Petrologic and geochemical examination of the Early Devonian, Evandale porphyry Cu-Mo-(Au) deposit, southern New Brunswick: Geothermobarometric analysis of petrogenesis

T. White, D.R. Lentz and C.R.M. McFarlane

University of New Brunswick, Fredericton, New Brunswick

Abstract: Porphyry Cu-Mo-(Au) systems associated with the granitoid rocks in eastern North American orogenic belts have been researched using current deposit models; however, relatively few studies have examined the potential for late stage fine-grained porphyritic to aplitic intrusive phases being host to mineralization. The Evandale Granodiorite is an example of a well- preserved Mid-Devonian (U-Pb zircon age of 391.2 ± 3.2 Ma for the coarser granitoid, and 390.2 ± 1.6 Ma for the aplite) polyphase pluton intruding through deformed Silurian sedimentary and mafic volcanic rocks of the Mascarene Basin in southern New Brunswick. The two intrusive phases have been identified as I type granites with a minor sedimentary component. The pluton is separated both petrochemically and texturally into two distinct phases. The coarser phase ranges from medium- to coarse-grained seriate to porphyritic granodiorite to monzogranite and the later finer stage layered aplite ranges from a monzogranite to syeno-granite. INAA analysis of each phase found that the highest concentrations of Cu and Au (108 ppm Cu, and 33 ppb Au) are associated with pyrite, chalcopyrite, and arsenopyrite within the aplitic dykes sampled, whereas concentrations of up to 6 ppm Mo were detected within the c.g. granite. Current models suggest that the transport of metals (particularly Cu and Au) are sourced from secondary two-phase fluids at shallow depths (approximately 2 kb), and is controlled primarily by Cl fugacity of the magma. Analyses of biotite phenocrysts from both the aplite and granite contain an average of 0.21 wt% Cl, which is similar to other high grade Cu-Mo-(Au) porphyry deposits. Average zircon saturation temperatures were calculated to be 818°C for the aplite and 787°C for the granitoid. Average apatite saturation temperatures were found to be 880°C for the aplite and 934°C for the granitoid phase. Hornblende-plagioclase thermometry revealed the crystallization temperature of the granite to be 642°C and 600°C for the aplite, cooler than most deposits of the same type. Al in hornblende geobarometery indicates crystallization depths of ~2.1 kb for hornblende in the aplite and ~0.7 kb for the c.g. granite. The aplitic dykes were subject to higher crystallization pressures and lower crystallization temperatures suggesting that their formation may either be a result of pressure quenching of the melt during rapid ascent or by the sub-solidus recrystallization of the melt as pyroclastic flows.

Originally presented Fredericton 2014: Geological Association of Canada - Mineralogical Association of Canada Joint Annual Meeting, Special Session 3: Discovering the Next Generation of Porphyry Deposits: Advancements in Locating and Understanding Hidden Intrusion-related Mineralization. May 21, 2014.

Corresponding author: Travis White (Travis.White@unb.ca)

White, T., Lentz, D.R., and McFarlane, C.R.M., 2015. Petrologic and geochemical examination of the Early Devonian, Evandale porphyry Cu-Mo-(Au) deposit, southern New Brunswick: Geothermobarometric analysis of petrogenesis; *in* TGI 4 – Intrusion Related Mineralisation Project: New Vectors to Buried Porphyry-Style Mineralisation, (ed.) N. Rogers; Geological Survey of Canada, Open File 7843, p. 343-360.

The Early Devonian, Evandale Porphyry Cu-Mo-(Au) Deposit, Southern New Brunswick

Petrologic, Geochemical, Geothermobarometric, and Geochronologic Characterization of the Host Rocks and its Origin

Department of Geology
University of New Brunswick

By: Travis White
Supervised by: Dr. David Lentz

UNB
UNIVERSITY OF NEW BRUNSWICK

Outline

- Current Model
- Evandale Introduction
- Geochronology
- Geochemistry
- Mineral Saturation Temperatures
- Geothermometry
- Geobarometry
- Conclusion

The Porphyry Copper Model

- Porphyry copper deposits mostly contain copper, with minor amounts of molybdenum and gold
- Porphyry stocks are usually between 0.1 to 1 km in diameter (John, *et al.,* 2010; Sillitoe, 2010)
- Stocks normally crystalize at depths of 2-5 km
- Hypogene ore zones can reach up to 1.5 km depth, with supergene ore at <300 m (John, *et al.,* 2010)

The Porphyry Copper Model

- Linked to the evolution of magmatic arcs along convergent plate margins (John, *et. al.,* 2010)

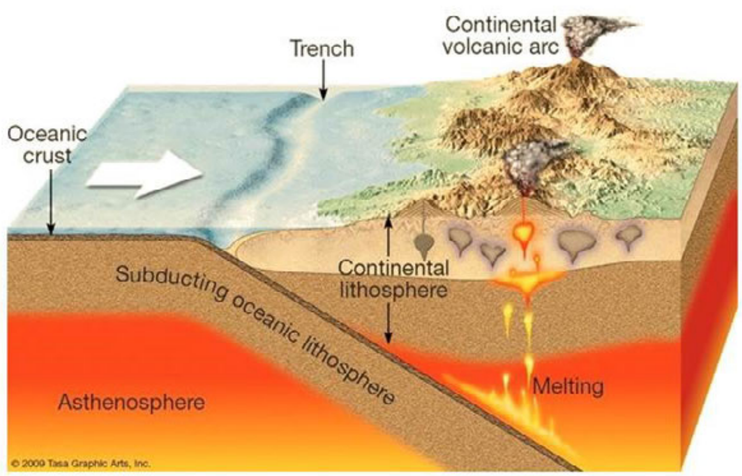

Fig. 01: Diagram of a Convergent Margin (http://tasaclips.com/illustrations.html)

The Porphyry Copper Model

- Crystallization progresses inwards, increasing volatile pressures and fracturing the surrounding rock (Sillitoe, 2010)

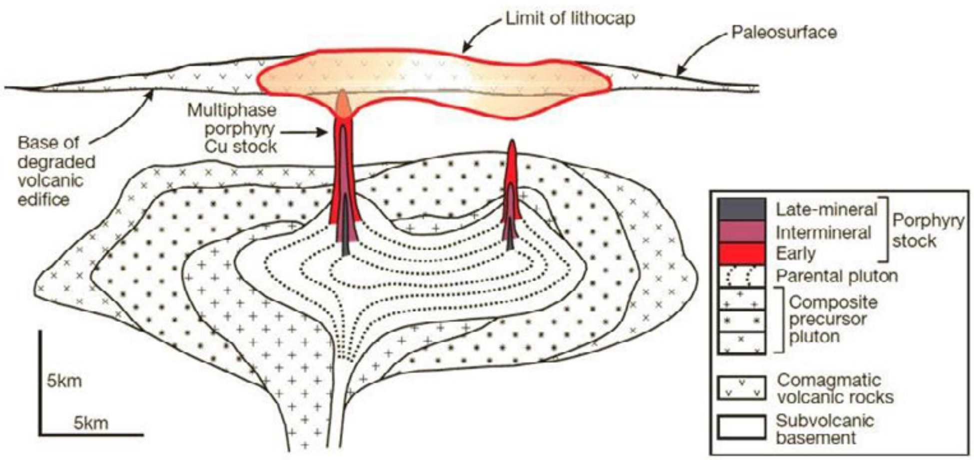

Fig. 02: Conceptual model of a porphyry stocks, in relation to the underlying pluton (Sillitoe, 2010).

The Porphyry Copper Model

- Escaping Fluids move outward from the stock cooling to about 350°C start precipitating metals
  - Cu+Mo → Zn+Pb with Au occurring throughout
- Fluid escape occurs in multiple phases and each phase typically decreases in grade (John, *et. al.,* 2010)
  - Early Porphyries (most mineralization)
  - Intermineral porphyries (less mineralized)
  - Late mineral porphyries (typically barren)
- Typical low grade ore is between 0.5-1.5% Cu, <0.04% Mo, and <1.5g/t Au (Sillitoe, 2010)

The Porphyry Copper Model

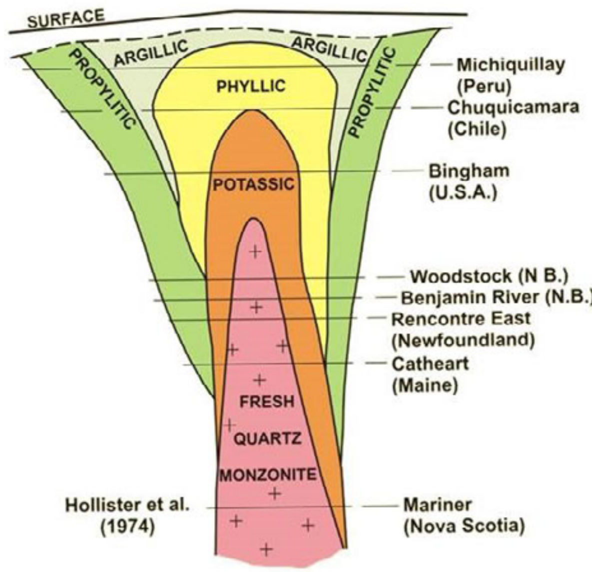

Fig. 03: Conceptual model of a porphyry stock, with examples of current exposure levels (Hollister et al., 1974).

Intro to Evandale

- The Evandale Porphyry Cu-Mo-(Au) deposit is located 30km North of Saint John
- 2.5 km diameter cylindrical stock granite stock intruding through deformed Silurian aged sedimentary and mafic-volcanic rocks
- A 60m greenschist grade contact aureole surrounds the stock
- Mineralization occurs as:
  - Gold bearing quartz veinlets (NW trending)
  - Phenocrysts of chalcopyrite and pyrite within both the coarser granite and the aplite phase of the deposit

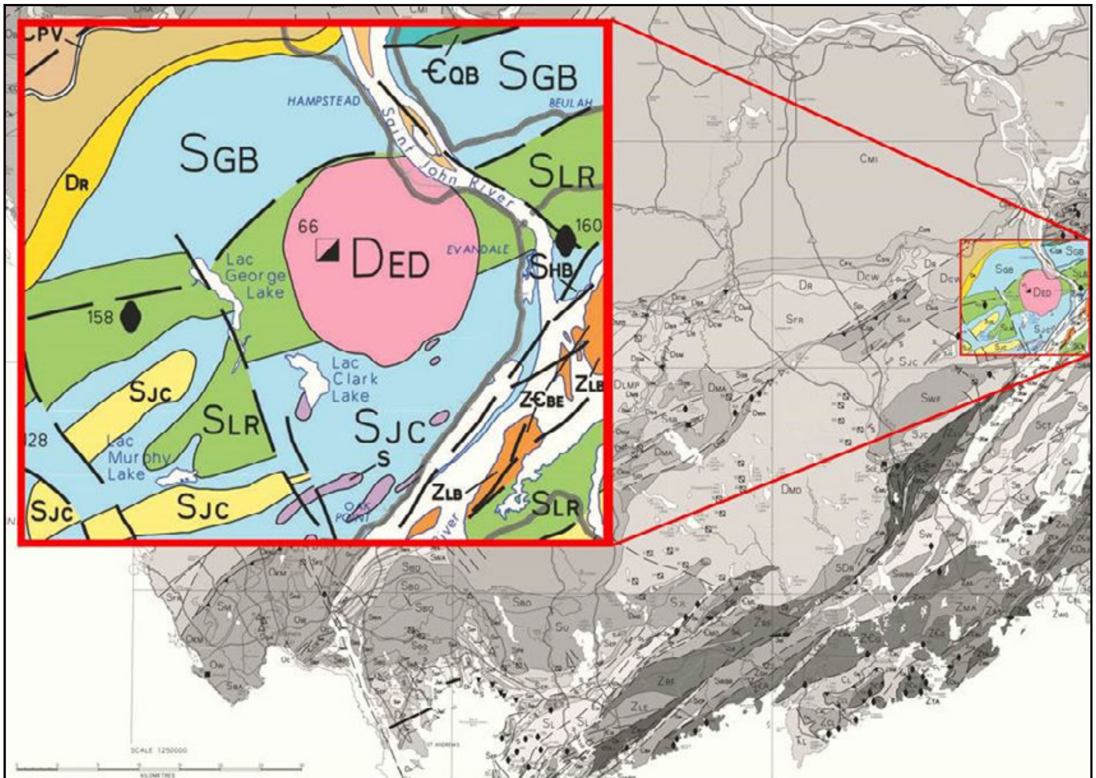

Fig. 04: Surficial Geology Map of New Brunswick with claim area modified from DNR-5.

Previous Exploration

- Discovered in 1967 by Rio Tinto Canadian Exploration Limited
- 1979 a 13 hole diamond drilling program totaling 1619 m
  - Best intersection was 0.7ft containing 14.7ppm Au, 293.8ppm Ag, 2.41% Cu, 6.67% Zn, 0.07% Mo, 0.02% WO3
- 1989 a total field magnetic survey, very low frequency electro-magnetic survey, and a gravity survey
  - Four conductive areas were defined, exploration continued but did not return any promising results
- All exploration programs concluded that the mineralization was not great enough to be considered economic

Petrology

- Samples were collected from drill core and grab samples from out crop
  - 15 thin sections were prepared
    - 12 from the diamond drill core
    - 3 from a rock quarry in the northern region of the deposit
- Examination of thin sections shows there are two primary intrusive phases based on texture
  - The seriate to porphyritic medium grained hbl-bt granite; and
  - The equigranular to porphyritic aplite

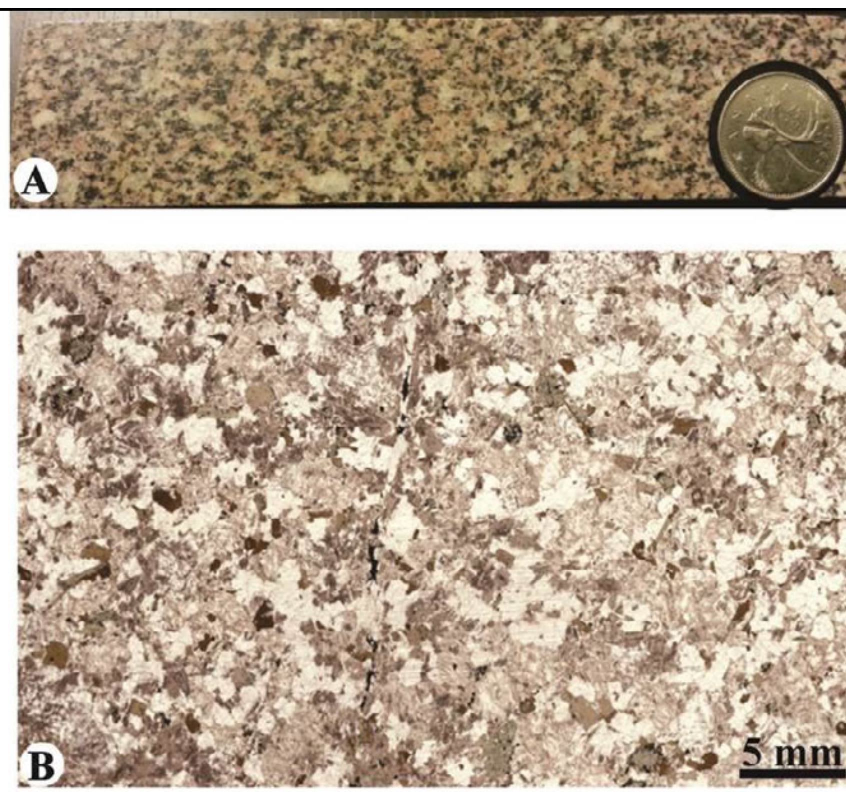

Fig. 05: Sample CB06 Polished slab (A) and respective thin section scan (B) of the seriate granite phase, at the Evandale stock.

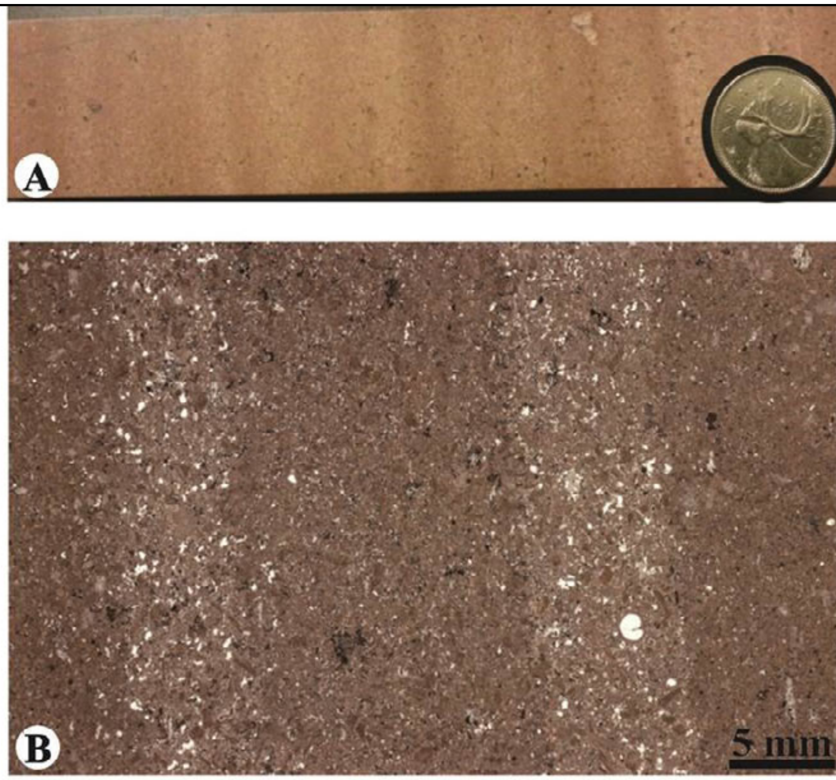

Fig. 06: Sample CB08 Polished slab (C) and respective thin section scan (D) of the fine grained aplite phase, at the Evandale stock.

Petrology: Aplite Texture

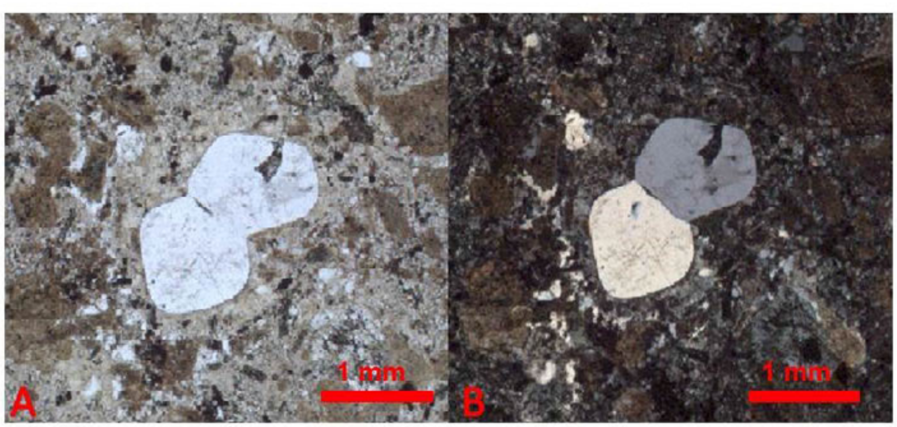

Fig. 07: Sample CB06 Photomicrograph of partially resorbed quartz crystal in PPL (A) and XPL (B).

Petrology: Mineralization

- Chalcopyrite mineralization occurs in both the granitic and aplitic phases
  - Within the granite it usually occurs as fracture fills, with associated hydrous iron oxides
  - Within the aplite it occurs typically as up to 5 mm phenocrysts
- Sulfide mineralization becomes pyrite dominated at shallower depths

Petrology: Chalcopyrite

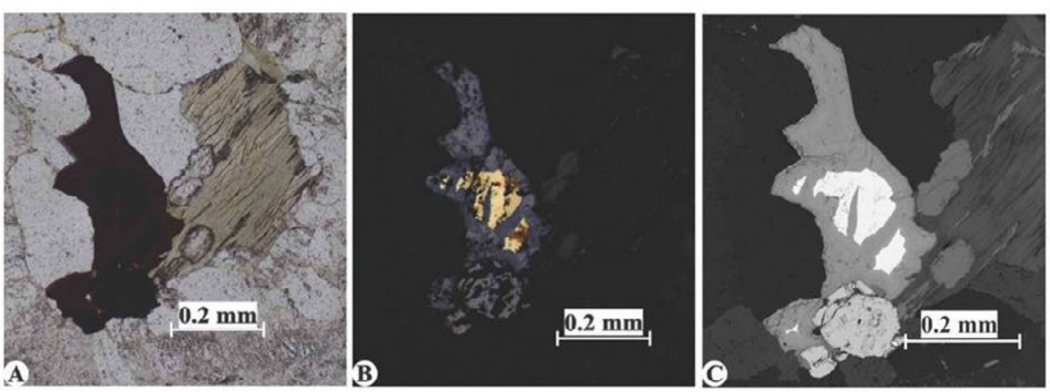

Fig. 08: Photomicrograph of a chalcopyrite grain (35.5% Cu) enveloped by a hydrous iron phase (14.65% Cu), from sample CB03 (granite phase). (A) Image taken in PPL. (B) Image taken in reflected light (RL). (C) Backscatter electron Image taken on scanning electron microscope (SEM).

Geochronology

- U-Pb dating of zircons using Laser Ablation Inductively Coupled Plasma-Mass Spectrometry (LA ICP-MS)
- Two representative samples from each textural phase, covering a total of 16 grains
- Two distinct ages were found:
  - 391.2 ±3.2 Ma for the granite (CB02 & CB03); and
  - 390.2 ±1.6 Ma for the aplite (CB12 & CB15)

Geochronology: Granite

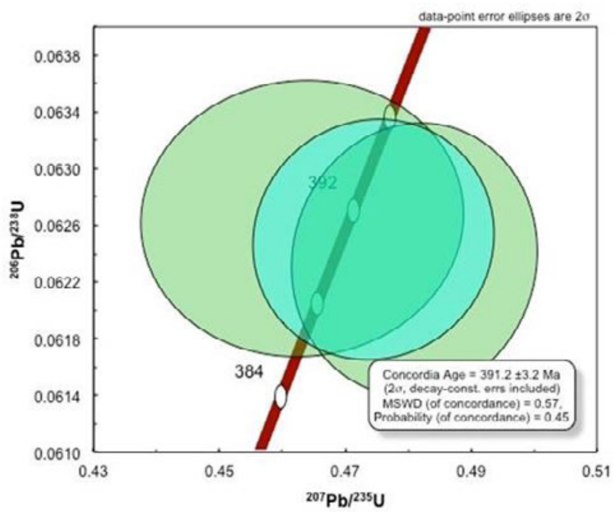

Fig. 09: Concordia diagram for samples CB02 and CB03, age is concordant, all samples plotted along the Concordia line suggesting a zircons within this system cogenetic.

Geochronology: Aplite

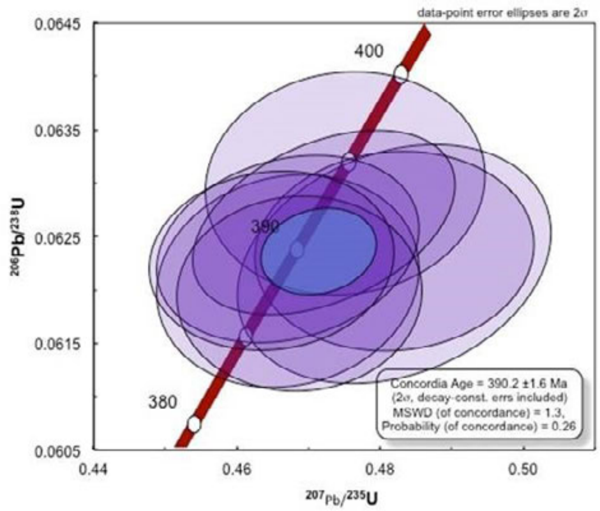

Fig. 10: Concordia diagram for samples CB12 and CB15, age is concordant, all samples plotted along the Concordia line suggesting a zircons within this system cogenetic.

Geochemsitry

- 15 samples were crushed to 200-mesh at UNB and prepared for the each analytical method used
- Analyses Conducted:
  - X-Ray Fluorescence (Memorial University)
  - Instrumental Neutron Activation Analysis (Actlabs)
  - Inductively Coupled Plasma – Mass Spectrometry (Actlabs)

QAP Classification

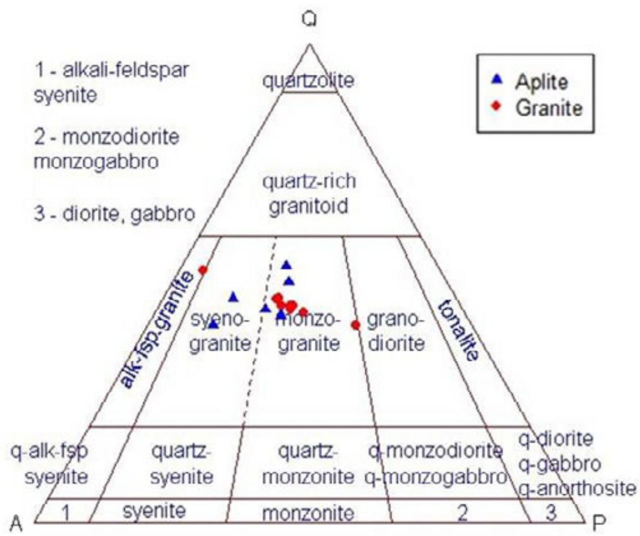

Fig. 11: QAP diagram by Streckeisen (1974), with samples norms calculated from XRF whole rock analyses. Diagram created using GCDkit, version 3.0 (Janoušek *et al.* 2006).

Classification: Fe-Number

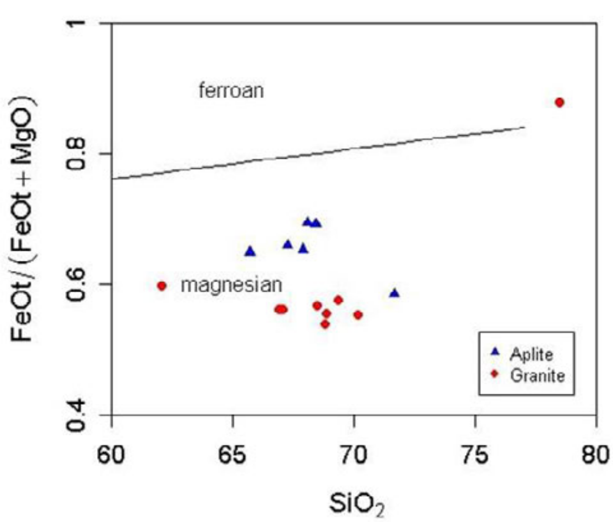

Fig. 12: (FeO/FeO+MgO) versus SiO2 (wt. %) discrimination diagram from Frost et al. (2001). This diagram describes the differentiation history and is used to distinguish between granitoids from different tectonic environments. Created using GCDkit, version 3.0 (Janoušek et al. 2006).

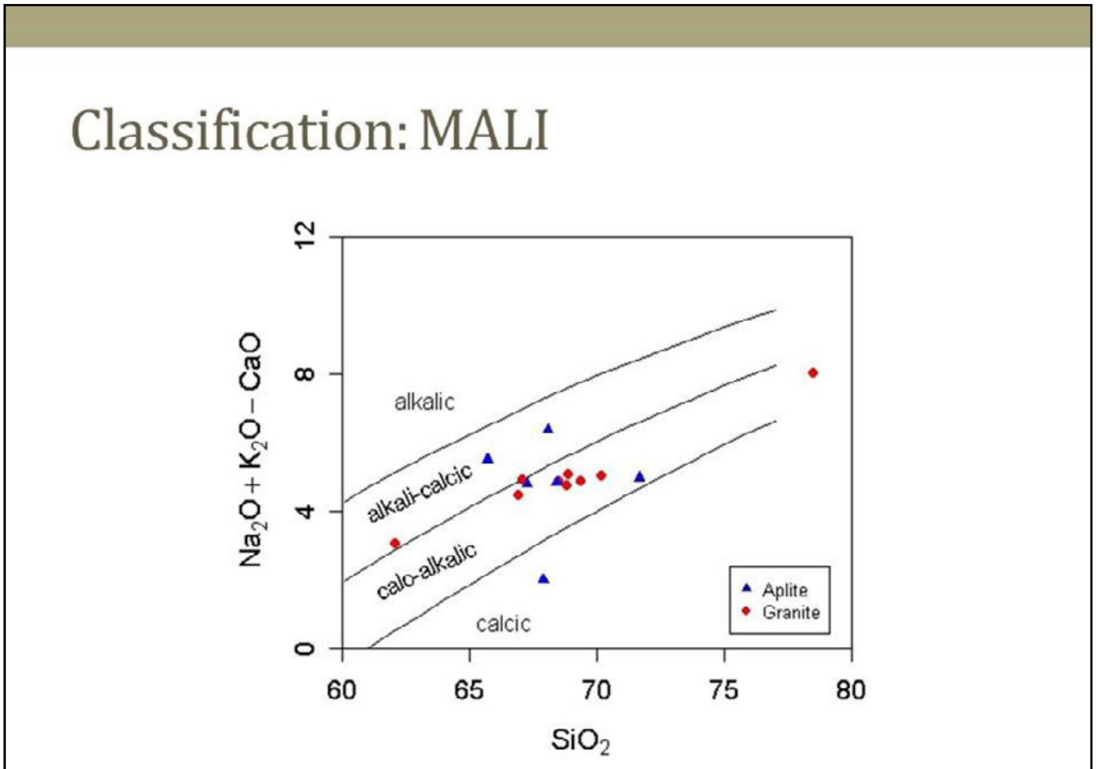

Fig. 13: The Modified Alkali Lime Index (MALI) diagram (Na2O + K20 – CaO versus SiO2) from Frost (2001). Created using GCDkit, version 3.0 (Janoušek et al. 2006).

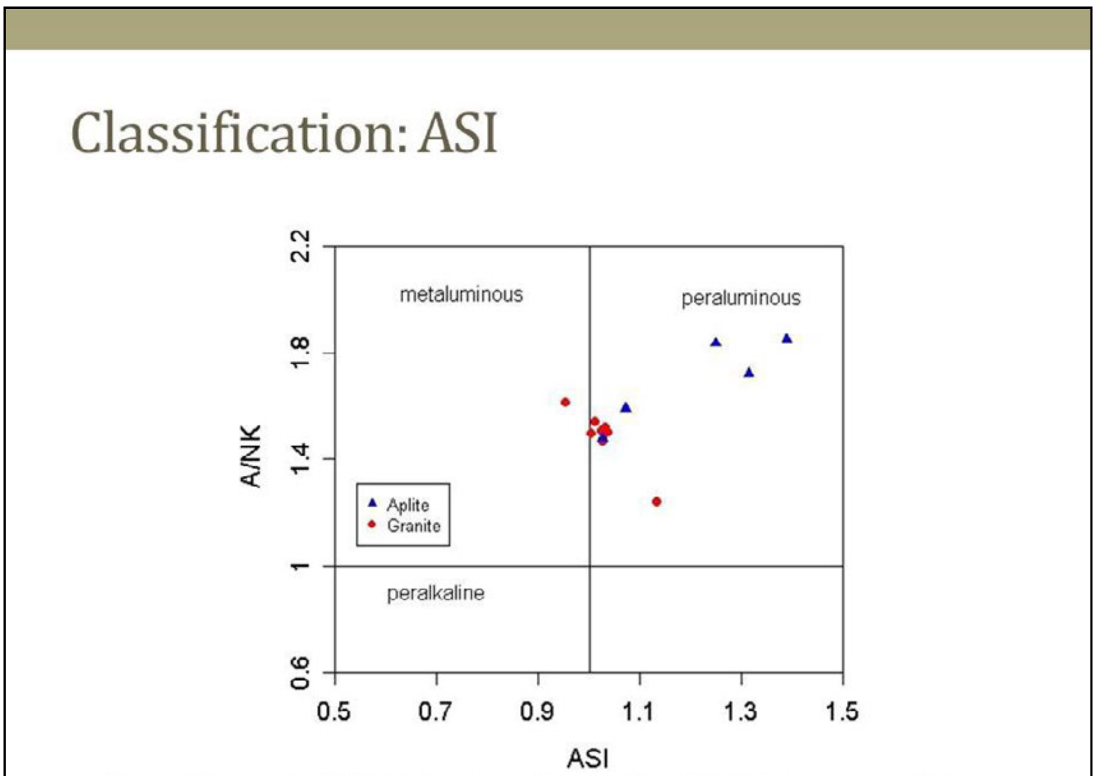

Fig. 14: ASI versus A/NK. Where ASI = [Al/(Ca-1.61P+Na+K)] , and A/NK = [Al_2O_3/(Na_2O+K_2O)]. This diagram identifies whether the rock is metaluminous, peraluminous or peralkaline. Calculations and plot created using GCDkit, version 3.0 (Janoušek *et al.* 2006).

Tectonic Discrimination

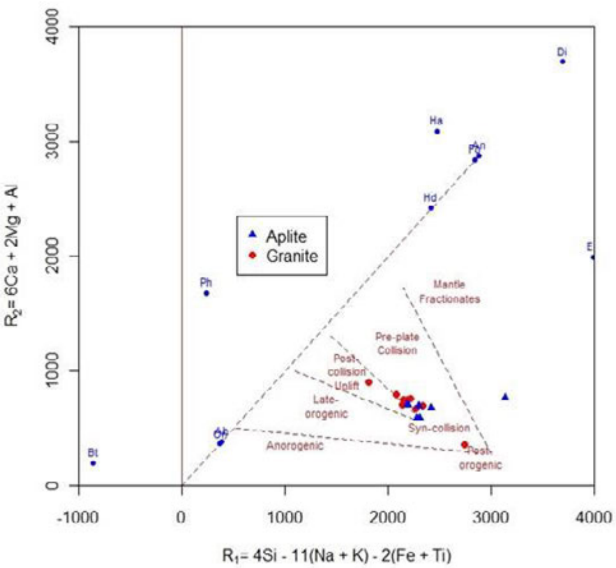

Fig. 15: R1 versus R2 tectonic discrimination diagram with field boundaries (Batchelor and Bowden 1985), Evandale data from this study compared to samples from Yang et al. (2008). Created using GCDkit, version 3.0 (Janoušek et al. 2006).

Tectonic Discrimination

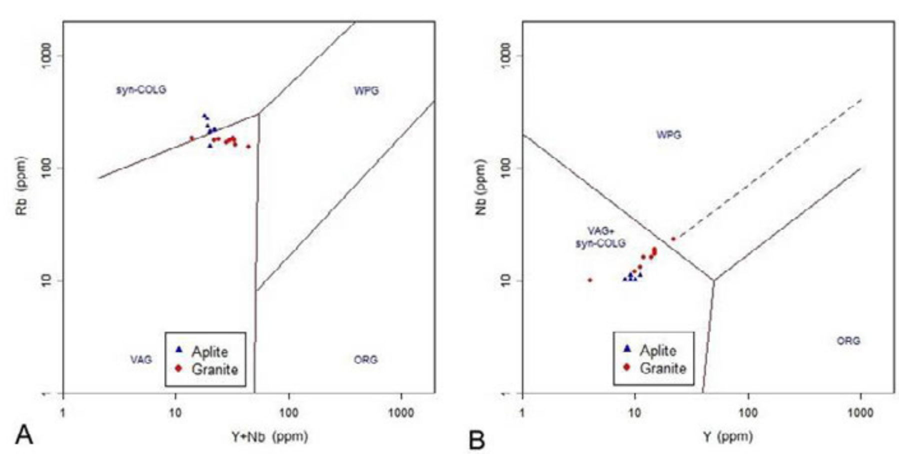

Fig. 16: Geotectonic geochemical discrimination diagrams: (Top) Rb versus Y+Nb (ppm), and (bottom) Nb versus Y (ppm). Ocean Ridge Granite (ORG); Within Plate Granite (WPG); Volcanic Arc Granite (VAG); and Syn- and Post-collision Granite (syn-COLG and post-COLG). Field boundaries are from Pearce et al. (1984). Created in GCDkit (Janoušek et al. 2006).

Zircon & Apatite Saturation

- Calculated used the model from Watson and Harrison (1984)

- Zircon saturation temperatures:
  - 787°C for the granite
  - 818°C for the aplite

- Apatite saturation temperatures:
  - 880°C for the granite
  - 934°C for the aplite

Geothermometry

- Hbl-Pl thermometer developed by Blundy and Holland (1990)
- Electron Microprobe Analyses of hornblende
  - Total of 54 spot measurements over 18 grains

$$T = \frac{0.677P[\text{kb}] - 48.98}{-0.0429 - 0.0083144 \ln \left\{ \left(\frac{\text{Si}-4}{8-\text{Si}}\right) X_{\text{Ab}}^{\text{Pl}} \right\}}$$

Equation 1: Si = atoms per formula unit (a.f.u.), X(pl/ab) = mole fraction of albite in plagioclase.

Geothermometry

- Previous calculations found combined average temperatures of:
  - 617 degrees Celsius (Yang, 2005)
  - 648 degrees Celsius (Godbout, 1997)
- Results from this study, average for each phase:
  - 642°C for the granite
  - 600°C for the aplite

Geobarometry

- Al in Hbl geobarometry is done using the methods from Anderson and Smith (1995)
- Previous results from Yang and Lentz (2005):
  - 0.6 kbar (60 MPa) for the granite
  - 1.5 kbar (150 MPa) for the aplite
- Present Study:
  - 0.7 kbar (70 MPa) for the granite
  - 2.1 kbar (210 MPa) for the aplite

Conclusion

- Textures and banding within the aplite suggest it may have formed as pyroclastic flows.
- Geochronology indicates both the granite pluton and the aplite are cogenetic forming after the Taconic Orogeny.
- Evandale pluton formed in a post collisional tectonic setting, predominantly I type with a moderate sedimentary component.
- Crystallization temperatures and pressures, volatile concentrations in the melt (Yang and Lentz, 2005) are similar to that of many other porphyry Cu forming systems.

Acknowledgements

- Dr. Chris McFarlane for assistance with U-Pb zircon data;
- NB Department of Energy and Mines for funding and support; and
- Dr. David Lentz for funding, and the continued support to make this project possible.

References

- Burton, D. M. (1989). Report of Geophysical Surveys, Evandale Option, NovaGold Resources Inc. *NB Assessment Report , 473643.*
- Fournier, R. O. (1999). Hydrothermal processes related to movement of fluid from plastic into brittle rock in the magmatic-epithermal environment. *Economic Geology , 94*, 1193-1211.
- Fyffe, L. R., Pajari, G. E., & Cherry, M. E. (1981). The Acadian Plutonic Rocks of New Brunswick. *Maritime Sediments and Atlantic Geology , 17*, 23-36.
- Giggie, K. V. (1991). Report of Drilling and Tenching, Evandale Option, NovaGold Resources Inc. *NB Assessment Report , 473996.*
- Govett, G. J., & Atherden, P. R. (1988). Applications of Rock Geochemistry to Productive plutons and Volcanic Sequences. *Journal of Geochemical Exploration , 30*, 223-242.
- Harris, N. (1996). Radiogenic isotopes and the interpretation of granitic rocks. *Episodes , 19* (4), 107-113.
- Meinert, L. D., Hedenquist, J. W., Satoh, H., & Matsuhisa, Y. (2003). Formation of anhydrous an dhydrous skarn in Cu-Au ore deposits by magmatic fluids. *Economic Geology , 98*, 147-156.
- Meinert, L. D., Hefton, K. K., Mayes, D., & Tasiran, I. (1997). Geology, zonation, and fluid evolution of the Big Gossan Cu-Au skarn deposit, Ertsberg district, Irian Jaya. *Economic Geology , 92*, 509-534.
- Ossandón, G., Fréraut, R., Gustafson, L. B., Lindsay, D. D., & Zentilli, M. (2001). Geology of the Chuquicamata mine: A progress report. *Economic Geology , 96*, 249-270.
- Shewman, R. (1968). Geological Report on the Evandale Stock. *NB Assessment Report , 470171.*
- Sillitoe, R. H. (2010). Porphyry Copper Systems. *Society of Economic Geologists , 105*, 3-41.
- Taylor, W. R. (1979). Report on Diamond Drilling, Evandale Project, Dome Exploration Ltd. *NB Assessment Report , 472550.*
- Whalen, J., Jenner, G., Longstaffe, F., & Hegner, E. (1996). Nature and Evolution of the Eastern Margin of Iapetus: Geochemical and Isotopic Constraints from Siluro-Devonian granitoid plutons in the New Brunswick Appalachians. *Canadian Journal of Earth Sciences , 33*, 140-155.