My fascination with the nature, origin, and evolution of mountains began during the summer of 1952, when, after only one course in geology, I had the good fortune to be employed on Geoffrey B. Leech’s GSC (Geological Survey of Canada) field party in the Purcell Mountains of southeastern British Columbia. Having never before been in the mountains, I was enthralled and intrigued by their majesty, formidable beauty, and mystery. Fortunately for me, Geoff Leech was an amazing mentor and role model. He nurtured my fascination with the mountains and my latent interest in geology with the result that my scientific focus shifted from physics and chemistry to geology. My principal scientific quest became: “Whence the Mountains?” particularly the mountains of the southeastern Canadian Cordillera. Thanks to the GSC, I was able to launch my scientific career with a PhD thesis focused on that question, and also to spend ten years at the Geological Survey of Canada exploring the southern Canadian Rocky Mountains in a strip stretching 425 km northward from Glacier National Park in Montana to the Yellowhead Pass near Mount Robson and Jasper. Sixty years later, equipped with a wealth of new information and many new conceptual models, (some of my own making), I now can articulate comprehensible explanations for the nature, origin, and evolution of the southeastern Canadian Cordillera, and thereby for some other mountain belts elsewhere.

S. Warren Carey, Harry H. Hess, and Walter Bucher, three of my mid-twentieth century geotectonics heroes, have inspired me in my quest for insight on mountain building. In 1952 S. Warren Carey provided an elegant exposition on how our thinking in tectonics and structural geology is done with models, and how some of these models are empirical but not readily applicable very far beyond the scale of time and the scale of length of the observations with which they were formulated. In his geo-poetical “expanding earth” conceptual model for the origin of the ocean basins, Carey focused on structural evidence of continental rifting and divergence between conjugate continental fragments, and on
conceptual models such as “megashears” that, like transform faults, linked “sphenochasms” and “rhombochasms” to explain the opening of ocean basins and the apparent “drift” between continents. **Harry H. Hess** presented a different more comprehensive, insightful and elegant conceptual model for “The History of the Ocean Basins” in his classic 1962 paper, which he himself called an “**essay in geo-poetry**”. In this paper, which is arguably the most innovative and influential global tectonics article of the 20th century, Hess suggested that **thermal convection within the mantle drives the continuous creation and destruction of ocean floors by the symmetrical generation of new ocean floor above divergent, gravity-driven buoyant upwellings of hot mantle, and by the reciprocal asymmetrical gravity-driven sinking of solid, older, colder, negatively buoyant ocean floor**. In this conceptual model, ocean basins are ephemeral; they open and close as divergent upwelling currents cause continents to split apart and carry the pieces away from each other; and as sinking currents give rise to oceanic trenches, magmatic arcs, the deformation of continental margins, terrane accretion, and continental collisions. **Walter H. Bucher**’s GSA presidential address, titled “Role of Gravity in Orogensis”, was published in the October 1956 issue of the GSA Bulletin. This was the first issue of the GSA Bulletin that I received as a new GSA member! This paper was particularly inspirational for me because of Bucher’s elaboration and elucidation of **conceptual models of gravitational lateral spreading for foreland thrust-and-fold belts and of intrusive fold-nappes that flow almost horizontally within the metamorphic core zones or orogenic belts** directly aided my quest for understanding of the origin and evolution of my small corner of the world --- the southeastern Canadian Cordillera, and thereby for some other mountain belt elsewhere.

The southern part of the Canadian Cordilleran foreland thrust-and-fold belt, which comprises the Southern Canadian Rockies and adjacent parts of the Purcell and Cariboo Mountains, consists of thrust slices of supracrustal strata have been detached from the under-riding edge and margin of Laurentia by an over-riding tectonic collage of allochthonous terranes that originated mainly as oceanic magmatic arcs. The detached sedimentary strata came from four different superimposed sedimentary basins: the Mesoproterozoic Belt-Purcell intracontinental rift basin, the late Neoproterozoic Windermere intracontinental rift basin, the Cambrian to Middle Jurassic Cordilleran miogeocline (a passive-margin, continental terrace-wedge basin), and the syn-orogenic Upper Jurassic to Paleocene Cordilleran foreland basin. The concept of tectonic heredity as expressed in the different configurations and locations of
the margins of these basins is important for the elucidation of mountain building. This complex, composite wedge of sedimentary rock was compressed horizontally and thickened (i.e. extended vertically) by imbricate thrust faulting and related folding as it was being displaced up to more than 200 km northeastward. Seismic reflection imaging and aeromagnetic anomaly maps show that the Paleoproterozoic crystalline basement of the Interior Plains extends under the Canadian Rockies without disruption. The deformation was ‘thin-skinned’.

Bucher’s gravitational spreading model involved pervasive flow from regions of higher elevation and higher pressure toward regions of lower elevation and lower pressure. In the area with higher surface elevations the deformation in the model involves vertical compression (surface subsidence) and horizontal extension; in the area with lower surface elevations it involves horizontal compression and vertical extension (surface uplift), but how does this happen and what happens in between?

**Simple shear** (laminar flow with no stretching or shortening in the direction of flow) is the most popular geological conceptual model for flow in rocks, and it has been used to analyze gravity-driven lateral flow in mountain belts. However, it is an inappropriate conceptual model because **simple shear is a special condition that marks the boundary between two quite different flow regimes: extending flow (extension in the direction of flow) and compressing flow (compression in the direction of flow)**. The application of this more comprehensive conceptual model for gravity-driven flow in orogenic belts provides important tectonic insights that are not available with the simple shear model. The characteristics of extending flow in gravitational spreading are: horizontal stretching (stretching in the direction of flow), vertical thinning (vertical compression), boudinage and excision of less ductile layers, converging flow lines, and increasing displacement in the direction of flow. The characteristics of compressing flow in gravitational spreading are: horizontal shortening (compression in the direction of flow), vertical thickening (extension), diverging flow lines, and decreasing displacement in the direction of flow. **Deformation in the Cordilleran foreland thrust-and-fold belts bears the earmarks of compressing flow.** Whereas, **the deformation within mid-crustal metamorphic rocks that were exhumed as crustal-scale boudins in the interior of the southern Canadian Cordillera bear the earmarks of extending flow** that occurred before as well as during their tectonic exhumation by Eocene regional dextral transtension.
What we perceive of the deformation within the Cordilleran foreland thrust and fold belt depends upon the scale at which we observe it. Our conceptual models of the nature and evolution of the deformation must be adapted to meet the changes in our perceptions between one scale of observation and another. In the external part of the Southern Canadian Rockies foreland thrust-and-fold belt, pieces of rock that have undergone horizontal displacements of many tens of km together with associated large rotations generally provide little or no evidence of internal deformation at the scale of a thin section or hand specimen. Delicate intricate details of sedimentary and fossil structures are preserved without distortion. However, at the scale of an outcrop, or a larger scale, the supracrustal strata comprise stratified mosaics of meter-scale to centimeter-scale blocks of rock that are bounded by fractures. The ‘fractures’ are mainly parallel or perpendicular to the bedding. Some of the ‘bedding-perpendicular’ fractures are extension fractures that may or may not be filled or coated with carbonate minerals or quartz; some are stylolites that mark ‘planes’ along which there has been ‘pressure solution’; some are polished or slicken-lined shear surfaces on which slicken lines commonly are parallel with bedding. Bedding surfaces may be stylolitic, but they commonly are polished or slicken-lined shear surfaces on which slicken lines are perpendicular to the hinge lines of adjacent folds. Some of the fractures are small faults that are commonly polished or slicken-lined shear surfaces. These small faults are inclined to the bedding, generally at ~30°, if they are ‘contraction faults’, which produce bedding-parallel shortening, or at >60° if they are ‘extension faults’, which produce bedding-parallel stretching. At the outcrop scale and beyond, the fracture-controlled rheology of the deformed stratified rock mass can be geo-poetically described as “cataclastic ductility”. Distortion of formations and of individual beds has been accomplished by the integration of opening, closing, and slipping along discrete fractures, including small faults that offset the bedding. Why do these small faults show preferred orientations with respect to the bedding surfaces, but not to gravity. Evidently, because the bedding surfaces were surfaces of low shear strength, and slip along the bedding reduced the shear stress along the bedding, thus making the local orientation of the principal stresses within the beds parallel and perpendicular to the bedding.

On the scale of a mountainside, compressing flow deformation within these unmetamorphosed supracrustal strata is expressed as listric thrust faulting and thrust-related, flexural-slip, chevron-style and concentric-style folding. The tip lines of blind
thrust faults that propagated along the axial zones of the kinematically elegant chevron folds form the centre-lines of the curvature within overlying concentric folds.

On a regional scale the thrust faults all ‘die out’ along strike. The northeastward tapering wedge-shaped mass of supracrustal strata as been shortened, thickened, and displaced northeastward by thrust-fault displacements that are distributed over a myriad array of discrete displacement discontinuities, all of which are embedded within an otherwise coherent mass of rock; they also are linked downward to a basal detachment zone close to the top of the underlying Paleoproterozoic basement. When viewed at a scale that is much larger than the largest thrust fault, the deformation involves large distortion with out loss of overall cohesion, and therefore is a type of flow.

There are large lateral gradients in the amount of displacement on the individual thrust faults. Individual incremental displacements on the thrust faults must have propagated as “smeared out” dislocations at a maximum velocity that was small compared to the area of the fault that was affected by the incremental displacement, so that only part of this area was subject to displacement at any one time. The so-called “mechanical paradox of large overthrusts” is due to a fallacious assumption in a conceptual model that was used to analyze the mechanics of overthrusting, namely that thrust displacements occurred simultaneously over an entire fault.

Viewed at the proper scale, the flow within the Cordilleran foreland thrust-and-fold belt was analogous to the flow of the Pleistocene ice sheets that covered most of the interior of Canada. However, because of the much greater specific gravity and thickness of the rocks, the Cordilleran foreland thrust-and-fold belt created a much larger isostatic flexure in the continental lithosphere than was created by the ice sheets. This flexure, the foreland basin, subsided and trapped the Cordilleran detrital outwash only when the thrust-and-fold belt was rising and spreading laterally. When the thrust-and-fold belt was not rising and spreading laterally there was no subsidence to trap sediment within foreland basin, and consequently the sediment eroded from the mountains then by-passed the foreland basin, as it does today. According to this conceptual model subsidence and sediment-accumulation in the foreland basin occurred only of times of thrusting and related folding, and therefore gaps in the sedimentary record in the foreland basin deposits are associated with times when thrusting and related folding were not occurring. This is contrary
to previous conceptual models, which did not recognize isostatically induced subsidence, and interpreted times of erosion as times of uplift and mountain building.

My balanced (retro-deformable) structure sections are based on the concept that whatever occurs on one side of a fault must have a compatible counterpart on the other side. Thus, what is discernible along the hanging wall of the thrust fault has been used to predict what exists out of view along the footwall; and likewise what is discernible along the footwall of a thrust fault has been used to reconstruct what has been eroded from the hanging wall. Retro-deformable structure sections have been used to construct palinspastically restored structure sections that portray the configuration and location of the remaining, uneroded deformed strata, but where they existed prior to thrusting, not where they are now. Sets of palinspastically restored retro-deformable structure sections have been used for the construction of palinspastically restored maps portraying the locations, configurations (isopachs), and structural relationships of the pre-existing Belt-Purcell, Windermere, and Cordilleran miogeoclinal sedimentary basins that have been incorporated into this part of the Cordilleran foreland thrust-and-fold belt.

Tectonic heredity (exemplified in the southern Canadian Rockies by sequential reactivation of structures aligned with the Vulcan structure, a major Paleoproterozoic crustal suture that has been identified along the northwest side of the Archean Medicine Hat block under southern Alberta) is responsible for a 225 km dextral offset in the eastern margin of the Cordilleran miogeocline from southeastern British Columbia to northeastern Washington. Reactivation of the Vulcan structure also influenced the configuration of the eastern margin of the late Neoproterozoic Windermere basin, and the evolution of the Mesoproterozoic Belt-Purcell basin. As a result of the tectonic inversion that occurred while the supracrustal strata in the Belt-Purcell, Windermere, and Cordilleran miogeoclinal basins were being detached and displaced upward and northeastward on to the flat surface of the craton, the thick sedimentary sequences filling the basins were transformed into very large tectonic culminations. The orientations of the flanks of the culminations, which were inherited from the orientations of the basin margins from whence the displaced supracrustal strata came, controlled the topographic gradients and thus the directions of lateral gravitational spreading within the foreland thrust-and-fold belt. The northwest trend of the thrust-and-fold belt in northern Montana and southern Canada is inherited from the orientation of the Belt-Purcell basin. The north-south trend of the thrust-and-fold belt in southern Alberta and
British Columbia is inherited from this part of the margin of the Cordilleran miogeocline, and the local northeast-trending, southeast-verging thrust-and-fold structures in southeastern British Columbia are inherited from the orientation of the dextral offset in the margin of the Cordilleran miogeocline that was, in turn, inherited from the Paleoproterozoic Vulcan structure.

Most of the northeastward tectonic displacement across the foreland thrust-and-fold belt of the southern Canadian Cordillera occurred during a mid-Cretaceous to Late Paleocene interval of dextral transpression between Laurentia and the Cordilleran accreted terranes. During this interval much of the convergence and tectonic shortening across the southern part of the Canadian Rockies was transformed northward into dextral strike-slip along the Northern Rocky Mountain trench fault zone and related faults to the west of it. The amount of tectonic shortening across the southern Canadian Rockies decreases substantially in the region north of the Athabasca River (~53° N). This northward decrease in tectonic shortening is reflected in a matching northward decrease in the thickness and extent of the Late Cretaceous-Paleocene sediment in the Cordilleran foreland basin.

A transition from dextral transpression to dextral transtension at the end of the Paleocene terminated shortening across the southern Canadian Rockies and initiated a episode of early Eocene regional extension and crustal-scale boudinage in south-central British Columbia. There, dextral strike slip was transferred, by crustal stretching across the central Cordillera, from the Tintina-Northern Rocky Mountain trench fault system in the north to the Yalakom-Ross Lake fault zone in the southern Coast Mountains and the northern Cascade Mountains. The basal detachment zone of the foreland thrust-and-fold belt is at the surface or just below the surface in three en echelon, 35-km thick, crustal boudins (Monashee complex, Valhalla complex, and Priest River complex) that were tectonically exhumed as overlying supracrustal high-grade metamorphic rocks were displaced eastward into adjacent zones of crustal necking in which the crust is now ~15 km thick. The zones of crustal necking are adjacent to the undeformed Paleoproterozoic continental crust that forms the basement of the foreland thrust-and-fold belt beneath the Southern Canadian Rockies and is ~35 km thick.

Lithoprobe geophysical investigations have demonstrated that the Moho under south-central British Columbia is relatively flat and at a depth of 30-35 km. In contrast, there are variations
in structural relief of up to 25 km or more between tectonically exhumed metamorphic core complexes (the crustal boudins) and adjacent supracrustal rocks. These are not accommodated by underlying variations in the depth to the Moho. Metamorphic mineral assemblages that are preserved in the crustal boudins, 35 km above the Moho, formed at depths of up to 20 km or more beneath supracrustal rocks that now reside within adjacent zones of crustal necking. At the beginning of the Eocene, prior to the dextral transpression, the crust was 55 – 60 km thick. The present-day 35-km thick crustal section under south-central British Columbia is a result of reciprocal crustal stretching involving crustal boudins that were exhumed by stretching and removal of overlying supracrustal strata and zones of crustal stretching and necking that are overlain by the supracrustal strata that were removed from above the crustal boudins.

This region, which is in the back-arc of the Cascadia subduction system, is now a region of shallow asthenosphere and abnormally high heat flow. The sustained high heat flow in the back-arc region has been explained with a conceptual model involving retrograde thermal convection in the asthenosphere that is linked to the mantle corner flow that is associated with the downward movement of the subducting oceanic lithosphere in the Cascadia subduction zone. This conceptual model may be applicable to the initial stages of Mesozoic terrane accretion to the western margin of Laurentia, which involved the collapse of the Slide Mountain back-arc basin, the obduction of Slide Mountain terrane over the margin of the Cordilleran miogeocline, and then the juxtaposition of Quesnellia, as a tectonic flake, over the outboard margin of Laurentia.

**Geological maps of fault surfaces** are helpful in the elucidation of thrust faulting. A comparison of structure-contoured balanced geological maps of the both the hanging wall and footwall of the Hosmer thrust fault has been used to illustrate the three-dimensional pattern of displacement on a fault that involved complex patterns of superimposed thrust fault displacements associated with changes in the direction of lateral gravitational spreading during the lifetime of the fault. A **geo-poetic conceptual model of the effects of superposition of early Eocene dextral transtension on late Cretaceous-Paleocene dextral transpression** is illustrated with a structure-contoured regional geological map of the footwall of the basal detachment fault of the entire foreland thrust-and-fold belt, extending northward from ~48° to 54°, and westward beyond the culminations of three crustal boudins that locally expose rocks that are below or very close to the basal detachment in the
Monashee metamorphic complex, the Valhalla metamorphic complex, and the Priest River complex.

**Tectonic wedging and delamination** occurs at all scales from the microscopic to the lithospheric. It is the compressing flow counterpart of the boudinage and excision that are associated with extending flow. It involves intrusive compressing flow and it occurs at various places in the Canadian Cordillera. At the ‘blind’ tip-line of the foreland thrust-and-fold belt, there is wedge-shaped thrust-duplex with a foreland-vergent floor thrust and a retro-vergent roof thrust, which is known locally as “the triangle zone”. Growth and propagation of the thrust-duplex wedge involves coordinated slip on the floor thrust, the imbricate thrusts and the roof thrust, and it delaminates the stratigraphic succession within which it is propagating.

**Tectonic wedging and delamination at a crustal- or lithospheric-scale, in combination the conceptual model of retrograde thermal convection in the asthenosphere that is linked to the mantle corner flow associated with the downward movement of the subducting oceanic lithosphere provides a simple explanation for the collapse of the Slide Mountain back-arc basin, the obduction of Slide Mountain terrane over the margin of the Cordilleran miogeocline, and the juxtaposition of Quesnellia, as a tectonic flake, over the outboard margin of Laurentia.**

It has been 56 years since I first read Walter H. Bucher inspiring paper on “Role of Gravity in Orogenesis”. My appreciation of the topic has evolved significantly in that time. Therefore, I will conclude with a brief summary of my current (but never final) view of the:

**ROLE OF GRAVITY IN OROGENESIS**

**Planet earth is a gravity-drive heat engine.**

Gravity-driven thermal convection in the molten outer core generates the magnetic field and heats the base of the mantle.

**Because of gravity, buoyant hot rock rises vertically through the mantle.**

**Because of gravity it diverges symmetrically as it approaches the surface and flows horizontally forming new oceanic crust and oceanic lithosphere that is itself constrained by gravity to flow parallel with earth’s spherical surface.**
Because of gravity, cooler, thicker, stiffer negatively buoyant spherical plates of oceanic lithosphere are bent as they sink below the spherical surface of the earth, thus forming an oceanic trench plus a magmatic belt within the over-riding plate.

Thickening of buoyant crust at convergent plate boundaries produces gravity-driven rock uplift and thus the topographical relief that drives lateral gravitational spreading, including both extending flow deep within the continental crust and compressing flow along the margins of mountain belts.

Thank you Walter Bucher, Harry Hess, and Sam Carey; and thank you GSA.
The Influence of Conceptual Models and Geo-poetry on Tectonics and Structural Geology

Penrose Gold Medal Lecture -- 05 November 2012

Raymond A. Price
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“Our thinking in tectonics and structural geology is done with models.” The importance of gravity increases with the size of tectonic features.


Oceanic crust, created by gravity-driven, symmetrically divergent buoyant upward flow of hot mantle, is continuously re-cycled through the mantle by gravity-driven colder mantle asymmetrically sinking at oceanic trenches. Mountain building occurs above above sinking crust. Ocean basins are ephemeral.

Walter H. Bucher, 1956: “Role of Gravity in Orogenesis” (GSA Presidential Address), GSA Bulletin, Oct, 1956 (This was the first issue that I received after joining the GSA.)

Lateral gravitational spreading observed in analogue models of orogenic belts (and in ice sheets) provides a conceptual model for the elucidation of foreland thrust-and-fold belts.
THE SOUTHERN CANADIAN CORDILLERA

Magnetic field data from Geological Survey of Canada
BUCHER’S 1956 LATERAL GRAVITATIONAL SPREADING MODEL

CLEAR ‘STITCHING WAX’

LAYERS OF ‘STITCHING WAX’ AND GREASE

Structure produced by solid flow in layers of stitching wax with layers of grease, due to lateral spreading of a block of clear stitching wax (after Bucher, 1956, plate 1, figure 1.)

FIGURE 5 — The transition from extending flow to compressing flow in lateral gravitational spreading.

From Price, 1972, Proc. 24th IGC (after Bucher, 1956, GSA Bulletin v.67, n.10 -- GSA presidential address)
BUCHER’S 1956 LATERAL GRAVITATIONAL SPREADING MODEL

IN VolVES CONCURRENT SIDE-BY-SIDE EXTENDING FLOW AND COMPRESSING FLOW

Structure produced by solid flow in layers of stitching wax with layers of grease, due to lateral spreading of a block of clear stitching wax (after Bucher, 1956, GSA Bulletin v.67, n.10 -- GSA presidential address).

EXTENSION IN THE DIRECTION OF FLOW

COMPRESSION IN THE DIRECTION OF FLOW

FIGURE 5 — The transition from extending flow to compressing flow in lateral gravitational spreading.

From Price, 1972, Proc. 24th IGC (after Bucher, 1956, GSA Bulletin v.67, n.10 -- GSA presidential address)
THE SIMPLE SHEAR CONCEPTUAL MODEL
(NO DISTORTION IN THE DIRECTION OF DISPLACEMENT)

IS THE MOST POPULAR CONCEPTUAL MODEL FOR FLOW IN ROCKS.

FOR EXAMPLE, IT IS COMMONLY USED IN THE ANALYSIS OF CHANNEL FLOW

(as illustrated below by Godin et al., 2006, Geol. Soc. London, SP #268)

BUT SIMPLE SHEAR IS A SPECIAL CONDITION AT THE BOUNDARY BETWEEN:
1.) EXTENDING FLOW (EXTENSION IN THE DIRECTION OF FLOW) AND
2.) COMPRESSING FLOW (COMPRESSION ON THE DIRECTION OF FLOW)

NB  BECAUSE MATERIAL FLOWS ACROSS THIS BOUNDARY, IT IS DIACHRONOUS
EXTENDING FLOW

EXTENSION (STRETCHING) IN THE DIRECTION OF FLOW
FLOW LINES CONVERGE IN THE DIRECTION OF FLOW
DISPLACEMENT INCREASES IN THE DIRECTION OF FLOW

FIGURE 1 — (left) — Prandtl compressed cell (after Kanizay, 1962) for extending flow.

FIGURE 2 — Slip-line field for extending flow and normal faulting (active Rankine state of plastic equilibrium).

From Price:

24th IGC, 1972 — SECTION 3
EXTENDING FLOW
BOUDINAGE WITH EXCISION OF AMPHIBOLITE LAYERS IN MIGMATITIC PARAGNEISS – Shuswap Metamorphic Complex, Three Valley Lake, B.C.
COMPRESSING FLOW

COMPRESSSION (SHORTENING) IN THE DIRECTION OF FLOW
DISPLACEMENT DECREASES IN THE DIRECTION OF FLOW
FLOW LINES DIVERGE IN THE DIRECTION OF FLOW

FIGURE 3 — (left) — Modification of Prandtl cell (after Kanizay, 1967) for compressing flow.

FIGURE 4 — Slip-line field for compressing flow and thrust faulting (passive Rankine state of plastic equilibrium).

From Price: 24th IGC, 1972 — SECTION 3
COMPRESSING FLOW -- ALL THRUSTS DIE OUT ALONG STRIKE. DISPLACEMENT (SLIP) WAS DISTRIBUTED AMONG A MYRIAD ARRAY OF DISCRETE DISPLACEMENT DISCONTINUITIES ALL OF WHICH ARE EMBEDDED WITHIN A COHERENT ROCK MASS THAT HAS FLOWED NORTHEASTWARD.
an outcrop-scale CONCEPTUAL MODEL

“CATACLASTIC DUCTILE DEFORMATION (FLOW) DURING FLEXURE OF SEDIMENTARY STRATA”

DISTORTION OF FOLDED STRATA IS ACCOMMODATED BY INTERSTRATAL SLIP, SLIP ON JOINTS AND SMALL CONTRACTION AND/OR EXTENSION FAULTS, AND BY OPENING OF FISSURE VEINS AND CLOSING OF STYLOLITES BETWEEN BLOCKS OF SEDIMENTARY ROCK THAT ARE EFFECTIVELY UNSTRAINED.
EXTENSION FAULTS (EXTENSION = GAP) INTERSECT BEDDING AT >60 degrees.

CONTRACTION FAULTS (COMPRESSION = OVERLAP) INTERSECT BEDDING AT ~30 degrees
COMPRESSING FLOW --- SYNTHETIC AND ANTITHETIC CONTRACTION FAULTS ASSOCIATED WITH INTERSTRATAL FLEXURAL SLIP (SHEAR)
Compressing Flow – Contraction Faults --- Thrust duplex & Associated Interstratal Shear
Livingstone range Anticlinorium
SW Alberta Foothills; view north
Flexural slip, chevron-style folds in Carboniferous carbonate rocks in Livingstone anticlinorium.

Interstratal shear and coordinated "cataclastic ductility (flow)" within beds generally preserve the integrity and thickness of beds and of formations in spite of external rotation and large-scale translation of stratified rock.

COMPRESSING FLOW IN THE FORELAND THRUST AND FOLD BELT
COMPRESSING FLOW COMPRISING SLIP DISTRIBUTED AMONG DISCRETE DISPLACEMENT DISCONTINUITIES THAT ARE EMBEDDED WITHIN THE FLOWING ROCK MASS

DISCRETE INTER-LEAVED IMBRICATE THRUST FAULTS ‘DIE OUT’ ALONG STRIKE
The Lewis Thrust at Crowsnest Mountain
COMPRESSING FLOW by thrust-related folding at the northern tip-line of the Lewis Thrust fault

MOUNT KIDD
EAST-WEST STRUCTURE SECTION & RESTORED SECTION AT 49° 45’

THE HORIZONTAL UPPER JURASSIC SEA-LEVEL DATUM IN THE RESTORED SECTION IS THE CONTACT BETWEEN UPPER JURASSIC MARINE AND NON-MARINE STRATA.

From:
Undeformed wedge of supracrustal rocks

Tectonically thickened supracrustal rocks

No isostatic compensation

Regional isostatic lithospheric flexure

Amount of subsidence,

of the basement surface

of the foreland basin
BALANCED (RETRO-DEFORMABLE) STRUCTURE SECTION AND CORRESPONDING PALINSPASTICALLY RESTORED SECTION

Whatever occurs on one side of a fault must have a compatible counterpart on the other side.

Section after Price and Fermor, 1985, Geological Survey of Canada Paper 84-14
Prior to Late K-Paleocene Dextral Transpression

Prior to Early Eocene Dextral Transtension

After Early Eocene Dextral Transtension

80 Ma

58 Ma

40 Ma
AT ~58 Ma

after Late K-Paleocene
Dextral transpression
and
prior to early Eocene
Dextral transtension
LITHOPROBE SOUTHERN CORDILLERA TRANSECT
LITHOPROBE SOUTHERN CORDILLERA SIMPLIFIED COMPOSITE SECTION
LITHOPROBE Pn VELOCITIES AND CRUSTAL THICKNESSES

(Modified after Hyndman and Lewis, 1998; Zelt and White, 1995; Burianyk et al., 1997)
EOCENE DEXTRAL TRANSTENSION AND CRUSTAL-SCALE BOUDINAGE
BOUDIN

NECK ZONE
HANGING WALL AND FOOTWALL GEOLOGICAL MAPS OF THRUST FAULTS

WHATSOEVER OCCURS ON ONE SIDE OF A FAULT MUST HAVE A MATCHING COUNTERPART ON THE OTHER SIDE.

A HANGING-WALL GEOLOGICAL MAP PROVIDES A TEMPLATE FOR RECONSTRUCTION OF A GEOLOGICAL MAP OF THE DEEPLY BURIED FOOTWALL.

A FOOTWALL GEOLOGICAL MAP PROVIDES A TEMPLATE FOR RECONSTRUCTION OF A MAP OF THE ERODED HANGING WALL.

MATCHING FOOTWALL & HANGING-WALL GEOLOGICAL MAPS OF A THRUST FAULT PROVIDE A 3-D PALINSPASTIC RESTORATION OF VARIATIONS IN THE DIRECTIONS AND MAGNITUDES OF DISPLACEMENT ON THE THRUST FAULT
THE HOSMER NAPPE – Footwall Map
GEOLOGICAL MAP OF THE BASAL DETACHMENT OF THE FORELAND THRUST-AND-FOLD BELT DRAPED OVER EARLY EOCENE TRANSTENSIONAL METAMORPHIC CORE COMPLEX CRUSTAL BOUDINS
TECTONIC WEDGING

OCCURS AT ALL SCALES FROM MICROSCOPIC TO LITHOSPHERIC

Photo courtesy of M.E. McMechan
TECTONIC WEDGING AND DELAMINATION are the compressing flow counterparts of extending flow.
BOUDINAGE AND EXCISION
E-verging obduction followed by crustal-scale tectonic wedging with a W-verging roof thrust and then by detachment and tectonic inversion of Mesoproterozoic and Neoproterozoic-Paleozoic basins.

after Price, 1981, Jour. of Structural Geol.
LITHOSPHERE-SCALE TECTONIC WEDGING

A – Onset of collapse of Slide Mtn. Basin;

B - Obduction of Slide Mountain terrane

<200 Ma

187-173 Ma

173-168 Ma

C - Tectonic Wedging of the continental margin by Quesnellia (Nicola Arc) & Kootenay terrane.
THE ROLE OF GRAVITY IN OROGENESIS

PLANET EARTH IS A GRAVITY-DRIVE HEAT ENGINE.

GRAVITY-DRIVEN THERMAL CONVECTION IN THE MOLTEN OUTER CORE GENERATES THE MAGNETIC FIELD AND HEATS THE BASE OF THE MANTLE.

BECAUSE OF GRAVITY, BUOYANT HOT ROCK RISES VERTICALLY THROUGH THE MANTLE.

BECAUSE OF GRAVITY IT DIVERGES SYMMETRICALLY AS IT APPROACHES THE SURFACE AND FLOWS HORIZONTALLY FORMING NEW OCEANIC CRUST AND OCEANIC LITHOSPHERE THAT IS ITSELF CONSTRAINED BY GRAVITY TO FLOW PARALLEL WITH EARTH’S SPHERICAL SURFACE.

BECAUSE OF GRAVITY, COOLER, THICKER, STIFFER NEGATIVELY BUOYANT SPHERICAL PLATES OF OCEANIC LITHOSPHERE ARE BENT AS THEY SINK BELOW THE SPHERICAL SURFACE OF THE EARTH, THUS FORMING AN OCEANIC TRENCH PLUS A MAGMATIC BELT IN THE OVERIDING PLATE.

THICKENING OF BUOYANT CRUST AT CONVERGENT PLATE BOUNDARIES PRODUCES ROCK UPLIFT AND THE TOPOGRAPHICAL RELIEF THAT DRIVES LATERAL GRAVITATIONAL SPREADING --- BOTH EXTENDING FLOW DEEP WITHIN THE CONTINENTAL CRUST AND COMPRESSING FLOW ALONG THE MARGINS OF MOUNTAIN BELTS.
THANK YOU FOR YOUR ATTENTION