crystal (Newberry, 1979). Virtually nothing is known about the polytype or trace-element content of the molybdenite at Adanac. If there is a variation in polytype, it may be correlated with age, vein type or location, and thus may be indicative of an evolving system.

Regional Exploration Model

A much broader study of other Mo deposits by comparison of datasets, such as whole-rock geochemistry, is necessary to update and refine the exploration model for these deposits. In particular, preliminary work indicates that the geochemistry of plutons associated with molybdenite deposits and intrusion-hosted Au deposits is similar (e.g., redox state of the associated plutons; trace- and major-element chemistry of associated plutons; mineral and elemental assemblages such as high Be, Te and W, and low and peripheral Cu, Pb and Zn). Additional work is required to determine just how similar the geochemistry is, and whether there is a genetic link between these deposit types. This will proceed on two fronts, which are described below.

We will continue to compile and compare data from molybdenite and intrusion-related Au deposits in the western Cordillera of North America. In particular, we expect to both compile and generate some new data, such as isotopic data, that can be utilized in conjunction with more traditional geochemical data to help delineate similarities and differences among systems in the Cordillera.

At a more local scale, exploration of the connection between the Adanac Mo deposit and local placer gold deposits may yield insights into possible links between Mo and Au. To do this, the initial Os isotope signature of local placer gold will be compared with the initial Os isotope signature of the Adanac hydrothermal system. Samples of magnetite in the same vein with molybdenite have been collected and (if sufficient Os is present for analysis) will be analyzed for initial Os isotope ratios. These data should be similar to the calculated initial Os isotope ratio from the molybdenite. The data from the Adanac deposit will then be compared with the initial Os isotope signature of placer gold samples from the lower reaches of Ruby Creek, just downstream from Adanac. If the signatures are similar, it may be postulated that a hydrothermal system(s) of the same age in the same area are responsible for both Au and molybdenite mineralization. Thus the two systems may have a genetic link. This has obvious ramifications for both molybdenite and Au deposits at a large scale in terms of both genesis and exploration.

Conclusions

The Adanac Mo porphyry deposit falls into the category of a climax-type deposit on the basis of geochemistry of Rb, Sr and $K_2O_{57.5.}$ The hostrock and mineralizing pluton is a peraluminous, alkalic granite. Trace-element distributions indicate a central blanket of Mo with coincident, but sporadic W. Highest F values occur peripheral to the main Mo zone, and other metals show an ambiguous zoning pattern. Hydrothermal alteration is similar to, but considerably less intense than, typical climax-type systems.

Further refinement of the alteration and trace-metal zonation patterns is underway. Geochronological measurements over the coming year will more clearly elucidate the timing and duration of both magmatic and hydrothermal mineralization events. Broader comparison of Adanac to other molybdenite deposits, as well as to intrusion-hosted Au deposits, will allow us to further refine our genetic and tectonic models for both deposit types in the Canadian Cordillera.

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