Towards an integrated model for alkalic porphyry and epithermal deposits in British Columbia

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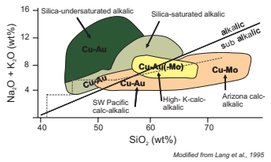
Alkalic mineral deposits share some features with 'classic' porphyry and epithermal systems, but other aspects of their geology distinguish them from sub-alkalic systems. In contrast to calc-alkalic deposits, less systematic work has been undertaken towards developing a coherent model that integrates the characteristics of various alteration styles that can develop in either a shallow- or deep-level alkalic settings. Recent discoveries have raised awareness of the economic importance of the alkalic class of porphyry and epithermal deposits, and have provided opportunities to better define the characteristics of these somewhat anomalous but potentially metal-rich mineral systems.

British Columbia is the type-area for alkalic porphyry deposits and consequently is the focus for our study. Case studies include the Mount Polley, Mount Milligan, Galore Creek and Lorraine deposits. Collectively, the systems span the depth range of the porphyry environment, from high-level breccia hosted bodies to deeper-level intrusive-centered sulfide accumulations. In order to build a coherent model for alkalic porphyry deposits, the integration of structural, paragenetic, alteration zonation and geochemical information is essential. As alkalic epithermal systems are under-represented in BC, three global examples are also being studied (Cowal, Australia; Porgera and Ladolam, Papua New Guinea) as an improved understanding of their characteristics may have exploration implications in BC.

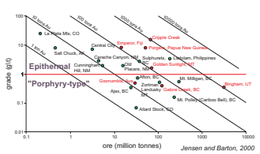
Alkalic mineral deposits

Alkalic mineral deposits:

- Magmatic-hydrothermal deposits can be distinguished on the basis of their association with calc-alkalic or alkalic series intrusions (e.g. Barr et al., 1976), as defined on basis of whole rock geochemical analyses of total alkalic-silica compositions.
- Alkalic porphyry and epithermal deposits are less common than their calc-alkalic counterparts.
- They are exclusively of Cu-Au character, in some cases with PGE credits.



Modified from Lang et al., 1995



Jensen and Barton, 2000

- British Columbia (BC) is best-known alkalic porphyry province, and New South Wales (NSW) is becoming more important.

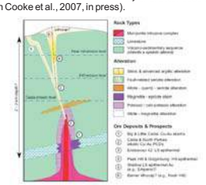
Examples: Mount Polley, Mount Milligan, Galore Creek, Lorraine - BC; Cadia - NSW.

- Alkalic epithermal deposits occur in isolated locations, and contain high concentrations of gold.

Examples: Cripple Creek - Colorado; Porgera, Lihir - Papua New Guinea; Emporer - Fiji.

New understanding from research in New South Wales:

Recent research has defined key characteristics for alkalic porphyry deposits in NSW (as summarized in Cooke et al., 2007, in press).



- Pipe-shaped intrusive bodies control mineralization.
- Small targets
- Low total sulfide contents
- Distinct zonation of S isotopes with respect to high-grade mineralization
- Subtle relationships between potassic, propylitic, calc-potassic and sodic alteration.
- Fault-controlled phyllic alteration
- Potential relationship to skarn and alkalic low sulfidation (?) and high sulfidation (?) systems.

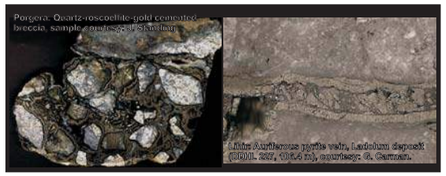
Alkalic epithermal deposits

Alkalic epithermal deposit characteristics:

- Includes some of the largest epithermal deposits in terms of contained gold (Ladolum, Cripple Creek).
- Diversity of mineralization styles (flat veins, breccias, steep veins).
- Oxidizing fluids (anhydrite, roscoelite, negative S isotopes).
- Te enrichment in some systems (Emporer, Cripple Creek).

Porgera: Oxidized fluids with alkalic affinity related to stage 2 Au-mineralization.

Ladolum: Mineralization telescoped during sector collapse of Luise volcano.



Linked alkalic porphyry and epithermal systems?:

- The Cowal deposit, located in the Macquarie Arc of NSW, may be an alkalic epithermal deposit (reduced fluid characteristics) that occurs in what is better known as a porphyry district.

Do alkalic epithermal deposits form within the same district as their deeper porphyry counterparts?

Come and see us at the Map Tent!

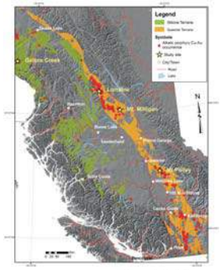
Alkalic porphyry deposits in British Columbia

General alkalic porphyry characteristics:

- Small and complicated alteration footprints, including abundant calc-potassic alteration and garnet.
- Varying intrusion geometries (pipes, dykes, stocks).
- Includes some of the highest gold grades in porphyry systems (Ridgeway, Cadia Far East).
- Sulfur isotope zonation patterns with most negative values in cores.

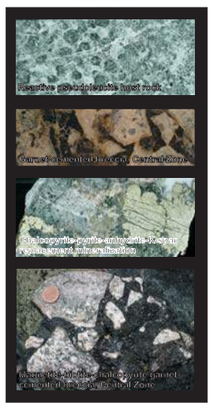
Characteristics of British Columbia alkalic porphyry systems:

- Alkalic porphyry systems of BC are hosted in the Quesnel and Stikine terranes, and are Late Triassic - Early Jurassic in age.
- Host-rock associations may be Si-saturated or Si- undersaturated. In BC, mineralization is almost exclusively associated with undersaturated systems. Where quartz veins are present in mineralized systems, they are late and barren (e.g. Mount Polley, Galore Creek).
- Propylitic alteration forms outboard of and approximately synchronous with K-silicate alteration (e.g. Mount Milligan). Argillic and advanced argillic alteration is absent in BC systems.
- Calcite is a major gangue mineral and occurs as veins, cement and as pervasive alteration.
- Metal zonation is complex and variable in BC systems, with PGE enrichment locally (e.g. Lorraine).
- Systems characterized by no quartz, abundant breccias and replacement-style mineralization.



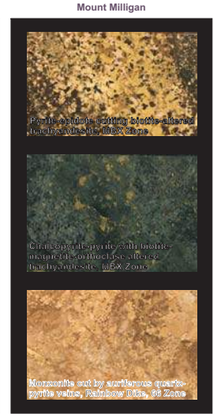
Map compiled by K. Simpson

Galore Creek



Mount Polley

Mount Milligan



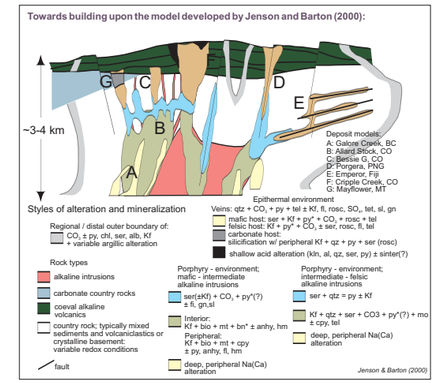
Is there potential for gold-rich alkalic epithermal deposits in BC?

Key characteristics and model development

Key features:

- Mineralization: clusters of small to medium deposits; low sulfide; presence of both K and Na alteration; pervasive replacement, veins, cemented breccias styles of mineralization.
- Controls: pipe-like intrusion geometries; reactive host rocks.
- Fluids: magmatic source; saline; highly oxidized.
- Alteration: Na, Na-Ca-(Fe), K, K-Ca-(Fe), propylitic.
- Quartz: absent in most BC porphyry systems, but present in NSW porphyries.
- Zoning: complex temporal and spatial zonation within and around related intrusions.

Towards building upon the model developed by Jenson and Barton (2000):



Jenson & Barton (2000)

Ongoing research questions:

- Is the sulfur isotope zonation of alkalic porphyry deposits mirrored in epithermal systems?
- How did hydrothermal breccias develop in both the surface and subsurface environments?
- What does the presence of oxidized fluids in shallow-level deposits mean for linked porphyry-epithermal systems in the alkalic environment?
- Does the apparent deeper formation of alkalic epithermal deposits provide encouragement for their exploration in prophyry districts in BC and NSW?

References:
Cooke D.R., Wilson A.J., House M.J., Wolfe R.C., Walshe J.L., Lickfold V. and Crawford A.J. (in press, 2007): Alkalic porphyry Au-Cu and associated mineral deposits of the Ordovician to Early Silurian Macquarie Arc, NSW; *Australian Journal of Earth Sciences.*
Jensen, E.P. and Barton, M.D. (2000): Gold deposits related to alkaline magmatism; Reviews in Economic Geology, volume 13, pages 279-314.
Lang, J.R., Lueck, B., Mortensen, J.K., Russell, J.K., Stanley, C.R. and Thompson, J.M. (1995a): Triassic-Jurassic silica-undersaturated and silica-saturated alkalic intrusions in the Cordillera of British Columbia: implications for arc magmatism; Geology, volume 23, pages 451-454.
Lang J.R., Stanley C.R., Thompson J.F.H. and Dunne K.P.E. (1995b): Na-K-Ca magmatic-hydrothermal alteration in alkalic porphyry Cu-Au deposits, British Columbia; Mineralogical Association of Canada, Short Course 23, pages 339-336.

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