STABLE ISOTOPE EVIDENCE FOR A MASSIVE METEORIC-HYDROTHERMAL SYSTEM RELATED TO THE CORYELL INTRUSIVE SUITE, BRITISH COLUMBIA, CANADA

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Introduction

This stable isotope study documents a massive and intense meteoric-hydrothermal system associated with the intrusion of the Coryell Intrusive Suite (CIS) into the shallow crust during the latest stages of extension in southern British Columbia. The CIS (Tempelman-Kluit and Parkinson, 1986; Carr and Parkinson, 1989) is located in southern British Columbia and occurs between the Okanagan and Valhalla metamorphic core complexes. It marks the latest stage of magmatism in the Southern Omineca Belt (Parrish et al., 1988). Mesozoic-to-early Cenozoic magmatism occurred in multiple pulses in response to Jurassic accretion of the Intermontane Superterrane, the Cretaceous-Paleocene accretion of the Insular Superterrance and subsequent Paleocene-to-Eocene orogenic collapse and detachment faulting (e.g., Parrish et al., 1988). Steep thermal gradients formed during detachment faulting as the hot lower plate was exhumed below a colder upper plate; this drove the large meteoric-hydrothermal systems that have been documented across southeastern British Columbia (Magaritz and Taylor, 1986; Beaudoin et al., 1992; Nesbitt and Meulenbachs, 1995; Holk and Taylor, 2007).

The alkaline CIS is a group of post-kinematic plutons in the upper plate of the Valkyr shear zone just west of the Valhalla Complex. One pluton is bisected by Lower Arrow Lake (Holk and Taylor, 2007). Other CIS plutons occur mostly in the lower plate of detachment faults correlated to the Okanagan Fault (Carr and Parkinson, 1989). A 100-km displacement for the Okanagan Fault is documented by a 51 Ma CIS pluton that cuts it (Tempelman-Kluit, 1986). This latest stage of magmatism is likely the product of decompression melting of the lithosphere during unloading associated with exhumation of metamorphic core complexes (Ghosh, 1995). This resulted in very high heat flow in the Southern Omineca Belt (e.g., Parrish et al., 1988). The epizonal emplacement of these syenitic plutons into an extensional tectonic regime makes the CIS a prime candidate for the study of a massive meteoric-hydrothermal system like those associated with major ore deposits.

There are two possible models of hydrothermal fluid circulation related to the CIS: (1) a fracture-controlled system dominated by faults (e.g., Criss and Champion, 1991; Beaudoin et al., 1992; Holk and Taylor, 2007) and (2) a convective system centered on shallow intrusions (e.g., Criss and Taylor, 1982; Magaritz and Taylor, 1986; Holk et al., 2008). This stable isotope study of the CIS aims to delineate controls on meteoric-hydrothermal activity between these two competing models.

Methodology

All stable isotope values were determined using the ThermoFinnigan DeltaPlus-XP isotope ratio mass spectrometer at the Institute for Integrated Research in Materials, Environments and Societies at California State University, Long Beach. The thermo-reduction method of Sharp et al. (2001) and laser fluorination method (Sharp, 1990) were employed for the acquisition of δD and $\delta^{18}O$ values, respectively. Calibration, accuracy, and analytical precision of isotope data (δD = ±2‰; $\delta^{18}O$ = ±0.2‰) were determined using NBS-30 biotite (δD = –65.7) and Caltech Rose Quartz ($\delta^{18}O$ = +8.45) standards. Mineral separates for isotopic analyses were prepared by crushing followed by hand picking and magnetic, density, or centrifuge separation, if needed. Primary and alteration mineralogy were determined by thin section petrography, PIMA spectroscopy, and powder XRD.

Results

The most dominant lithology in the CIS is porphyritic pink syenite characterized by orthoclase megacrysts in a matrix of plagioclase, amphibole and biotite, with minor clinopyroxene and/or quartz. Minor lithologies with the CIS include mafic biotite-rich monzonite, granite, quartz syenite, and ultramafic to mafic rocks. Plutons are homogeneous in both composition and fabric, with miarolitic cavities suggesting shallow emplacement. Most samples display significant epithermal alteration dominated by chlorite, epidote, and montmorillonite, suggesting alteration at ~350°C. This is consistent with variable biotite and hornblende weight percent H_2O contents (up to 7.8%) that indicate hydration by infiltrating fluids.

Stable isotope data from the CIS reveal extensive post-solidus interaction with meteoric-hydrothermal fluid. Whole-rock $\delta^{18}O$ values range from –5 to +6.5, with samples collected along the shores of Arrow Lake having the lowest values. Primary magmatic $\delta^{18}O$ values are hinted by quartz with $\delta^{18}O$ values that cluster at +8.5 at the Arrow Lake pluton and +6.0 at an unnamed pluton west of Castlegar, B.C. Orthoclase and plagioclase $\delta^{18}O$ values (–4.4 to +7.6) are out of equilibrium with coexisting quartz, indicating that variable amounts of meteoric-hydrothermal fluids affected these rocks. Hornblende (–2.8 to +7.4) and biotite (–7.5 to +5.7) $\delta^{18}O$ values display a similar degree of variability. Most biotite, hornblende, and chlorite δD values range between –175 and –130, with very few samples (δD as high as –68) above these very light values. These hydrogen and oxygen isotope data (Figure 1) define an inverted "L" pattern (e.g., Criss and Taylor, 1983) with most data plotting along the horizontal limb defined by constant δD values and variable $\delta^{18}O$ values, indicating a high water-rock ratio system. Fluids in equilibrium with the most altered rocks have δD values between –120 and –100 and $\delta^{18}O$ values ~ –5.

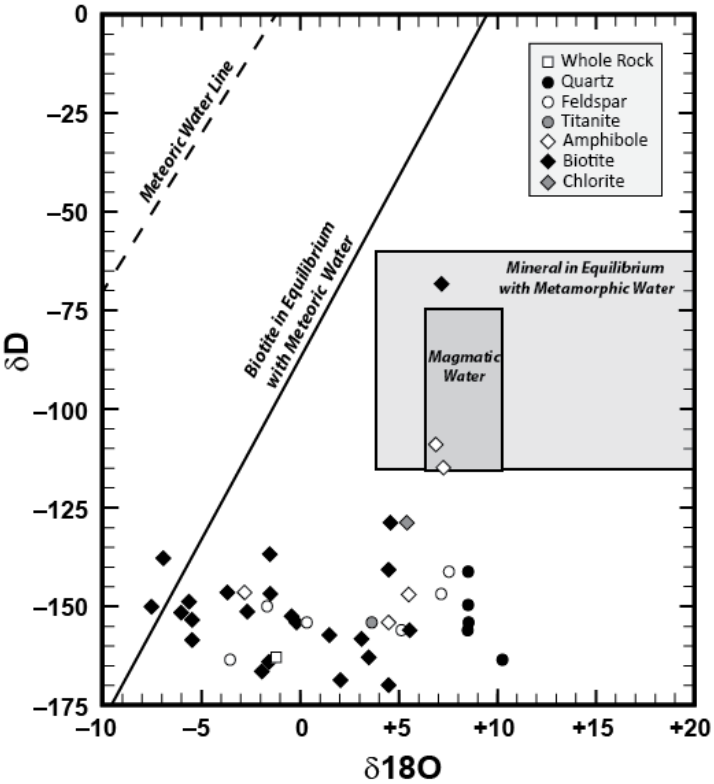

Figure 1. Plot of mineral $\delta^{18}O$ and δD values from the Coryell Intrusive Suite. Data are from this study, Magaritz and Taylor (1986), Nesbitt and Muehlenbachs (1995), and Holk and Taylor (2007). The $\delta^{18}O$ values of non-hydrous minerals are plotted at the position of the δD values of the coexisting hydrous mineral. Fields for magmatic and metamorphic water are approximate for values $\delta^{18}O$ and δD of minerals in equilibrium with such fluids at 400°C.

Discussion & Conclusion

Our stable isotope studies of the CIS document a massive meteoric-hydrothermal system that affected a >10,000 km^2 area in southern British Columbia. This mid-Eocene hydrothermal event related to the shallow intrusion of the CIS alkaline magmas is superimposed on an older, Early Eocene episode of meteoric-hydrothermal activity that affected most of the southern Omineca Belt in response to displacements along detachment faults that brought hot (~700°C) lower plate rocks to shallow crustal depth (Nesbitt and Muehlenbachs, 1995; Beaudoin et al., 1992; Holk and Taylor, 2007). The CIS rocks from Arrow Lake and those directly to the south have the greatest degree of lowering of δD and $\delta^{18}O$ values, consistent with the observations made by Magaritz and Taylor (1986) that inferred the presence of a large fracture zone that bisects this large pluton. However, most of the hydrothermal activity occurred in response to the delivery of large amounts of heat to the shallow crust during the intrusion of the CIS magmas after extension ceased to the east (Slocan Lake Fault), but continued to the west (Okanagan Fault).

Maximum quartz and feldspar δ^{18}O values (+8.5 and +7.5, respectively), interpreted to be primary magmatic values, indicate a lower crustal or mantle lithosphere source for the CIS; this is consistent with Sr and Nd isotope data (Ghosh, 1995). This contrasts with the much higher quartz δ^{18}O values (+12) from the Early Eocene Ladybird granite of anatectic origin (e.g., Holk and Taylor, 1997), the characteristic plutonic unit in the lower plate of detachment faults. The highest biotite δ^{18}O values (~ +6.5) from the CIS are similar to those from the Penticton Group volcanics (Mallory et al., 2010); this, along with a shared alkaline composition indicates that these two units are parts of the same magmatic system. Higher δD values (~ –130) from the Penticton Group (Mallory et al., 2010) relative to those from the CIS (~–160) indicates that the synvolcanic plutons experienced a greater degree of fluid-rock interaction than their volcanic equivalents, similar to observations in ancient caldera systems (e.g., Holk et al., 2008).

References

BEAUDOIN, G., Taylor, B. E., & SANGSTER, D. F., 1992. Silver-lead-zinc veins and crustal hydrology during Eocene extension, Southeastern British Columbia, Canada. *Geochemica et Cosmochimica Acta*, **56**, 3513-3529.

CARR, S. D. and PARKINSON, D. L., 1989. Eocene stratigraphy, age of the Coryell batholith, and extensional faults in the Granby Valley, Southern British Columbia. In: Current Research, Part E, Geological Survey of Canada Paper, **89-1E**, 79-87.

CRISS, R. E. and TAYLOR, H. P.,1983. A $^{18}O/^{16}O$ and D/H study of Tertiary hydrothermal systems in the southern half of the Idaho batholith. *Geological Society of America Bulletin*, **94**, 640-663.

CRISS, R. E. and CHAMPION, D. E., 1991. Oxygen isotope study of the fossil hydrothermal system in the Comstock Lode mining district, Nevada. *The Geochemical Society, Special Publication*, No. **3**, 437-447

GHOSH, D. K., 1995. Nd-Sr isotopic constraints on the interactions of the Intermontane Superterrane with the western edge of North America in the Southern Canadian Cordillera. *Canadian Journal of Earth Sciences*, **32**, 1740-1758.

HOLK, G. J., TAYLOR, H. P., 1997. $^{18}O/^{16}O$ homogenization of the middle crust during anatexis: The Thor-Odin metamorphic core complex, British Columbia, *Geology*, **25**, 31-34.

HOLK, G. J. and TAYLOR, H. P., 2007. $^{18}O/^{16}O$ studies of regional metamorphism, anatexis, extensional magmatism, meteoric-hydrothermal activity and ore deposition in the Valhalla metamorphic core complex, British Columbia. *Economic Geology*, **102**, 1063-1078.

HOLK G. J., TAYLOR, B. E., and GALLEY, A.G., 2008. Oxygen isotope mapping of the Archean Sturgeon Lake caldera complex and VMS-related hydrothermal system, Northwestern Ontario, Canada. *Miner Deposita*, **43**, 623-640.

MAGARITZ, M. and TAYLOR, H. P., 1986. $^{18}O/^{16}O$ and D/H studies of plutonic granitic and metamorphic rocks across the Cordilleran batholiths of Southern British Columbia. *Journal of Geophysical Research*, **91**, 2193-2217.

MALLORY, M. D., HOLK, G. J., LARSON, P. B., and COCHRANE, M., 2010. A stable isotope and petrogenetic study of the alkaline Penticton Group volcanic suite: the White Lake basin, south-central British Columbia: *Geological Society of America Abstracts with Programs*, **42**, no. 4, p. 105.

NESBITT, B. E. and MUEHLENBACHS, K., 1995. Geochemical studies of the origins and effects of synorogenic crustal fluids in the Southern Omineca Belt of British Columbia. *Geological Society of America Bulletin*, **107**, 1033-1050.

PARRISH, R. R., CARR, S. D., and PARKINSON, D. L., 1988. Eocene extensional tectonics and geochronology of the Southern Omineca belt, British Columbia and Washington. *Tectonics*, **7**, 181-212.

SHARP, Z. D., 1990. A laser-based microanalytical method for the in situ determination of oxygen isotope rations of silicates and oxides. *Geochemica et Cosmochimica Acta*, **54**, 3153-1357.

SHARP, Z. D., ATUDOREI, V., and DURAKIEWICZ, T., 2001. A rapid method for determination of hydrogen and oxygen isotope rations from water and hydrous minerals. *Chemical Geology*, **178**, 197-210.

TEMPELMAN-KLUIT, D., and PARKINSON, D., 1986. Extension across the Eocene Okanagan crustal shear in Southern British Columbia. *Geology*, **14**, 318-321.