Radiogenic and Stable Isotopic Compositions of mid-Cretaceous Intrusions in the Selwyn Basin, Yukon and Northwest Territories

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Introduction

Extensive mid-Cretaceous felsic magmatism in the Selwyn Basin (SB) northeast of the Tintina Fault Zone in Yukon and westernmost Northwest Territories has been interpreted to be a result of syn to post-collisional back-arc magmatism related to dextrally oblique subduction and associated dextral compression along the western margin of North America (e.g., Mortensen et al., 2000; Hart et al., 2004a; Mair et al., 2006). Here, we classify the magmatism northeast of the Tintina Fault into two groups of plutonic suites: (1) a subalkalic belt in western to southern SB comprising the Hyland-Anvil and Tay River suites; and (2) a belt in northern and eastern SB comprising the subalkalic Tungsten and Mayo suites, and the weakly to strongly alkalic Tombstone suite (referred to collectively as the Tombstone-Tungsten Belt, or TTB; Hart et al., 2004b).

The Hyland-Anvil (109-95 Ma) and Tay River (98-96 Ma) plutonic suites mainly comprise large composite biotite ± hornblende or muscovite, quartz monzodiorite to granodiorite to monzogranite batholiths, commonly including abundant mafic enclaves and locally associated with felsic volcanism. This magmatism has been attributed to partial melting of over-thickened continental crust driven by regional compression (e.g., Woodsworth et al., 1991), or decompression melting during movement along deep transpressional structures (Gabrielse et al., 2006), and/or uplift and orogenic collapse (e.g., Hart et al., 2004a; Mair et al., 2006). Most of the larger intrusions were emplaced into thick Proterozoic rift-related sedimentary packages primarily eroded from crystalline Precambrian Laurentian basement.

The TTB plutonic suites are the youngest and most inboard mid-Cretaceous igneous rocks in the SB. These suites lack large batholiths and typically form very small to medium-sized circular plutons, locally cut by late mafic dykes. Tungsten suite plutons (99-95 Ma) are restricted to the eastern portion of the TTB, and form very small, reduced, biotite ± muscovite ± garnet monzogranite and leucogranitic plugs that are interpreted to be entirely crustally derived. In the eastern TTB, biotite ± hornblende ± clinopyroxene quartz monzonite to quartz monzodiorite to monzogranite Mayo suite (96-93 Ma, possibly up to 98 Ma), and monzonitic to monzogranitic Tombstone suite (94-89 Ma) intrusions also exhibit evidence for derivation from middle to upper crustal rocks but additionally display evidence for mafic melt input (e.g., Hart et al., 2004b). Tombstone suite plutons in particular have abundant intermediate and minor mafic components (e.g., enclaves, dykes) and this combined with mineralogical and geochemical features suggests the incorporation of a significant amount of lithospheric mantle-derived melt (Hart et al., 2004b). The TTB suites are interpreted to have formed following deformation in a tensional post-collisional setting (Mair et al., 2006; Gabrielse et al., 2006) and were emplaced as a very narrow (<50 km across) and long (~1000 km) belt into thin Paleozoic metasedimentary miogeoclinal (SB) rocks that overlie the Proterozoic rift-related packages.

Here, we contribute new geochronological and isotopic data that provide further insights into the petrogenesis of the mid-Cretaceous plutonic suites.

Methods and Results

Fifty-two representative plutonic and dykes samples were dated using U-Pb LA-ICP-MS or ID-TIMS methods on zircon, together with Sm-Nd and Rb-Sr isotopic analysis (whole rock), Pb isotopic analysis of feldspar, at the Pacific Centre for Isotopic and Geochemical Research, University of British Columbia, Vancouver. U-Pb age and isotopic data from an additional 22 samples from the southeastern SB were reported by Heffernan (2004). Stable isotopic analyses (S- whole rock; O-quartz) were also done on all 74 samples at the Nevada Stable Isotope Laboratory, University of Nevada-Reno.

Crystallization ages are consistent with the northeastward younging of magmatism described by other workers (e.g., Mortensen et al., 2000; Hart et al., 2004a) and these data have been used to better constrain the age ranges for the plutonic suites. The data suggest that magmatism in the SB occurred in a typical back-arc setting, coeval with calc-alkalic arc rocks to the southwest, until about 100 Ma. After 100 Ma magmatism in the SB stepped inboard for the next ~10 m.y., generating progressively younger plutonic suites to the northeast.

Neodymium isotopic compositions ($\varepsilon Nd_{t=100}$) for the intrusions range from -5.8 to -20.9 and form a broad array when plotted with $^{87}Sr/^{86}Sr_{t=100}$ (0.7081-0.7336) from compositions typical of Paleozoic sedimentary rocks and/or enriched mantle lithosphere (εNd = -5 to -12), to compositions typical of underlying Proterozoic rift-related sedimentary rocks eroded from Laurentian basement (εNd = -15 to -22). Mafic dykes yield multiple compositions but as with the plutonic samples, all have $^{87}Sr/^{86}Sr_{t=100}$ ratios >0.705, suggesting that all intrusive phases were derived from or very strongly contaminated by older radiogenic basement. The older batholithic Hyland-Anvil and Tay River suites range from moderately radiogenic to less radiogenic compositions with decreasing age, whereas the TTB intrusions have very similar highly radiogenic isotopic compositions, with the more radiogenic samples located in the northeast SB, and the somewhat less radiogenic samples located in the southeast SB.

Lead isotopic compositions ($^{207}Pb/^{204}Pb$: 15.66-15.86; $^{208}Pb/^{204}Pb$: 39.10-39.99; $^{206}Pb/^{204}Pb$: 19.11-19.77) are typical of a mainly middle to upper crustal lead source. Lead compositions fall in two groups in terms of $^{206}Pb/^{204}Pb$: <19.3 for several of the Mayo and Tombstone suite samples in the northeastern SB, and >19.3 for the remaining samples. This bimodal distribution suggests that at least two distinct lead reservoirs were sampled by the magmas.

All of the intrusions have high positive $\delta^{18}O$ (+8.4 to +16.9‰) and there is very little systematic variation, indicating that all of the plutonic suites were largely derived from crustal rocks. Many samples returned $\delta^{18}O$ values of +14 to +16.9‰, consistent with magma derivation primarily from partial melting of pelitic rocks. Generally lower $\delta^{18}O$ for intrusions in the southeastern SB may reflect melt generated from older and more radiogenic lower crustal rocks, or could be due to compositional variation in the basement.

Whole rock $\delta^{34}S$ values for the Cretaceous intrusions range from +2.4 to +13.6‰ with most values >+7‰ (particularly for Mayo and Tombstone suites in the northeastern SB). These values are typical of incorporation of seawater sulphate from evaporitic lithologies. The measured $\delta^{34}S$ generally becomes higher with decreasing age, suggesting greater incorporation of seawater sulphate in younger magmas. However, there is a second smaller but still significant population with lower $\delta^{34}S$ values (+3 to +7‰) for samples located in the southeastern SB. These isotopically lighter intrusions either incorporated less evaporitic material or were contaminated by mantle-derived or sedimentary-derived reduced (sulphide) sulphur. Many of these 'lighter' samples also yield some of the less radiogenic εNd values, suggesting that either the basement underlying the southeastern SB is isotopically more juvenile than the basement underlying the northeastern SB, or that a mantle-derived melt has contaminated plutons in the southestern region.

Discussion

Radiogenic and stable isotopic data for Cretaceous intrusions within the SB are compatible with derivation mainly by melting of Proterozoic rift-related rocks and/or the overlying Paleozoic basin-platform rocks, with two or more compositionally distinct basement domains. Despite very restricted higher metamorphic-grade regions (e.g., staurolite to garnet-grade contact aureoles associated with the batholithic plutonic suites; Smith and Erdmer, 1991), sub-greenschist facies metasedimentary rocks are typical of rocks at the present level of exposure (e.g., Gordey and Anderson, 1993). Therefore, crustal melts are likely to have been sourced primarily from deeper middle (to lower) crust where radiogenic Proterozoic rift-related metasedimentary rocks are interpreted to continue at depth (e.g., Cook and Erdmer, 2004). Trace element geochemistry and less radiogenic isotopic compositions for intrusions younger than ~100 Ma also indicate that radiogenic crust-derived magmas mixed with an intermediate to mafic melt. This intermediate to mafic melt input has been attributed to partial melting of underlying enriched mantle (e.g., Hart et al., 2004a; Mair et al., 2006) or sills and volcanic rocks exposed throughout the Proterozoic (and Paleozoic) metasedimentary rocks (e.g., Driver et al., 2000). Tectonic processes such as crustal thickening, orogenic collapse, and post-collisional extension associated with ongoing normal subduction along the western margin of ancestral North America were invoked as the primary mechanisms for partial melting in the crust ± mantle, leading to back-arc magmatism.

Subduction-related calc-alkalic arc magmatism in central and western Yukon and eastern Alaska appears to have been coeval with the back-arc Hyland-Anvil plutonic suites until ~100 Ma. However, there is no robust geochronological evidence for the continued existence of a magmatic arc in this region after 100 Ma, despite ongoing continental margin shortening through the mid- to Late Cretaceous and possibly younger (as described by Aitken et al., 1982). Most of the age data published for calc-alkaline intrusions in the west comprise scattered K-Ar and Rb-Sr data, which do not provide reliable constraints on the timing of arc magmatism. Based on the pattern of magmatism, the locus of crustal thickening and subsequent melting of the crust progressed northeastward with continued dextral oblique convergence and deformation across the SB, resulting in the post-100 Ma margin-parallel Tay River and TTB suites that become younger to the northeast. Compressive stresses in the SB during this period may have been largely accommodated by Early to mid-Cretaceous dextral transpressional structures along which the larger batholithic plutonic suites were emplaced, and by reactivation of Proterozoic rift-related structures (e.g., basal decollements) that may be partially responsible for the current position of mid-Cretaceous plutons up to 700 km inboard of the inferred subduction zone trench. In addition to radiogenic crustal melts, the Tay River suite also appears to have incorporated material that is isotopically similar to the upper crustal Paleozoic rocks; however, given the lack of upper crustal melting, these less radiogenic compositions could also be due to mixing with a more juvenile mafic melt sourced from deeper crustal levels. The most inboard and youngest plutons (TTB) display a range of compositions from peraluminous subalkalic intrusions that are apparently entirely crustally derived (Tungsten suite ± Mayo suite), to metaluminous subalkalic-alkalic intrusions that are primarily crustal crustally derived but also appear to have had some juvenile melt component (Tombstone suite ± Mayo suite). This compositional progression from radiogenic to more juvenile magmatic compositions suggests an increasing interaction between felsic crustal melts and mafic crustal ± mantle melts. Following ~89 Ma, the lack of voluminous wide-spread plutonism in the SB indicates an end to magmatism related to convergent margin processes well inboard of the northern Cordilleran continental margin.

Despite previous work, uncertainties still remain regarding the petrogenesis of mid-Cretaceous felsic magmatism in the SB. The lack of a well-constrained magmatic arc during ~100-89 Ma magmatism and shortening in the SB is problematic as it suggests that the mechanism for generating back-arc magmatism (e.g., ongoing normal subduction) was no longer operating. Furthermore, limited crustal stacking and shortening observed in the SB (e.g., Gordey and Anderson, 1993) entails a mechanism other than crustal thickening that is capable of inducing partial melting at middle and/or lower crustal levels throughout the SB, and in lower crust ± mantle over a very narrow >1000 km long belt well inboard of the continental margin. These unresolved geodynamic issues regarding the petrogenesis of mid-Cretaceous magmatism in the SB necessitate modifications to the current tectonic model in which syn- to post-collisional back-arc magmatism is a result of normal subduction along the western margin of North America.

Acknowledgements

Funding for this research was provided by Parks Canada, the Northwest Territories Geoscience Office, the Yukon Geological Survey, the Society of Economic Geologists, and a NSERC Discovery Grant to J.K. Mortensen. The authors thank Scott Heffernan for access to samples.

References

Aitken, J.D., Cook, D.G., and Yorath, C.J., 1982, Upper Ramparts River (106G) and Sans Sault Rapids (106H) map areas, District of Mackenzie: Geological Survey of Canada, Memoir 388, 48 p.

Cook, F.A., and Erdmer, P., 2004, An 1800 km cross section of the lithosphere through the northwestern North American plate: lessons from 4.0 billion years of Earth's history: Canadian Journal of Earth Science, 42, 1295-1311.

Driver, L.A., Creaser, R.A., Chacko, T., and Erdmer, P., 2000, Petrogenesis of the Cretaceous Cassiar batholith, Yukon-British Columbia, Canada: implications for magmatism in the North American cordilleran interior: Geological Society of America Bulletin, 112, 1119-1133.

Gabrielse, H., Murphy, D.C., and Mortensen, J.K., 2006, Cretaceous and Cenozoic dextral orogen-parallel displacements, magmatism, and paleogeography, north-central Canadian Cordillera: Paleogeography of the North American Cordillera, Evidence For and Against Large-Scale Displacements: Geological Association of Canada Special Paper 46, J.W. Haggart, R.J.Enkin, and J.W.H. Monger (eds), 255-276.

Gordey, S.P. ,and Anderson, R.L., 1993, Evolution of the northern cordilleran miogeocline, Nahanni map area (105I), Yukon and Northwest Territories: Geological Survey of Canada, Memoir 428, 214 p.

Hart, C.J.R., Goldfarb, R.J., Lewis, L.L., and Mair, J.L., 2004a, The northern cordilleran mid-Cretaceous plutonic province: ilmenite/magnetite-series granitoids and intrusion-related mineralization: Resource Geology, 54, 253-280.

Hart, C.J.R., Mair, J.L., Goldfarb, R.J., and Groves, D.I., 2004b, Source and redox controls on metallogenic variations in intrusion-related ore systems, Tombstone-Tungsten Belt, Yukon Territory, Canada: Transactions of the Royal Society of Edinburgh, Earth Sciences, 95, 339-356.

Heffernan, R.S., 2004, Temporal, geochemical, isotopic and metallogenic studies of mid-Cretaceous magmatism in the Tintina Gold Province, southeastern Yukon and southwestern Northwest Territories, Canada: Unpublished MSc thesis, University of British Columbia, British Columbia, Canada, 83 p.

Mair, J.L., Hart, C.J.R., and Stephens, J.R., 2006, Deformation history of the northwestern Selwyn Basin, Yukon, Canada: implications for orogen evolution and mid-Cretaceous magmatism: GSA Bulletin, 118, 304-323.

Mortensen, J.K., Hart, C.J.R., Murphy, D.C., and Heffernan, S., 2000, Temporal evolution of Early and mid-Cretaceous magmatism in the Tintina Gold Belt: The Tintina Gold Belt: Concepts, Exploration and Discoveries: British Columbia and Yukon Chamber of Mines, Special Volume 2, J. Jambor (ed), 49-57.

Plafker, G., and Berg, H.C. (eds), 1994, Overview of the geology and tectonic evolution of Alaska: The Geology of Alaska, The Geology of North America, GSA, Boulder, Colorado, 989-1021.

Smith, J. M. and Erdmer, P., 1990, The Anvil aureole, an atypical mid-Cretaceous culmination in the northern Canadian Cordillera: Canadian Journal of Earth Sciences, 27, 344-356.

Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L., 1991, Plutonic regimes: Geology of the Cordilleran Orogen in Canada: GSC Geology of Canada, H. Gabrielse and C.J. Yorath (eds), 491-531.