

The Cordilleran foreland thrust-and-fold belt in southern Canada: Plate Tectonics, Mantle Flow, Gravitational Spreading, and Tectonic Heredity

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The Late Jurassic-Paleocene North American Cordilleran foreland thrust-and-fold belt, like its presently active South American counterpart in the eastern Andes, is a retrograde, east-verging, back-arc, critical-taper accretionary wedge. It consists of supracrustal strata that were plowed off the under-riding continental craton as it converged with tectonically thickened continental crust that had developed above a prograde, west-verging, continental-margin subduction zone. In southern Canada the detached and displaced supracrustal rock came mainly from three distinct, but partly over-lapping, sedimentary basins: the 20-km thick Mesoproterozoic (1500 - 1400 Ma) Belt-Purcell intracontinental rift basin, the 5- to 10-km thick Neoproterozoic (850 – 600 Ma) Windermere intracontinental rift basin, and the 10- to 15-km thick Paleozoic Cordilleran miogeocline, a passive continental margin sedimentary terrace wedge.

A palinspastic map of an 850-km segment of the foreland thrust and fold belt between northern Montana (~48° N) and northeastern B.C. (~54° N), that is based on restorations of six published balanced regional structure sections, shows the hanging-wall traces of the main thrust faults in both their present and their palinspastically restored locations. This map provides a framework for reconstructing the 3-D shapes, locations, and mutual relationships among the three basins, and also for reconstructing the relationships of the basins to the Paleoproterozoic basement that extends under the eastern Cordillera from Alberta, where it has been explored with magnetic and gravity anomaly maps and radiometrically dated samples from deep boreholes, and also by deep geophysical imaging by the petroleum exploration industry and Lithoprobe. Isopach maps of the estimated total thickness of the palinspastically restored Belt-Purcell Supergroup, the Windermere Supergroup, and the EoCambrian to Middle Devonian strata of the Cordilleran miogeocline illustrate the overlap and truncation relationships among the three basins. In the restoration: 1.) The major negative Bouguer gravity anomaly of the SE Canadian Cordillera coincides with the area of thrust overlap of the displaced eastern margin of the miogeocline plus the underlying Windermere Supergroup relative to their matching autochthonous basin-margin ramp which occurs beneath Monashee Mountains in B.C. 2.) South of 50° N, the eastern margins of the miogeocline, and of the Windermere basin, are deflected ~220 km southwest, across the Belt Supergroup, along the Crowsnest Pass cross-strike discontinuity (CPCD), a transverse northeast trending fault zone created by reactivation of part of a tectonic suture in the Paleoproterozoic basement that extends under the Cordillera from the Vulcan structure southeast of Calgary. 3.) Near the CPCD, the southeast edge of the miogeocline overlaps the Windermere basin and lies directly on the Purcell Supergroup. 4.) The north-trending rift margin that severed the Belt-Purcell basin should be in the subsurface west of the Okanagan Valley, and in northern Washington it should be deflected 80 km southwest along the CPCD.

The palinspastic map illustrates how the sedimentary basin-fill was tectonically inverted and formed structural culminations as the strata were detached and displaced up basin-margin ramps and on to the flat surface of the under-riding continental craton. The amount of structural relief across the margin of a culmination is linked to the thickness of sediment that was detached and displaced out of basin, and the orientations of the margins are

inherited from the orientations of the rift structures that defined the sedimentary basins. These very large inverted basin-margin ramps control the orientations of very high (> 5 km) topographic slopes that provide the gravitational potential to drive lateral gravitational spreading within critically tapered thrust-and-fold wedges. These relationships explain the first-order structure of the southern Canadian Rockies including: 1.) the location and orientation of the eastern margin of the great arcuate structural culmination of the Main Ranges of the Canadian Rockies which provided the gravitational potential gradient that controlled the orientation of thrusting and related folding in the adjacent Front Ranges and Foothills; 2.) the Crowsnest Pass cross-strike discontinuity and the southeastward thrusting associated with it; 3.) the northwest-trending culmination produced by inversion of the Belt-Purcell basin and the northeastward thrusting associated with it; and 4.) the Crowsnest deflection in the southern Alberta Foothills, which is due to gravitational spreading eastward from the north-trending Main Ranges culmination and northeastward from the northwest-trending Belt-Purcell structural culmination.

The structure of the detached and displaced North American supracrustal rocks within the foreland thrust-and-fold belt in southern Canada provides evidence for horizontal convergence (shortening) between the North American craton and the accreted terranes that varies from place to place between 100 and 300 km. It shows that some of this convergence was transformed northwestward into dextral displacements on large strike-slip faults. However, the related deformation that occurred at depth and involved both the under-riding North American crust and mantle lithosphere from which these supracrustal strata were detached, and the subducting slab of oceanic lithosphere, is much less clearly understood, even with the geophysical deep imaging that has been provided by the Lithoprobe Project. However, the kinematics and geodynamics of this deformation are now being clarified. Recent advances in the elucidation of the nature and the geodynamic significance of a wide zone of high heat flow and extraordinarily shallow asthenosphere that occurs above the subducting Juan de Fuca slab, in the back-arc region of the Cascade arc¹, have led to the recognition of similar hot back-arc regions around the Pacific rim, beneath the high plateau of the Andes in the east as well as beneath back-arc ocean basins in the west². These discoveries help to explain the processes linking retrograde-vergent, critical-taper thrusting in the foreland thrust-and-fold belt to the prograde shear along the top of the subducting slab. The descending cold slab of oceanic lithosphere is a heat sink, and therefore the high temperatures documented in the back-arc mantle above the subducting slab are unexpected. The current consensus is that the high temperatures are due to retrograde mantle flow (corner flow) that is driven by the viscous coupling between the subducting slab of oceanic lithosphere and adjacent parts of the overlying mantle wedge, and by complementary buoyant upwelling of asthenosphere that carries heat from outside the subduction zone region into the mantle wedge³. This pattern of subduction related mantle flow provides a key to understanding several otherwise enigmatic aspects of the tectonic evolution of the southern Canadian Cordillera, and other continental margin orogenic belts.

In the southern Canadian Cordillera, retrograde mantle flow behind the Late Triassic Nicola arc was coupled with the sinking Cache Creek oceanic lithosphere and provided a simple explanation for the collapse of the Slide Mountain back-arc basin and the Early Jurassic obduction of Slide Mountain terrane over North American strata. The oceanic lithosphere that formed the floor of the Slide Mountain basin, which has disappeared, evidently was entrained with the retrograde back-arc downward flow above the subducting Cache Creek oceanic lithosphere and was returned to the mantle. The outer edge of the North American continental slope and shelf apparently was drawn, by the entrained Slide Mountain oceanic lithosphere to which it was attached, into the top of the subduction zone and thus pulled under the supracrustal rocks that comprise Slide Mountain terrane. Retrograde back-arc mantle flow may also have facilitated the delamination and removal of the oceanic crust and lithosphere of Quesnel terrane, which evidently was detached and displaced northeastward, as a "tectonic flake", over the thin wedge of North American basement that has been imaged by Lithoprobe under central British Columbia. In addition, heat transported by the upwelling hot asthenosphere may have reduced lower crustal ductility and facilitated the transformation of thrust displacement into ductile crustal flow in the root zone of the foreland thrust-and-fold belt; and following the termination, at ~40 Ma, of the Eocene episode of dextral transtension and crustal

boudinage, the mantle upwelling that sustains the abnormally high elevation of the Interior Plateau may also explain the high topographic relief of the southern Canadian Rocky Mountains and the Columbia Mountains.

Patterns of mantle flow associated with the gravitational sinking of subducting slabs of oceanic lithosphere may provide important insights on many aspects of Cordilleran geodynamics.

References

¹Hyndman, R.D. and Lewis, T.J., 1999. "Geophysical consequences of the Cordillera-craton thermal transition in southwestern Canada." *Tectonophysics*, v. 306, p. 397-422.

²Currie, C. A. and Hyndman, R. D., 2006. "The thermal structure of subduction zone back arcs". *Journal of Geophysical Research* v.111 (B08404): doi:10.1029/2005JB004024.

³Currie, C.A., Wang, K., Hyndman, R.D., and He, J., 2004, "The thermal effects of steady state slab-driven mantle flow above a subducting plate: the Cascadia subduction zone and backarc". *Earth and Planetary Science Letters*, v. 223, p. 35-42: doi:10.1016/j.epsl.2004.04.020.