Coast Belt Arc-Tempo Drives Rocky Mountain Foreland Basin

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Abstract

Plate margin dynamics typically drive inland tectonics and structure from afar. Arc magmatism is arguably the most important mechanism responsible for crustal growth, while lithospheric subduction and terrain accretion provide the necessary push behind foreland fold and thrust belts. In arcs formed on continental lithosphere, flare-ups correlate with regional structural events across broad domains of contraction and extension. Here the link is investigated between Cretaceous-Cenozoic volcanic arc assemblages and related events of the Coast Belt, with equivalent aged stratigraphy in the clastic foreland wedge of the Western Canada Sedimentary Basin (WCSB), as well as similar aged thrust faults of the Rockies and Foothills (Figures 1 and 2). Although a relationship with arc development and terrain accretion to the west has always been inferred in driving the fold and thrust belt with associated foreland sedimentation, here it is made explicit what some of those links actually are. A regional synthesis is presented of relevant data, incorporating regional maps, radiogenic age dates of igneous rocks, igneous geochemistry, deformation events, burial-uplift profiles for clastic rocks, and faulting.

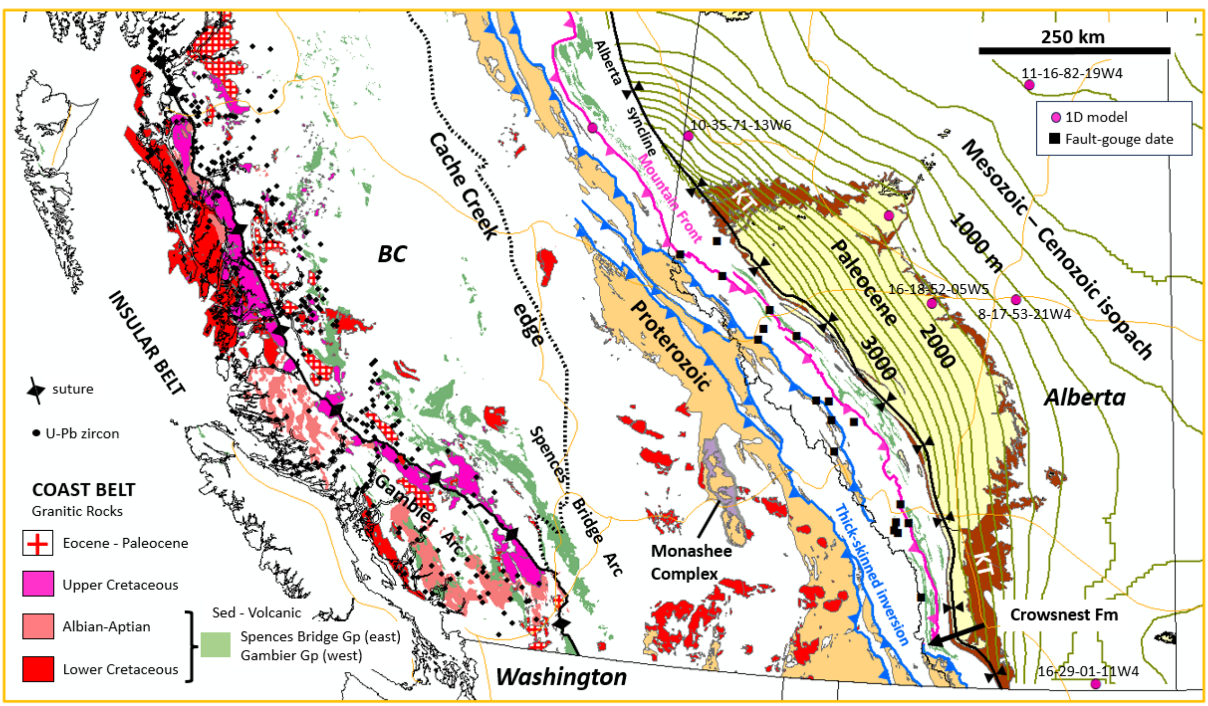

Figure 1. Geologic map of the southern Canadian Cordillera highlighting volcanic arc features of the Coast Belt, and age equivalent features of the Western Canada Sedimentary basin fold and thrust belt.

With the extensive coverage and availability of U-Pb zircon dates from the Coast Belt (Cecil et.al., 2018), a strong correlation can now be made between the rate of igneous activity, or arc-tempo, with thrust fault activity (Pana and van der Pluijm, 2015), and sediment accumulation in the foreland (Figure 3). Granitic and volcanic rocks dominate the Coast Belt, and although episodic flare-ups along and across arc are noted, magmatic activity was largely continuous from middle Jurassic, through to Paleocene time, ending abruptly in the Eocene; the span corresponds closely to the principal phase of Rocky Mountain foreland clastic sediment accumulation, beginning with the Fernie Group, and ending with the Paskapoo Formation, totalling 4 km in thickness (Figure 1). Following the end of igneous activity in the Coast Belt, uplift and erosion are recorded from fission track data (Parrish, 1982), during Eocene-Miocene time, also matching the principal stage of uplift in the foreland where 2 km of erosion is recorded after peak burial in the Paleocene.

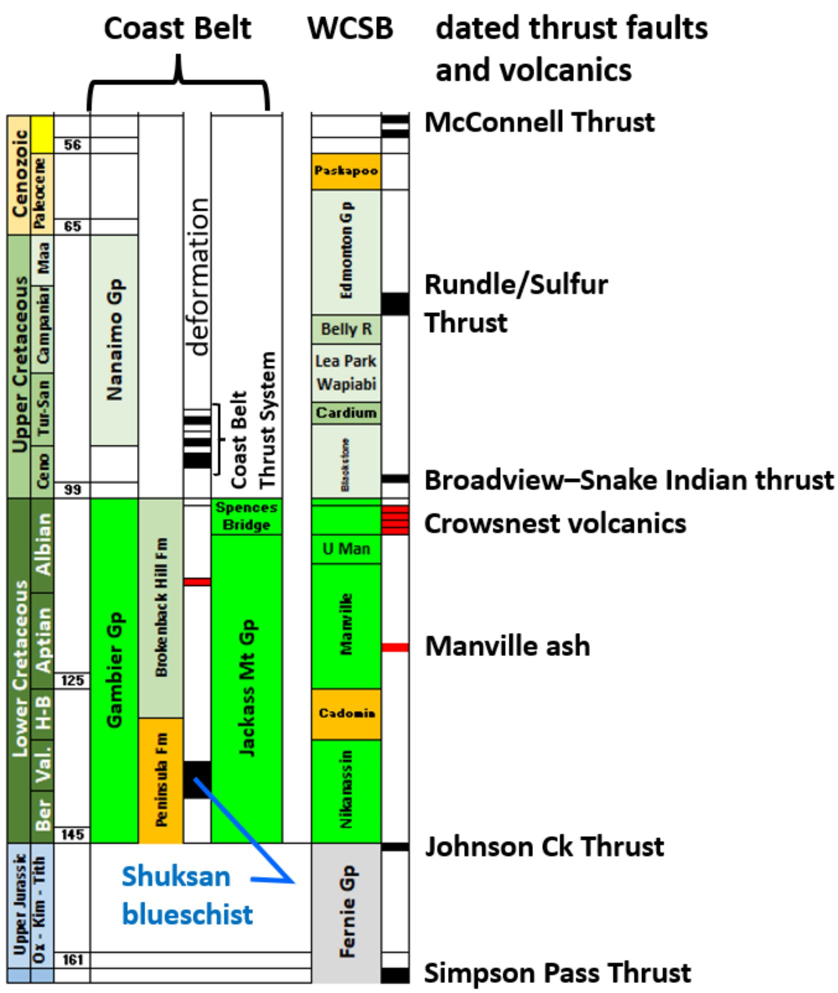

Figure 2. Simplified stratigraphic chart showing age equivalent Cretaceous-Paleogene stratigraphy from the Coast Belt and WCSB. Coast Belt Thrust System dates are from Journeay and Friedman (1993); foreland thrust dates are from Pana and van der Pluijm (2015); Manville ash from Fietz (2023).

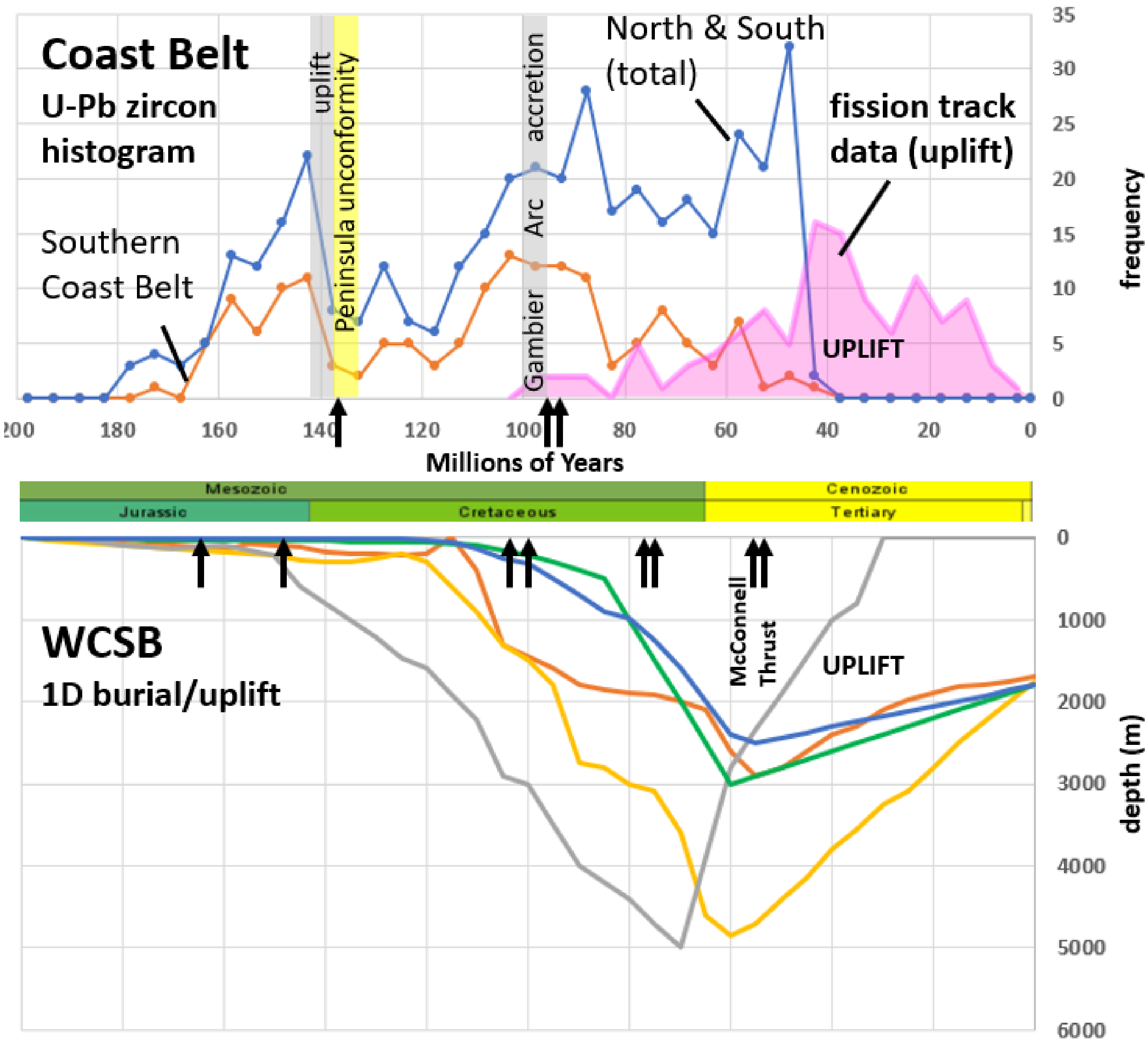

Figure 3. Coast Belt U-Pb zircon age date histogram (Cecil et al., 2018), depicting arc tempo match with WCSB burial depth and uplift profiles from 1D modelling (Roberts et al, 2005; Wright et al., 1994). Fission track data (Parrish, 1982) demonstrate late cooling and uplift following arc activity, also matching with WCSB uplift following peak burial. Arrows are dated thrust faults and deformation in the Rocky Mountains (Pană and van der Pluijm, 2015), and Coast Belt (Journeay and Friedman, 1993; Cordova et al., 2019)

Marine conditions persisted across the Coast Belt during the Lower Cretaceous, as recorded in the stratigraphy of the Gambier Group (Arthur et al., 1993), which was deposited in an offshore volcanic arc setting above an inferred west-dipping subduction zone, along the eastern flank of the Insular Super Terrane (Lynch, 1995; Hildebrand, 2009; Sigloch and Mihalynuk, 2017). The volcanic arc was developed unconformably over a Jurassic and older basement, featuring a well-developed granite-clast basal conglomerate. Lithofacies include tidal-flat and near-shore tidal channel IHS deposits (Figure 4) along side of subareal calc-alkalic volcanic edifices (Figure 5), with flanking offshore deposits of shale and euxinic shale. The Gambier arc developed outboard of the coeval and opposite facing Spences Bridge Arc to the east (Figure 1; Thorkelson and Smith, 1989; Lynch, 1995). The Albian volcanic and plutonic rocks of the Coast Belt arc system are also contemporaneous with landward volcanic rocks and plutons of the Crowsnest Formation and Howell Creek system, situated to the east within the southern Rocky Mountain fold and thrust belt (Figure 1). The geochemistry of these rocks however is markedly different, with the coastal system showing a calc-alkalic trend typical of volcanic arcs; whereas to the east the Crowsnest-Howell Creek rocks are strongly alkalic featuring trachitic to phonolitic compositions (Figure 6). It is noted that alkaline magmas can be characteristic of areas overlying deeply subducted plates (Irvine and Baragar, 1971); in which case the Crowsnest-Howell Creek rocks may represent the back-arc counterpart to the Spences Bridge fore-arc.

Apatite samples in Cretaceous strata of the foreland basin also display track characteristics suggestive of a contemporaneous volcanic source for the apatite (Isler et al., 1999); this is consistent with the widespread presence of Lower Cretaceous bentonite deposits in the foreland basin, demonstrating a direct material link between far-field volcanic activity and basin fill (Maiklem and Cambell, 1965; Mellon, 1967). Available Rare Earth Element data (REE) for Albian volcanic rocks and plutons, and from foreland bentonite layers are compared, demonstrating a spread in values matching both back-arc and fore-arc compositions (Figure 8), indicating likely material contributions from both. However, a pronounced Europium anomaly is recorded in the bentonites (Figure 7). Typically, Eu partitions strongly into the feldspars during crystallization (Hanson 1980); in which case the negative Eu anomaly for the bentonites may indicate that either (1) residual feldspar fractionation occurred in the magma chamber prior to magma filter-pressing and ash eruption; or possibly (2) airborne-fractionation occurred, due to coarser proximal crystal tuffs scrubbing Eu from the airborne mass, leaving far-travelled ash deposits to be depleted in Eu.

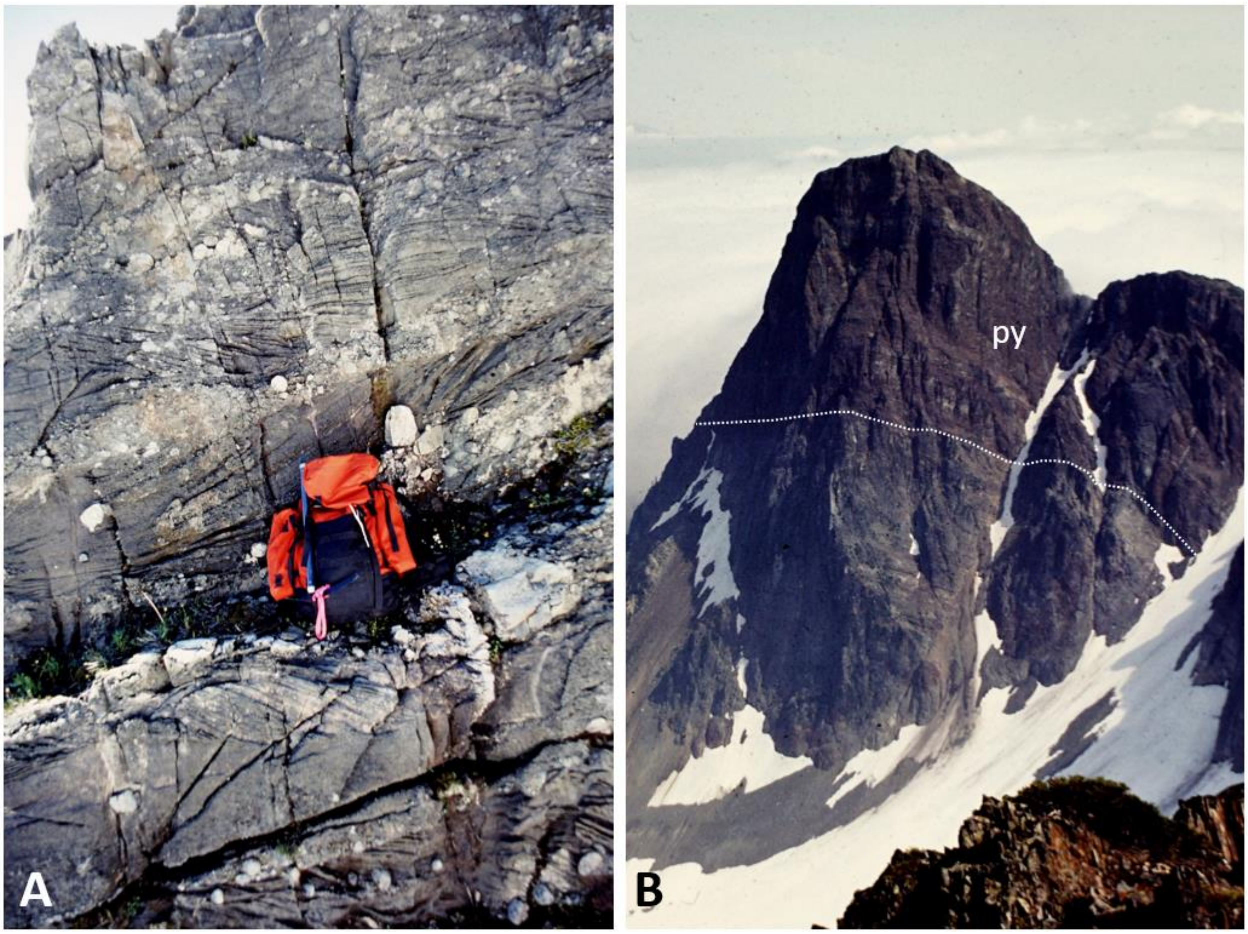

Figure 4. (A) Lower Cretaceous Gambier Group Peninsula Formation IHS tidal channel deposits of coarse dark epiclastic sandstone, displaying opposite-dipping strata and coarse granite clast conglomerate lags; (B) Peninsula Formation becoming shalier and pyritic in overlying strata; Coast Belt NW of Harrison Lake.

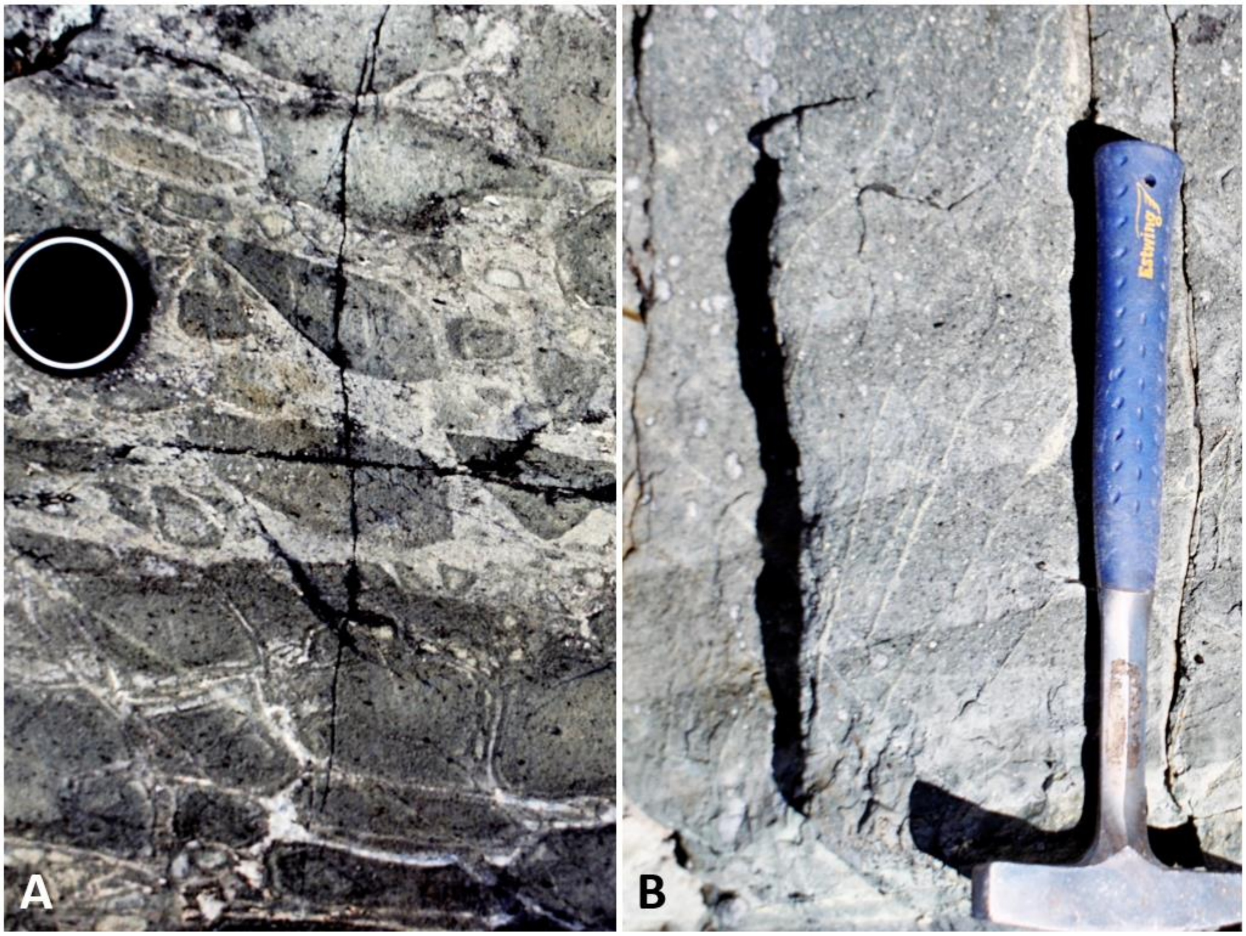

Figure 5. Lower Cretaceous Gambier Group Brokenback Hill Formation; (A) andesitic pyroclastic breccia, and (B) well bedded lapilli tuff; Coast Belt NW of Harrison Lake.

Uplift and erosion are recorded throughout the Cenozoic for both the Coast Belt as well as the Rocky Mountain Fold and Thrust Belt, and is most pronounced in the period from 40 Ma to the present, once volcanic activity had largely ceased and arc tempo reduced to zero (Figure 3). Fission track data (Parrish, 1982) records approximately 5 km of uplift along the axis of the Coast Belt since 40 Ma (and locally as much as 6-9 km); whereas the Western Canada Sedimentary Basin has undergone between 2-5 km according to 1D modelling, coal moisture data, and apatite fission track analysis (Isler et al., 1999). For the Western Canada Sedimentary Basin, basin-wide uplift and erosion is one of the key controls on the generation of present-day overpressures, and past hydrocarbon expulsion-migration via uplift through the frac-gradient; Figure 8 uses the tight Montney resource play as an example (Lynch and Stasiuk, 2011), with forward modelling in pressure-depth space through the uplift, to illustrate the effects of Cenozoic unloading on pressure distribution and hydrocarbon expulsion.

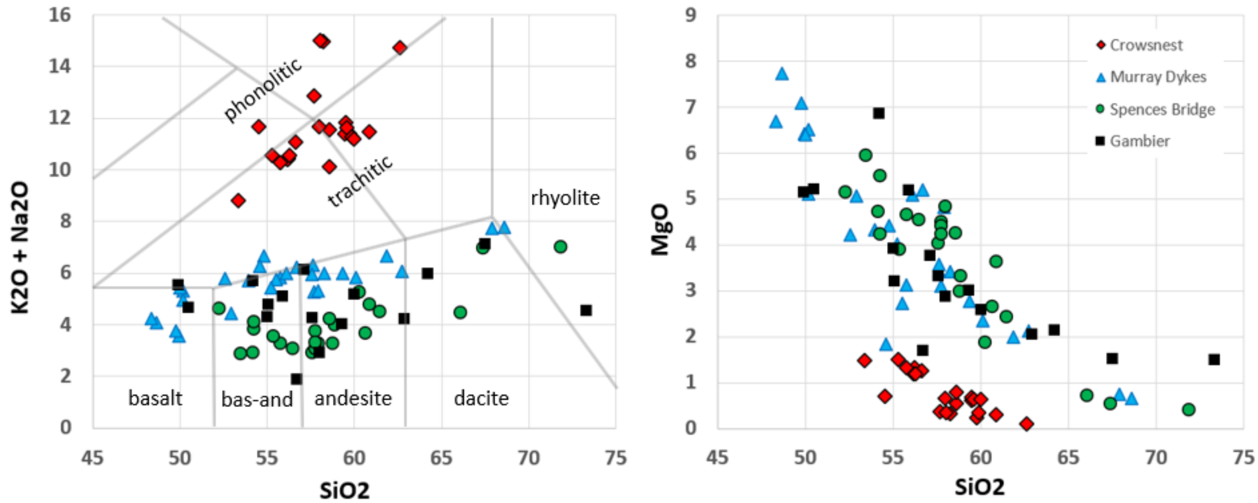

Figure 6. Alkali and Mgo Harker diagrams of Albian volcanic rocks and dykes from the Gambier Group (Lynch, 1995), Spences Bridge Group (Thorkelson, 1986), Murray Dykes (Ogloff, 2020), and Crowsnest – Howell Creek suite (Bowerman et al, 2006).

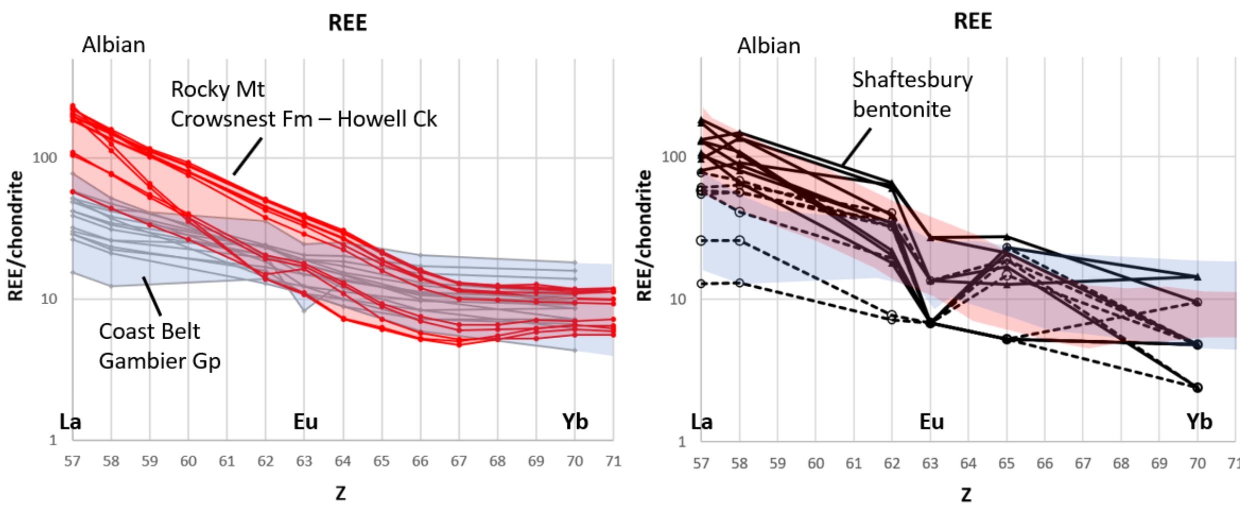

Figure 7. Rare Earth Element (REE) patterns for Albian volcanic assemblages, including: Coast Belt Gambier Group (Lynch, 1995); Rocky Mountain Crowsnest Formation – Howell Creek assemblage (Bowerman et al., 2006); and Alberta Plains Shaftesbury Formation bentonites (Dufresne et al., 1995). Dashed black lines indicate bentonites with REE compositions better matching Coast Belt volcanic rocks, whereas solid black lines with higher light-REE values have a stronger affinity with Crowsnest Formation compositions.

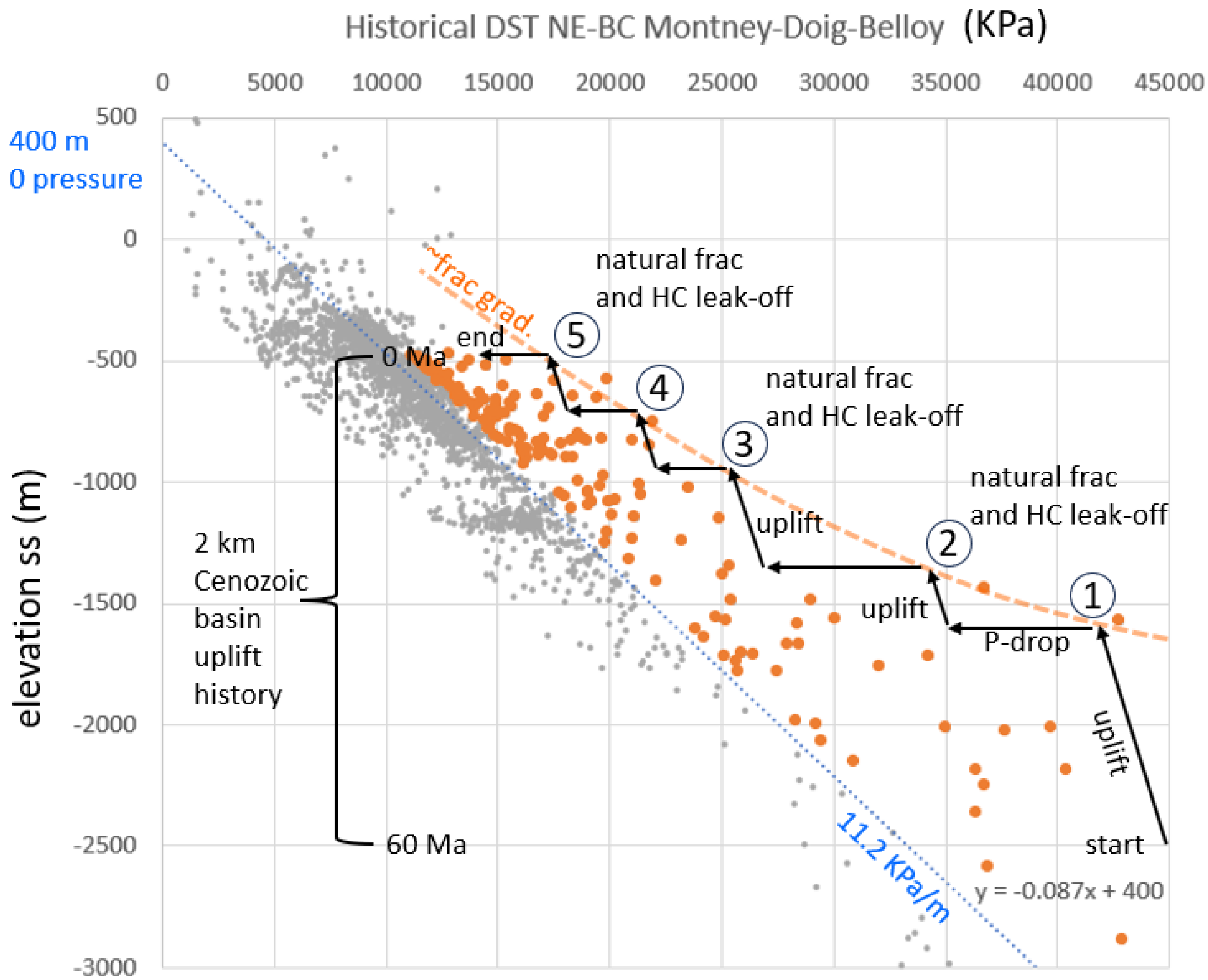

Figure 8. Modelled effects of Cenozoic isochoric uplift on overpressures, along thermal gradient, with step-wise forward modelling (1-5) illustrating potential incremental break-down of formation and hydrocarbon escape (using the Triassic Montney tight resource-play as an example; Lynch and Stasiuk, 2011). Historical DST data (BC Energy Regulator file: BCOGC-41984; https://bc-er.ca/data-reports/data-centre/) for Montney-Doig-Belloy, depicting the effects of >2 km of uplift through the frac-gradient, translating overpressures to shallower levels, creating leak-off allowing for hydrocarbon migration out of tight rocks. Here the conventional realm is fed from a hydrostatic head entering at 400 m altitude, along a hydrostatic brine gradient of 11.2 Kpa/m (= 1/0.087), with the blue-dashed line (altitude = -0.087 x pressure + 400) serving as a reference frame for defining conventional (grey dots) versus unconventional overpressured regimes (orange dots).

For accretion of the Gambier arc, the proposed suture runs along the axis of Coast Belt and eastern edge of the Insular Superterrane, extending from the Shuksan blueschist in the south (Cordova et.al., 2019), north through the Harrison Lake Shear Zone and Central Coast Belt Detachment (Journeay and Friedman, 1993) along the western margins of peri-Laurentia terranes, and further north into the Coast Shear Zone and associated faults (Rubin, et a., 1990;

Cecil et al., 2018). Much of the line is obscured by late intrusive bodies, as well as Upper Cretaceous deformation, and high-grade metamorphism (e.g. Sigloch and Mihalynuk, 2017). Final accretion here is defined by the end of Lower Cretaceous marine conditions covering the Coast Belt (Arthur et al., 1993), and by the record of overprinting Upper Cretaceous deformation (Rubin et al., 1990; Journeay and Friedman, 1993). Correspondingly, the paleogeography for the stratigraphy of the foreland basin to the east can be grouped into pre-accretionary, and post-accretionary packages, both affected differently by Coast Belt tectonics. Nikanassin/Blairmore/Manville and equivalent stratigraphy were deposited while the Gambier volcanic arc was active off the west coast under marine conditions; whereas younger stratigraphy corresponds with the elevated arc tempos related to accretionary suturing as well as post-accretionary deformation, and magmatism, terminating abruptly in the Eocene.

References

Arthur, A.J., Smith, P.L., Monger, J.W.H., and Tipper, H.W., 1993. Mesozoic stratigraphy and Jurassic paleontology west of Harrison Lake, southwestern British Columbia. Geological Survey of Canada Bulletin 441, 62 pages.

Bowerman, M., Christianson, A., Creaser, R.A., and Luth, R.W., 2006. A petrological and geochemical study of the volcanic rocks of the Crowsnest Formation, southwestern Alberta, and of the Howell Creek Suite, British Columbia. Canadian Journal of Earth Science. v. 43, p. 1621–1637.

Cecil, M. R., Rusmore, M. E., Gehrels, G. E., Woodsworth, G. J., Stowell, H. H., Yokelson, I. N., et al. 2018. Along-strike variation in the magmatic tempo of the Coast Mountains batholith, British Columbia, and implications for processes controlling episodicity in arcs. Geochemistry, Geophysics, Geosystems, v. 19, p. 4274–4289.

Cordova, J. L., Mulcahy, S.R., Schermer, E. R.., and Webb, L.E., 2019. Subduction initiation and early evolution of the Easton Metamorphic Suite, Northwest Cascades, Washington. LITHOSPHERE; v. 11, p. 44–58.

Dufresne, M.B., Eccles, D.R. and Leckie, D.A., 1995. The geological and geochemical setting of the mid-Cretaceous Shaftesbury Formation and other Colorado Group sedimentary units in Northern Alberta. Alberta Geological Survey, Special Report 09, 654 pages.

Fietz, S.W., (2023). Chronostratigraphy, Analogues, and Facies Characterization of Fluvio-Tidal Strata: McMurray Formation, Alberta, Canada. PhD. Thesis, Simon Fraser University, 174 pages.

Hanson, G. N., 1980. Rare earth elements in petrogenetic studies of igneous systems. Annual Review of Earth and Planetary Sciences, v. 8, p. 371-406.

Hildebrand, R.S., 2009, did westward subduction cause Cretaceous–Tertiary orogeny in the North American Cordillera? Geological Society of America Special Paper 457, 71 pages.

Irvine, T. N., and Baragar, W. R. A.,1971. A Guide to the chemical classification of the common volcanic rocks. Canadian Journal of Earth Sciences. V. 8, p. 523–548.

Issler, D.R., Willett, S.D., Beaumont, C., Donelick, R.A., Grist, A.M., 1999. Paleotemperature history of two transects across the Western Canada Sedimentary Basin: Constraints from apatite fission track analysis. Bulletin of Canadian Petroleum Geology, v. 47, p. 475-486.

Journeay, J.M., and Friedman, R.M, 1993. The Coast Belt Thrust System: evidence of Late Cretaceous shortening in southwest British Columbia. Tectonics, v. 12, p. 756-775.

Lynch, G., 1992. Deformation of Early Cretaceous volcanic-arc assemblages, southern Coast Belt, British Columbia. Canadian Journal of Earth Sciences, v. 29, p. 2706-2721.

Lynch, G., 1995. Geochemical polarity of the Early Cretaceous Gambier Group, southern Coast Belt, British Columbia. Canadian Journal of Earth Sciences, v. 32, p. 675-684.

Lynch, G., and Stasiuk, L., 2011. Characteristics of the Triassic Upper Montney Tight Gas Play, Groundbirch Area, Northeast B.C.; 2011 CSPG CSEG CWLS Convention, abstract, 2 pages.

Maiklem and Cambell, 1965. A study of the clays from Upper Cretaceous bentonites and shales in Alberta. The Canadian Mineralogist, v.8, p. 354–371.

Mellon, G.B., 1967. Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville Groups, Alberta Foothills and Plains; Research Council of Alberta, RCA/AGS Bulletin 21, 296 pages.

Ogloff, A.V., 2020. The Murray dyke swarm and its bearing on Cretaceous magmatism and tectonics in the Canadian Cordillera. MSc. Thesis, Simon Fraser University, 265 pages.

Pană, D.I., and van der Pluijm, B.A., 2015. Orogenic pulses in the Alberta Rocky Mountains: Radiometric dating of major faults and comparison with the regional tectono-stratigraphic record. GSA Bulletin, v. 127, p. 480–502.

Parrish, R.R., 1982. Cenozoic thermal and tectonic history of the Coast Mountains of British Columbia as revealed by fission track and geological data and quantitative thermal models. University of British Columbia PhD Thesis, 166 pages.

Roberts, L.N.R., Higley, D.K., and Henr, M.E., 2005. Input data used to generate one-dimensional burial history models, central Alberta, Canada. USGS Open-File Report 2005-1412, 14 pages.

Rubin, C. M., Saleeby, J.B., Cowan, D.M., Brandon, M.T., and McGroder, M.F., 1990. Regionally extensive mid-Cretaceous west-vergent thrust system in the northwestern Cordillera: Implications for continent-margin tectonism. Geology, v.18, p. 276-280.

Sigloch, K., and Mihalynuk, M., 2017. Mantle and geological evidence for a Late Jurassic–Cretaceous suture spanning North America. Geological Society of America Bulletin, v. 129, p.1489- 1520.

Thorkelson, D.J., 1986. Volcanic stratigraphy and petrology of the mid-Cretaceous Spences Bridge Group near Kingsvale, southwestern British Columbia. MSc Thesis, University of British Columbia, 119 pages.

Thorkelson, D.J., and Smith, A.D., 1989. Arc and intraplate volcanism in the Spences Bridge Group: Implications for Cretaceous tectonics in the Canadian Cordillera. Geology, v. 17, p. 1093–1096.

Wright, G.N., McMechan, M.E., and Potter, D.E.G., 1994. Chapter 3 - Structure and architecture of the Western Canada Sedimentary Basin. Atlas of the Western Canada Sedimentary Basin. G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, URL https://ags.aer.ca/atlas-the-western-canada-sedimentary-basin/chapter-3-structure-and-architecture.