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Middle Cretaceous trimodal Dawson Range magmatism in western Yukon: inferences on sources and tectonic setting (NTS 115-I, -J and -K)

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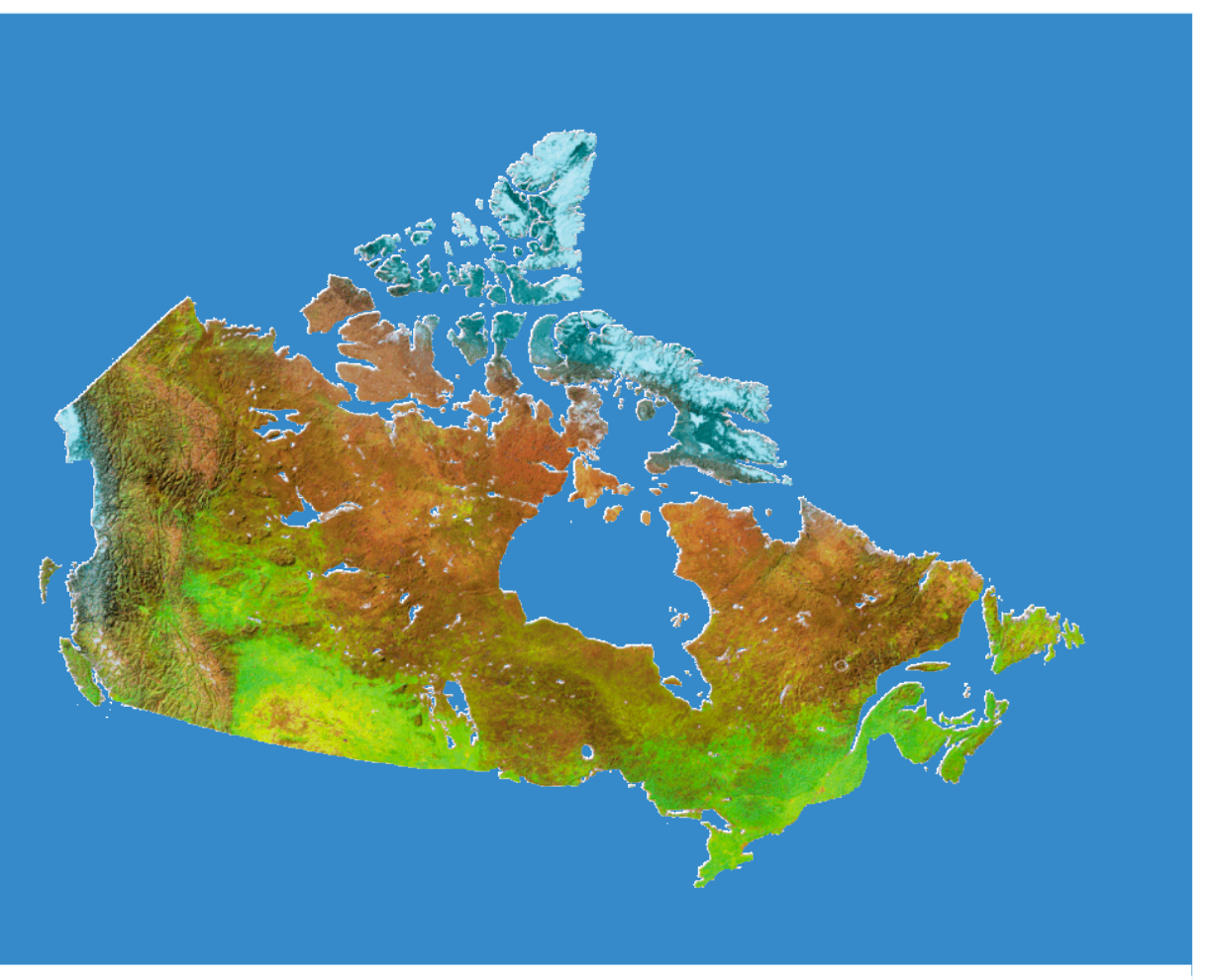


Introduction

The basement of the northern Stevenson Ridge area of west-central Yukon comprises a complex collage of pre-Devonian to Jurassic sedimentary, volcanic and plutonic rocks that were variably metamorphosed to sub-greenschist and amphibolites facies. These rocks are intruded and overlain by Middle to Late Cretaceous igneous suites which generally coincide with the topographic core of the Dawson Range. The Whitehorse plutonic suite is by far the most spatially extensive plutonic suite and underlies approximately 3500 km^2 in the Stevenson Ridge area alone. These rocks form part of a larger mid-Cretaceous igneous complex and continue to the northwest into the Stewart River and Tanacross map areas, and to the southeast into Mt. Nansen and Whitehorse areas. The tectonics of the Middle Cretaceous Cordillera are contentious and several different models have been presented to account for a magmatic bloom and generation of atypical magmatic suites across the Orogen. In detail, models range from arc magmatism followed by slab flattening, collision-related crustal thickening and anatexis, to slab breakoff (e.g., Selby et al., 1999, Driver et al., 2000, Mortensen and Hart, 2010, Hildebrand, 2013); however, all models require a change in tectonic setting at ca. 100 Ma. The purpose of this study is to utilize results of mapping, geochronology and geochemistry to clarify the relationships between Whitehorse plutonic suite phases in the Stevenson Ridge area. Utilizing new and compiled data, we make inference on the sources of Middle Cretaceous magmas and propose a model for the generation of the Whitehorse plutonic suite.

Field relationships, petrography and geochronology

In the Dawson Range area, the Whitehorse plutonic suite comprises a diverse suite of predominantly plutonic rocks ranging from diorite to syenogranite (major element classification). Diorite to monzogranite of the Dawson Range phase is the dominant phase. Tonalite and quartz diorite are the most distinctive rock types and are characterized by blocky porphyritic hornblende and lesser biotite. On the regional and outcrop scale, these are gradational with biotite-hornblende granodiorite and locally biotite ± hornblende monzogranite. U-Pb, Ar-Ar and Re-Os ages suggest that the Dawson range suite was emplaced very rapidly between ca. 104 and 100 Ma (this study; Wanless et al., 1978; Selby and Creaser, 2001; McKenzie et al., 2012). The Dawson Range phase was exhumed and unconformably overlain by the ca. 70 Ma Carmacks Group volcanic rocks. The unconformity and inter-formational Carmacks Group conglomerates commonly contain abundant blocky hornblende-biotite tonalite boulders derived from the Dawson Range phase.

The Dawson Range phase characteristically contains abundant equigranular to hornblende porphyritic diorite to quartz diorite enclaves that range in size from <1 to >10 cm. These enclaves are variably distributed, but, at least locally, form trains. Locally, pillowed hornblende-porphyritic diorite mingles with monzogranite indicating comagmatic emplacement. Hornblende-biotite diorite cuts the monzogranite phase and is also cut by it. Ar-Ar dating of hornblende diorite yielded 102.8 and 100.4 Ma ages (hbl and bt, respectively). These age and field relationships indicate that mafic and felsic magmatism were coeval. Abundant diorite enclaves likely represent disaggregated mafic sills and dykes that were emplaced co-magmatically into the felsic phases of the suite (e.g., Foster and Hyndman, 1990). The Dawson Range suite thus represents a hybridized and variably evolved mixture of mafic and felsic magma sources.

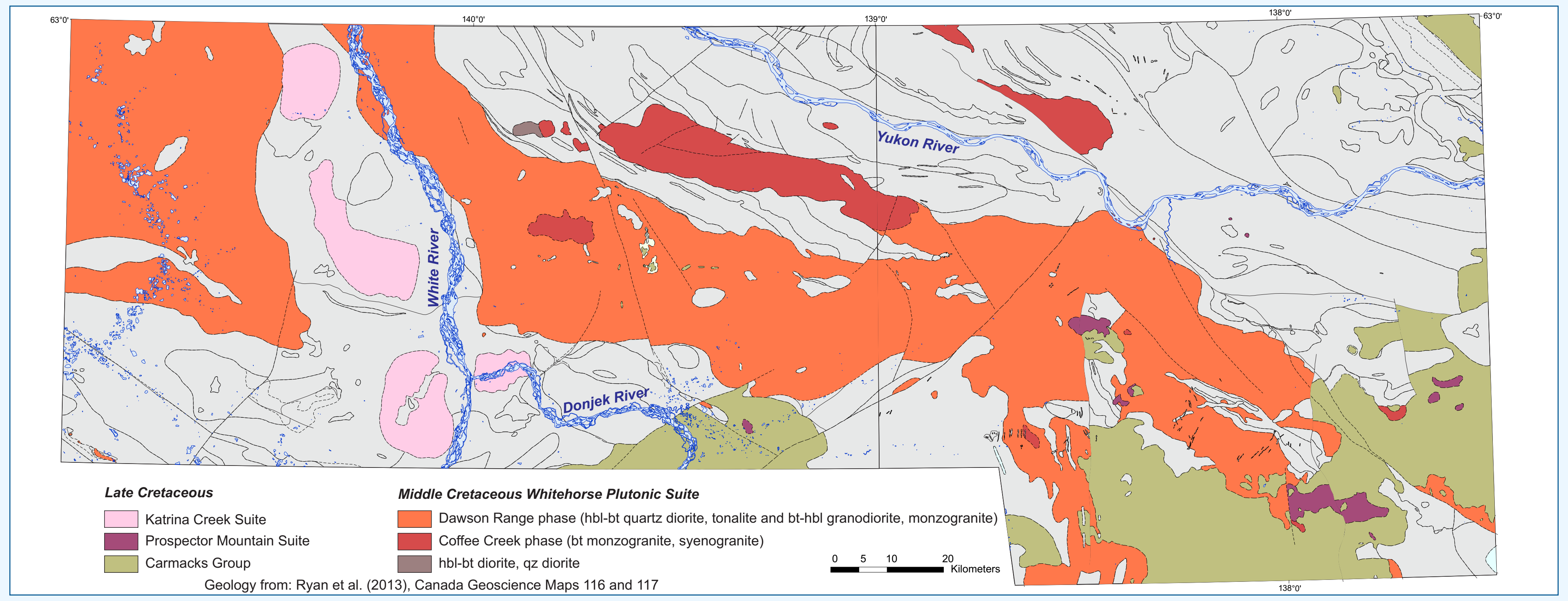
In several localities, isotropic Dawson Range phase appears to be interlayered with foliated melanocratic hornblende gabbro. Locally, foliated layered hornblende – plagioclase cumulates are present. Although these were not dated directly, these may represent the cumulate rocks to the Dawson Range phase. Their foliated nature makes them difficult to distinguish from foliated amphibolite of the Yukon-Tanana basement; however, their melanocratic nature and cumulate chemical compositions distinguish them from Paleozoic amphibolites.

The Coffee Creek phase forms discrete mappable bodies of homogeneous biotite syenogranite; however, the actual contact with the Dawson Range phase is indistinct. The Coffee Creek phase generally lacks mafic enclaves. U-Pb ages of the syenogranite indicate that it is broadly coeval to slightly younger than the Dawson Range phase (cf. Tempelman-Kluit, 1974).

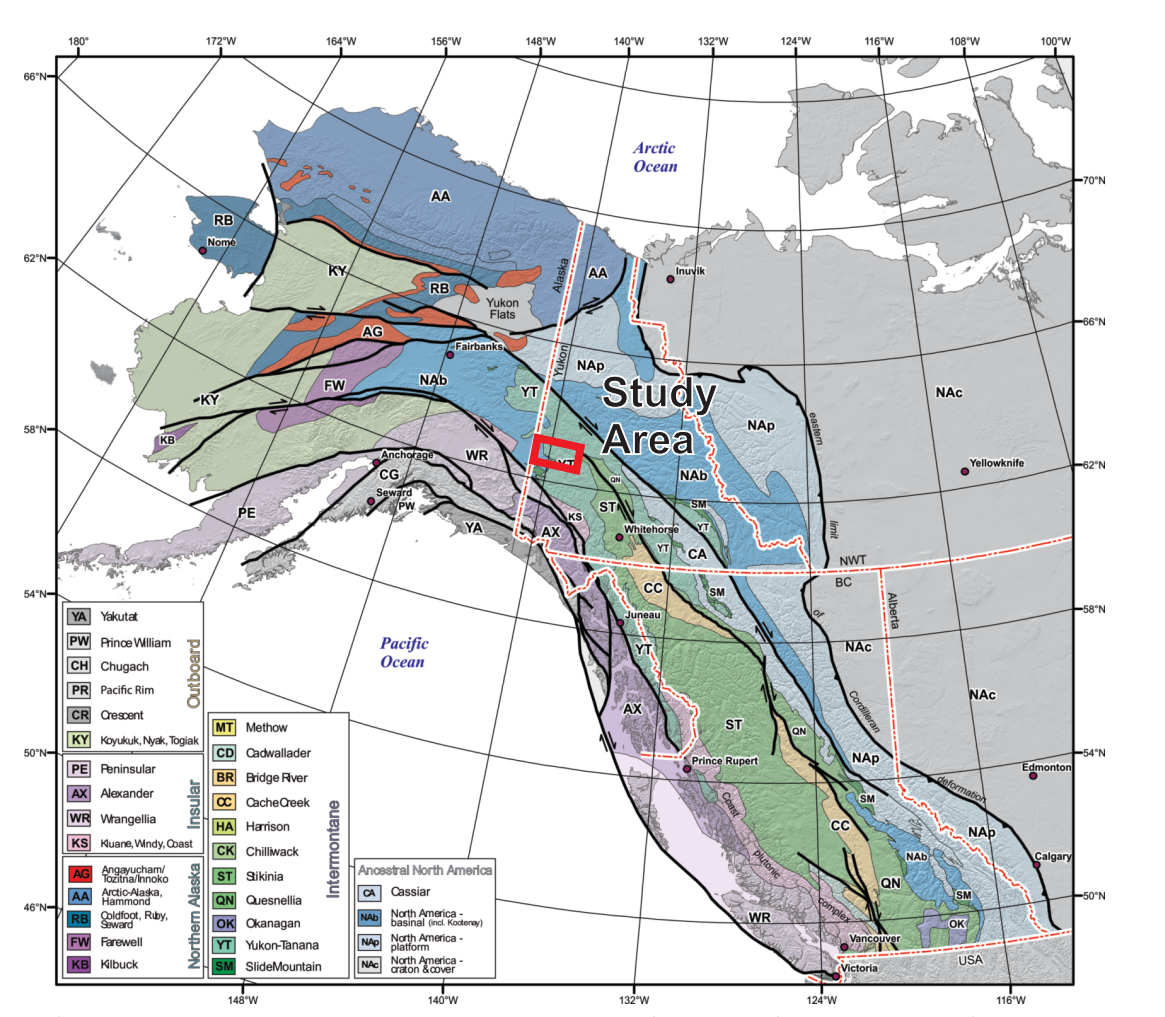
Geochemical characteristics

In the three-tiered granitoid classification of Frost et al. (2001), the Dawson Range phase rocks are (i) magnesian (oxidized) and (ii) plot along calc-alkalic to calcic trends. Dawson Range phase granitoids exhibit aluminum saturation index (ASI 0.8-1.2) that is characteristic of both peraluminous and metaluminous suites. As most samples contain primary hornblende, a characteristic of metaluminous suites, the high ASI values are attributed to weathering or alteration. All samples exhibit similar patterns on extended trace element diagrams, including LREE enrichment and negative La-Nb anomaly. Th is variably enriched and exhibits a generally collinear positive relationship with SiO$_2$ (not shown). The presence of negative Nb anomaly in the most mafic samples suggests that the Dawson Range phase was generated from an arc-like source. Sr-Nd-Pb Isotopic analyses by Selby et al. (1999) indicate strong contamination by or derivation from Precambrian crustal sources.

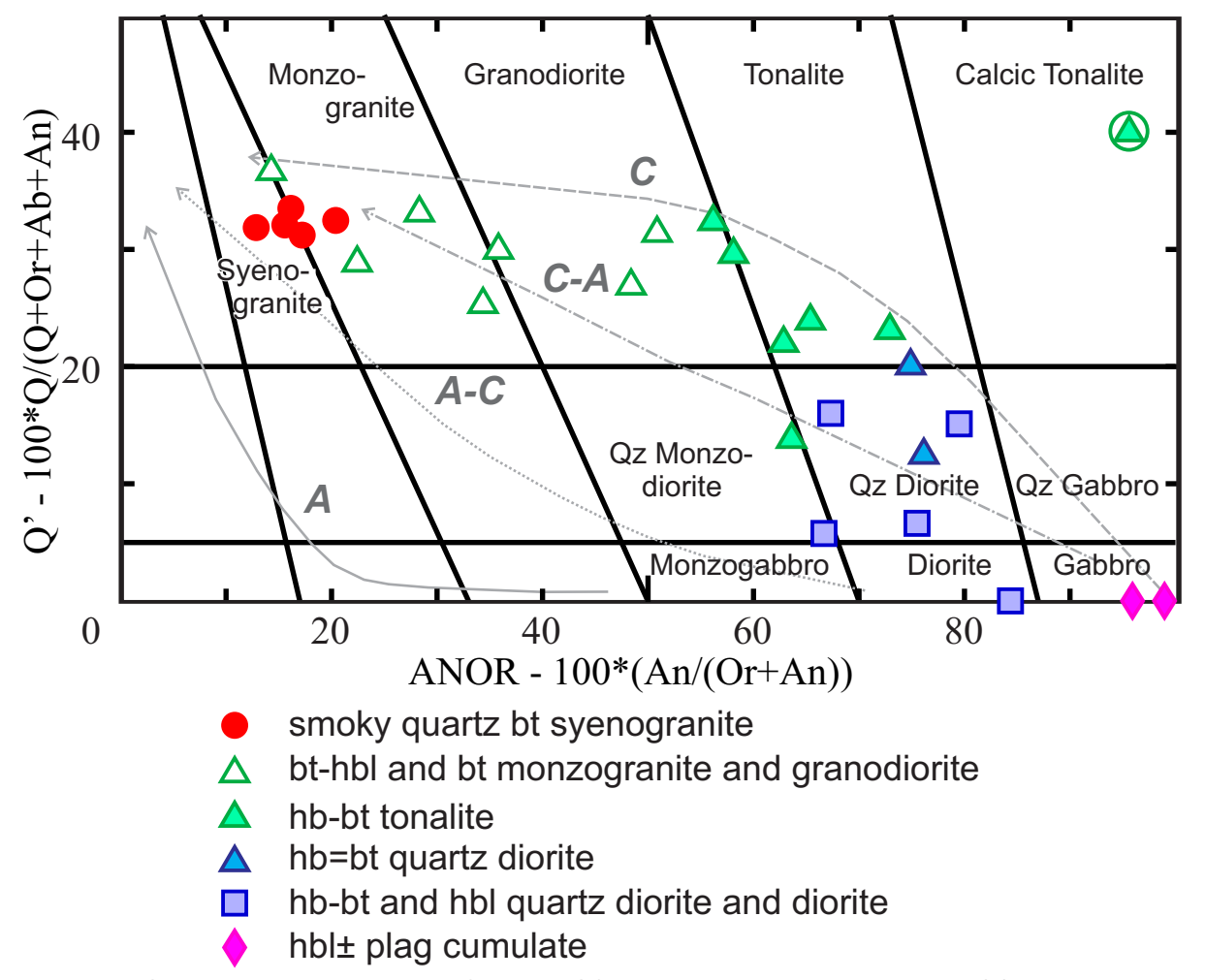
The Coffee Creek phase is highly evolved, magnesian and has high ASI values (1.04-1.08), although peraluminous mineral phases have not been observed. In contrast to the Dawson Range phase, it is characterized by high Nb, high Nb/Y and high Th/La ratios more typical of alkaline suites.



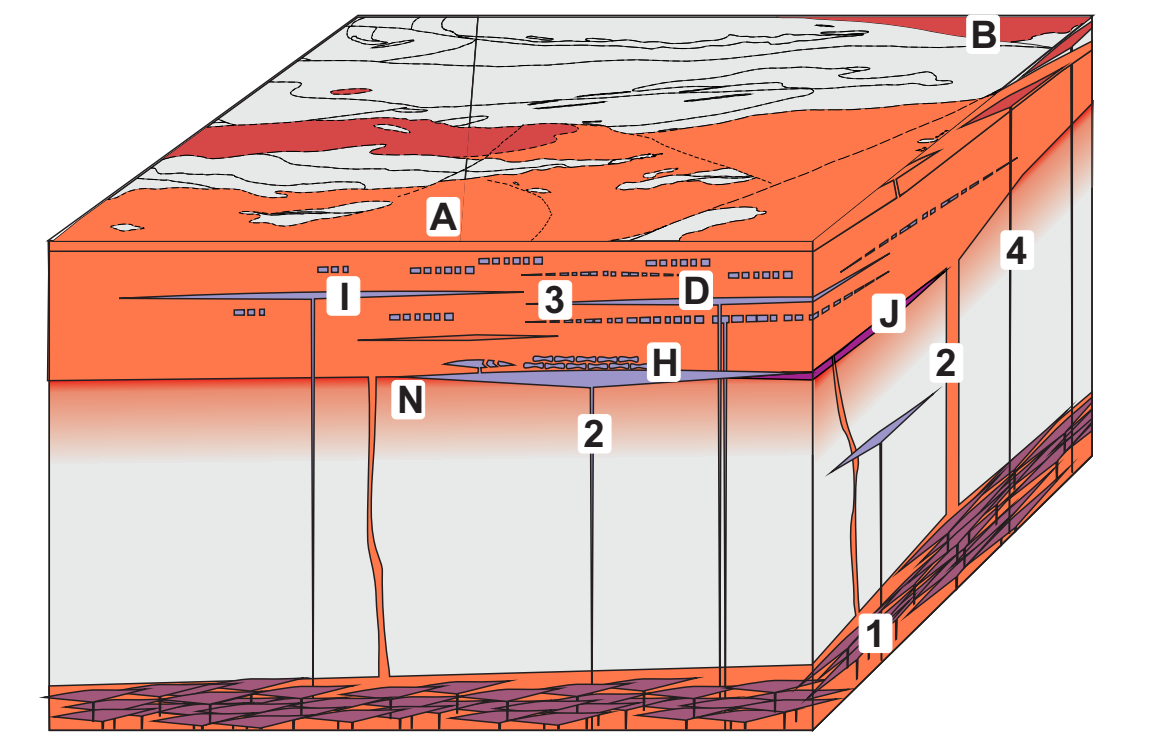
Geology from: Ryan et al. (2013), Canada Geoscience Maps 116 and 117



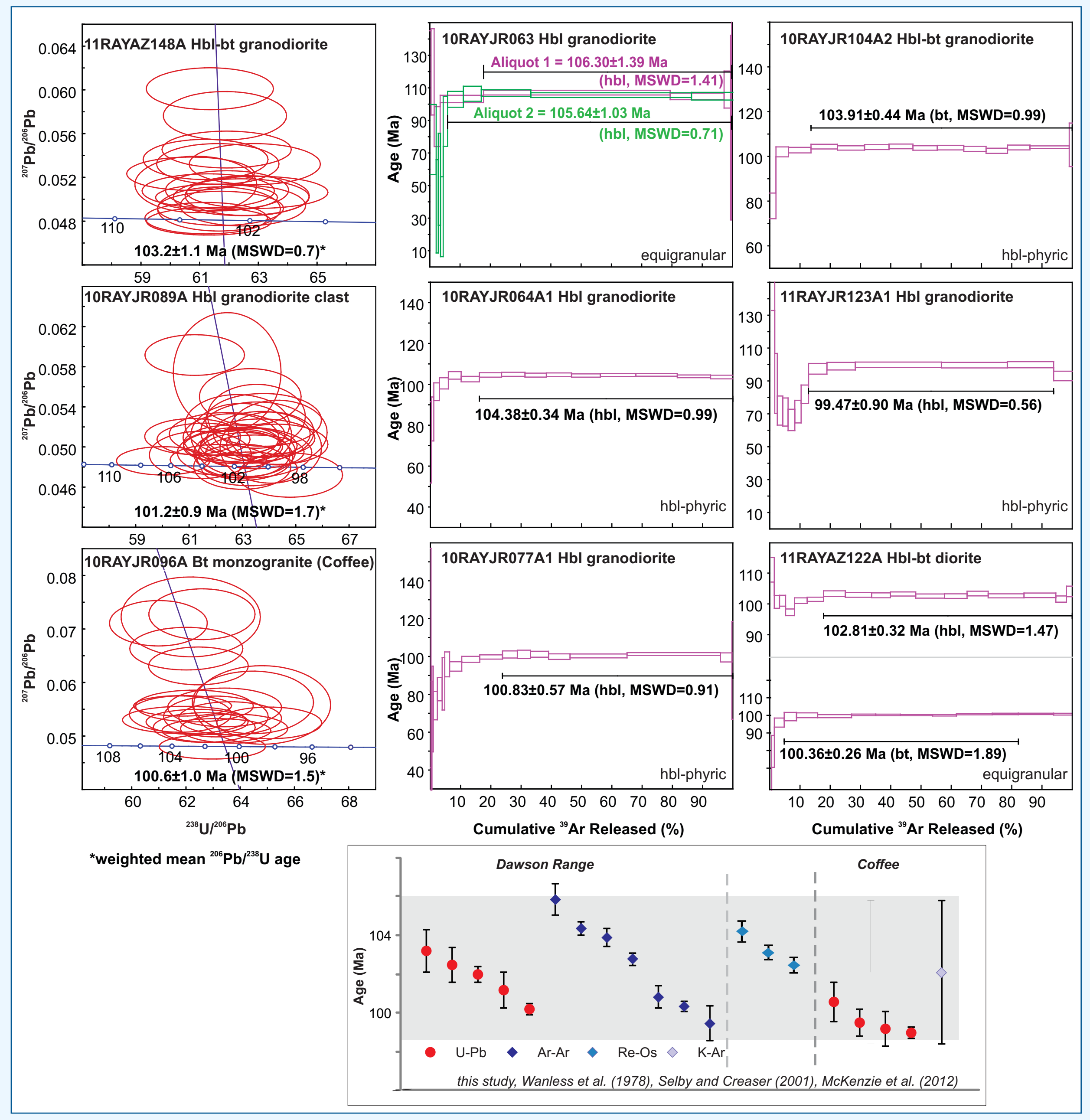
Colpron, M. and Nelson, J.L., 2011. A Digital Atlas of Terranes for the Northern Cordillera. Accessed online from Yukon Geological Survey (www.geology.gov.yk.ca), 10/2013

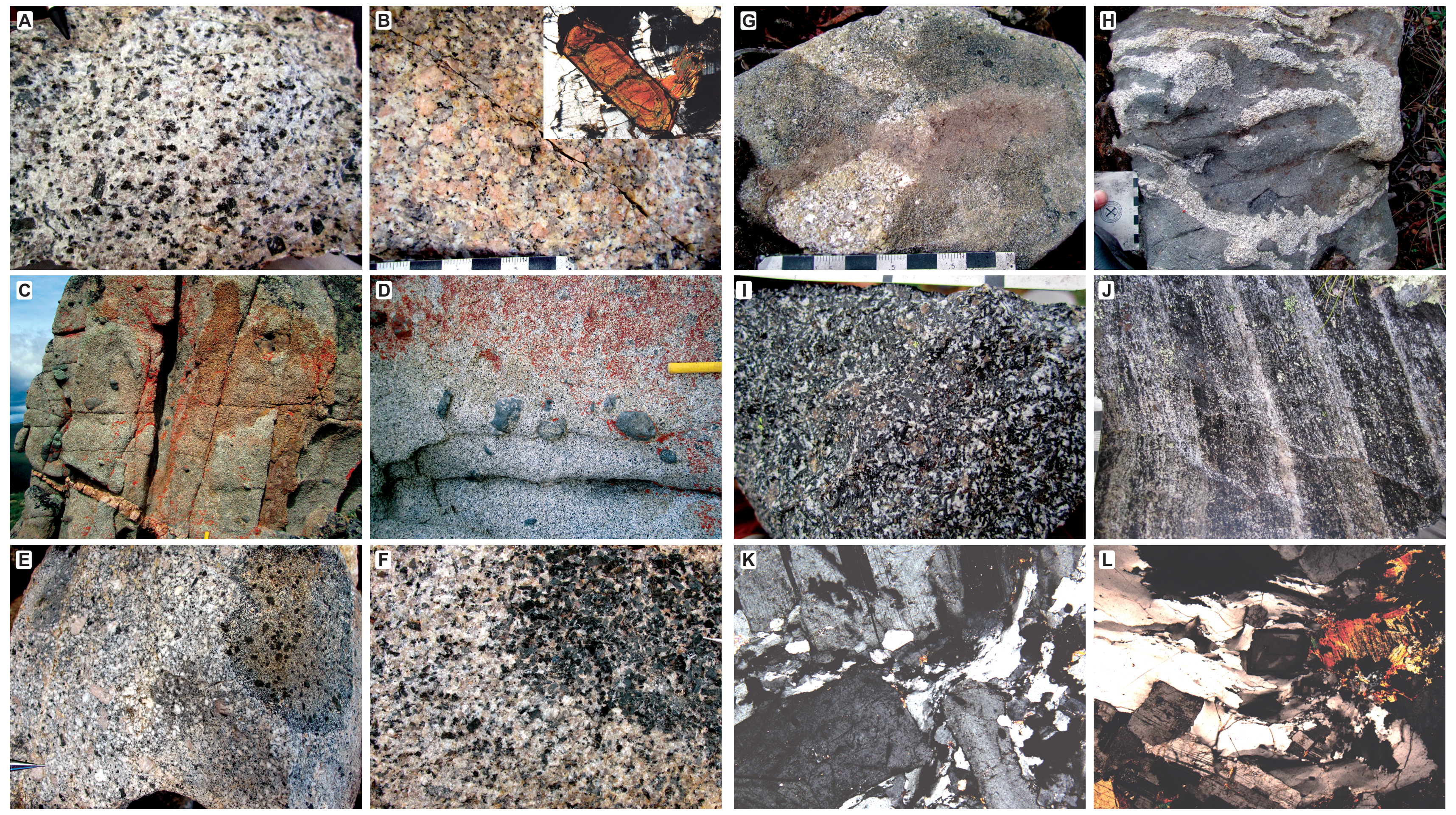


Plot from: Whalen, J. and Frost, C., 2013, GSA Abstracts with Programs., v. 45(3), 24.



Schematic model for melt interactions. 1. Emplacement of mantle-derived melt into the lower and middle crust leading to crustal anatexis. 2. Migration of melts into upper crust. 3. Emplacement of mafic sills into the upper crustal magma chamber leads to disaggregation, mixing and hybridization of the Dawson Range phases. 4. Emplacement of discrete Coffee Creek phase plutons. Examples are shown in photos (letters).



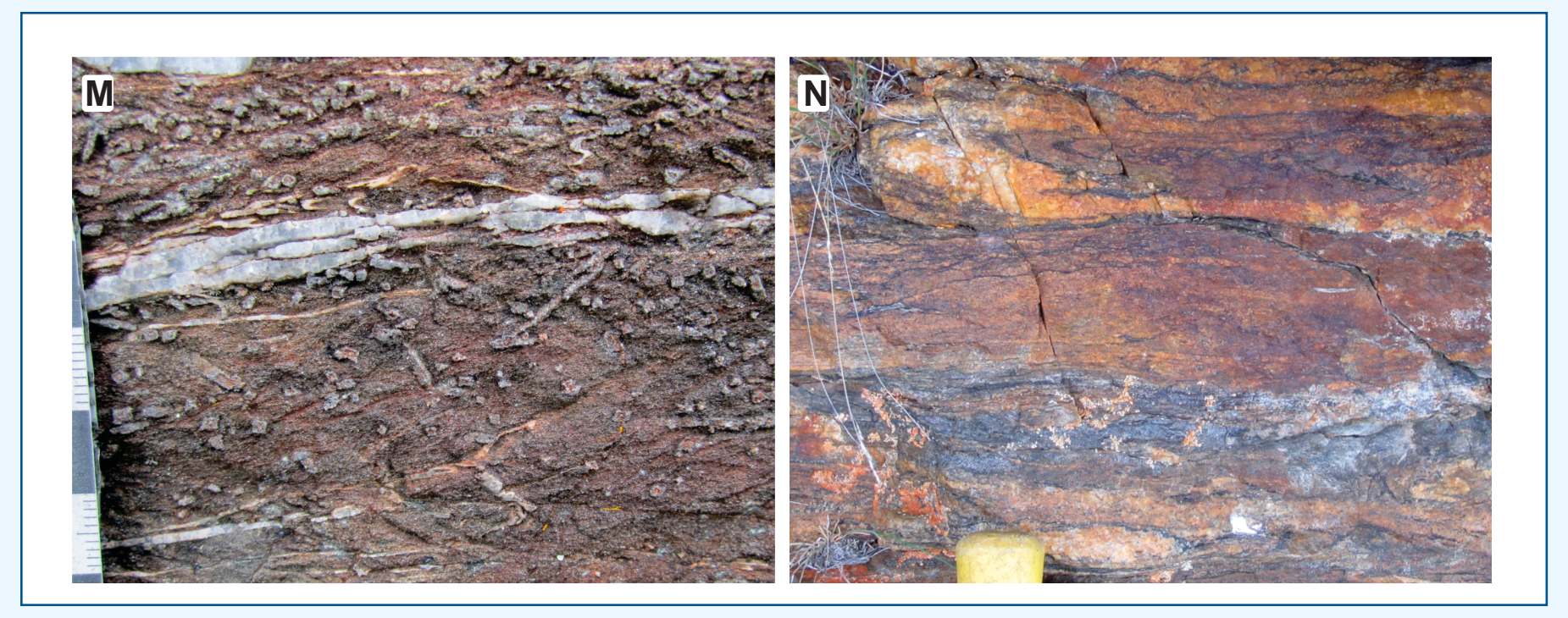


Representative photographs of Whitehorse Plutonic Suite in the Dawson Range area. A. Dawson Range phase hornblende-biotite grandodiorite with characteristic blocky hornblende. B. Coffee phase biotite syenogranite (Isaac Hayes pluton), inset: large allanite crystals are common in this phase. C. Characteristically abundant cognate hornblende diorite and gabbro inclusions in the Dawson Range phase. D. Train of diorite inclusions derived from a co-magmatic diorite dyke. E. Hornblende poprhyritic diorite enclave in K-feldspar porphyritic, biotite-hornblende Dawson Range monzogranite. F. Hornblende diorite enclave in Dawson Range phase hornblende-biotite grandodiorite. G. Dawson Range phase monzogranite dyke cuts hornblende quartz diorite. H. Pillowed diorite in Dawson Range phase monzogranite indicate coeval mafic and felsic magmatism. I. Hornblende-biotite diorite from a discrete diorite stock. J. Interlayered strongly foliated hornblende-plagioclase cumulate may form part of the basal Dawson Range suite. K, L. Photomicrographs of deformation fabrics in the Dawson Range phase granodiorite. Deformation is localized in quartz, locally resulting in development of quartz ribbons, and along grain boundaries, where plagioclase subgrains and neoblasts with deformation twins are formed. Ductile deformation of quartz and recrystallization of feldspar suggest that the deformation occurred during of shortly after emplacement of the Dawson Range batholith. M. Contact metamorphic aureole locally contains andalusite-bearing assemblages in metapelite. N. Abundant migmatite west of White River may represent the basal contact metamorphic aureole.

Discussion

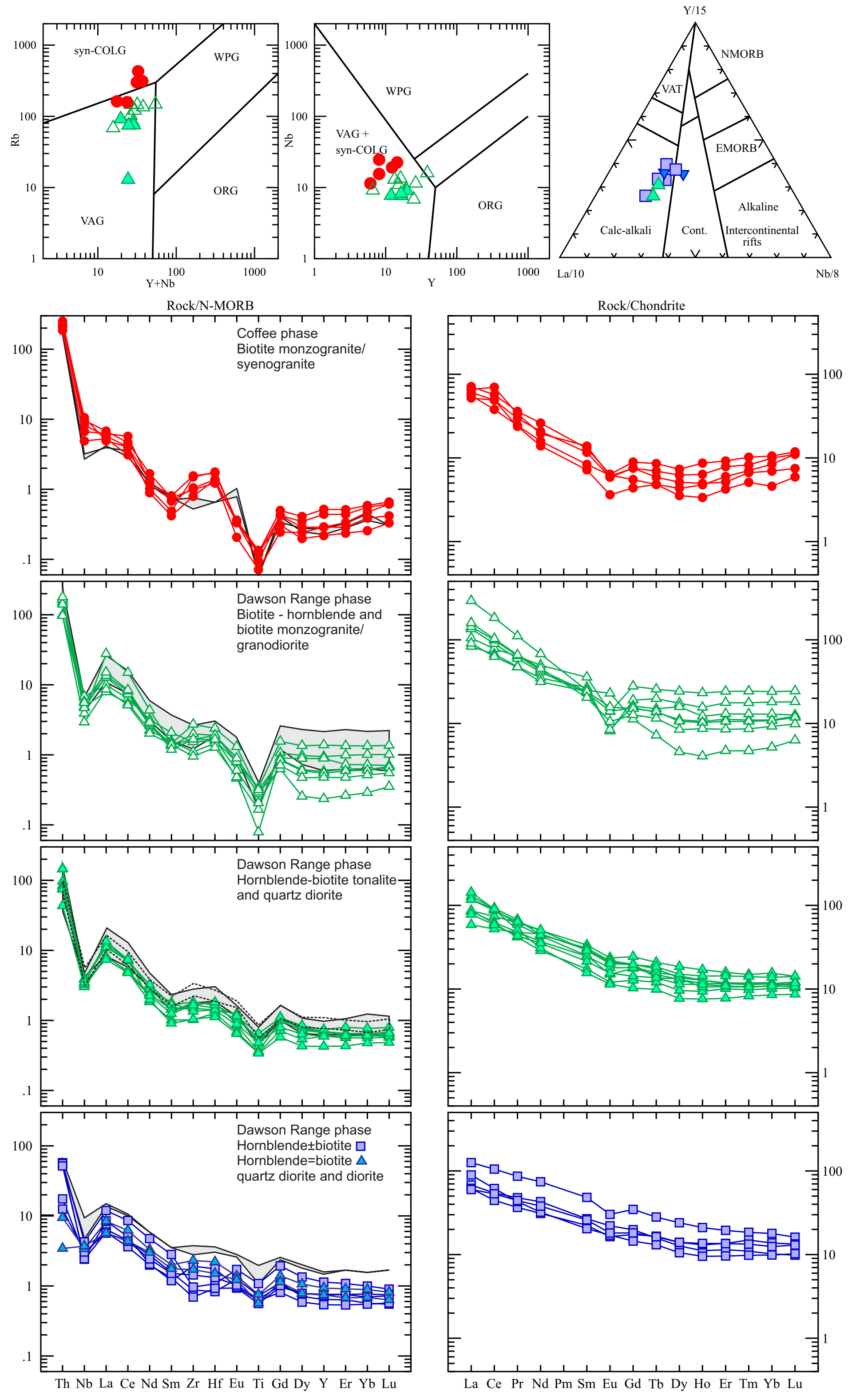
Geochronology of the Whitehorse plutonic suite in Dawson Range suggests that it was rapidly emplaced over duration of ca. 5 m.y. Field relationships and geochemical characteristics of the Dawson Range and Coffee Creek phases indicate that they originated from distinct sources that had limited interaction with each other. Specifically, the discrete bodies of the Coffee Creek phase lack abundant mafic inclusions that are typical of the Dawson Range phase. The geochemical characteristics of the Coffee Creek phase are also distinct, suggesting that there was limited interaction between the phases and that the Coffee Creek phase is not related to Dawson Range phase by fractionation.

Many workers suggested that the Whitehorse plutonic suite was emplaced syn-tectonically. Macroscopic magmatic lineation defined by hornblende and locally feldspar is common throughout the Dawson range phase supporting syn-tectonic emplacement (e.g., Payne et al., 1987; Johnston, 1999, Joyce, 2002), although the suite generally appears macroscopically undeformed. Microscopically, quartz commonly preserves evidence of extensive deformation as indicated by strongly undulose extinction and development of quartz ribbons. Deformation outside of quartz is concentrated along grain boundaries where it is accommodated by subgrain rotation and recrystallization of feldspar. These relationships indicate that the Dawson Range phase underwent solid-state deformation at amphibolites facies. As the Dawson Range magmatism is the last major plutonic episode, and zircon, hornblende and biotite record similar ages, the deformation was in part syn-magmatic and in part occurred during post-emplacement cooling of the Whitehorse plutonic suite. Preservation of phases that range from highly evolved to banded cumulate suggests that the Dawson Range phase likely has a sheet-like morphology that was inflated by progressive emplacement of mafic to felsic sills. This is supported by the exposure of a domain of basement rocks around White River, which likely forms part of a window through the Dawson Range phase. The migmatitic rocks that characterize this domain may be related to the contact metamorphism on the floor of the batholith.



Selby et al. (1999) interpreted the Dawson Range phase quartz diorite to monzonite to be produced by partial melting of crust following over-thickening of North American margin, similar to the coeval Cassiar batholith (Driver et al., 2000). This interpretation was in part based on isotopic evidence for significant involvement of continental crust (εNd -4.5 to -7.4) and on the lack of coeval mantle-derived mafic rocks. Our data indicate that the Dawson Range phase magmatism was bimodal and included significant volume of mafic to andesitic melts that are now preserved as either enclaves in hybridized granodiorite or as discrete stocks. Although isotopic data on the most primitive mafic to intermediate rocks are lacking, they cannot be generated by anatexis related to crustal thickening alone. Rather they were produced following emplacement of mantle derived melts into the lower and middle crust.

Syn-tectonic emplacement of bimodal Dawson Range phase and non-arc Coffee Creek phase, coeval with generation of S-type melts elsewhere in the orogen provides insight into the tectonic setting of Middle Cretaceous high magmatic flux episode. Normal arc-type magmatism does not adequately explain the voluminous S-type and non-arc melts (Driver et al., 2000) whereas crustal anatexis following thickening (Selby et al., 1999) does not adequately explain abundant I-type mafic to intermediate rocks nor the non-arc melts. Tectonic setting such as slab break-off can, in principle, explain emplacement of coeval I-type, S-type and non-arc magmas (e.g., Whalen et al., 2006). Alternatively, the Middle Cretaceous high magmatic flux episode may be explained by upper plate shortening and retro-arc under-thrusting of continental basement during active subduction (DeCelles et al., 2009). This process has been inferred to introduce fertile continental basement into the magma-generating region of the arc leading to episodic high magmatic flux that is followed by delamination of ultramafic melt residues (DeCelles et al., 2009).



Plots and normalization factors from: Pearce, J. A. et al., 1984, Journal of Petrology, v. 25, 956-983. Cabanis, B. and Lecolle, M., 1989, Comptes Rendus de l'Academie des Sciences, v. 309, 2023-2029. Sun, S. S. and McDonough, W. F., 1989, Geological Society Special Publications, v. 42, 313-345.

References

DeCelles, P. G. et al., 2009, Nature Geoscience, v. 2, 251-257; Driver, L. A. et al., 2000, GSA Bulletin, v. 112, 1119-1133; Hildebrand, R. S., 2013, GSA Special Paper 495, 169 p.; Johnston, S. T., 1999, Journal of Structural Geology, v. 21, 1103-1108; Joyce, N., 2002, M.Sc. thesis, University of British Columbia, 199 p.; McKenzie, G. G. et al., 2012, Yukon Exploration and Geology, 73-97; Mortensen, J. K. and Hart, C. J. R., 2010, GSA Abstracts with Programs, v. 42, 676; Payne, J.G. et al., 1987. Indian and Northern Affairs Canada, Open File 1987-3; Selby, D., and Creaser, R. A., 2001, Economic Geology, v. 96, 1461-1467; Selby, D. et al., 1999, Canadian Journal of Earth Sciences, v. 36, 1463-1481; Tempelman-Kluit, D. J., 1974, Geological Survey of Canada Paper 73-41, 97 p.; Wanless, R. K. et al., 1978, Geological Survey of Canada Paper 77-2; Whalen, J. B. et al., 2006, Lithos, v. 89, 377-404

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