Program with Abstracts: Crowsnest Pass '06

26th Canadian Tectonics Group Workshop

25 Years

CTG

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1981 - 2006

Co-hosted by the Structural Geology and Tectonics Division
of the Geological Association of Canada

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October 14-15, 2006
Crowsnest Pass, Alberta, Canada

Schedule of Events 26th CTG Workshop (Crowsnest Pass'06)

The program presents the schedule of talks, the list of poster presentations and the abstracts in alphabetical order. Oral presentations are 20 minutes long, with 5 minutes for questions.

Friday 13 October

21h00-23h00	**Welcome to the 2006 Canadian Tectonics Group Workshop. Registration, buffet and refreshments, poster set up**

Saturday 14 October

07h55	**Opening remarks: Willem Langenberg**
08h00-08h25	**Dazhi Jiang** The Motion of Porphyroclasts in Mylonites: Deformation Mechanism and Rheology Information from Microstructures
08h25-08h50	**Pierre-Yves F. Robin and Nadia Haider** Measuring a fabric ellipsoid from planar fabric elements using the Sorted Vector Addition (SVA) Method
08h50-09h15	**Paul F. Williams** Kinematic vorticity number and shear zones
09h15-09h40	**Christoph Schrank, David Boutelier and Alexander R. Cruden** Shear zone geometry and rheology: insights from physical modeling
09h40	**Poster introductions and Coffee break**
10h10-10h35	**W.M. Schwerdtner and Dan Landa** Folding of Grenville gneisses under orogen-parallel sinistral-normal shear on the kilometre scale
10h35-11h00	**Dinu Pană and Willem Langenberg** A new look at Andrew Lake "thrust" and Waugh Lake "Group" in the Alberta portion of the Taltson orogen
11h00-11h25	**Bruno Lafrance, David Legault and Doreen Ames** Origin of the Sudbury Breccia in the North Range of the Sudbury impact structure
11h25-11h50	**Shoufa Lin, Dazhi Jiang and Paul F. Williams** The importance of differentiating ductile slickenside striations from stretching lineations and variation of shear direction across a high-strain zone

11h50	**Lunch**
13h15-13h40	**Lori Kennedy and Steve Israel** Constraints on the rheological behaviour of migmatites: Preliminary work from the Atnarko Metamorphic Complex, BC
13h40-14h05	**F. Fueten, R. Stesky, P. MacKinnon, E. Hauber, K. Gwinner, F. Scholten, T. Zegers, G. Neukum and the HRSC Co-Investigator Team** Layering attitudes in southwestern Candor Chasma from HRSC image data and stereo-derived DTM
14h05-14h30	**Glen S. Stockmal, Chris Beaumont, Mai Nguyen and Bonny Lee** Dynamical numerical models of thin-skinned thrust-and-fold belts: linkages between structural style and foreland deposition
14h30-14h55	**Raymond A. Price** Fernie Map-area (82G): Nature and significance of profound change along the Cordilleran foreland belt
14h55	**Coffee break and poster viewing**
15h30-15h55	**Raymond A. Price** The nature and significance of deformation within the Lewis thrust sheet at Crowsnest Lake: A meso-scale perspective
15h55-16h20	**H. Daniel Gibson, Sarah Brown and David Trippett** Reexamination of Eocene Extension in the southeastern Canadian Cordillera
16h20-16h45	**Willem Langenberg** Initiation of the Turtle Mountain Thrust, Crowsnest Pass, Alberta
16h45-18h00	**Posters and refreshments**
18h00	**Dinner**
19h30	**After dinner Frank Slide Show by Monica Field (FSIC)**
20h00	**Annual GAC/SGTD meeting**

Posters

E. Konstantinovskaya and J. Malavieille
Impact of erosion on dynamics, internal structure and exhumation in accretionary wedges: insights from analogue modeling.

Jamie Kraft, P. Erdmer and R.I. Thompson
The transition between the Kootenay Arc and the mid-Paleozoic Eagle Bay basin at Upper Arrow Lake, southeastern Canadian Cordillera, British Columbia.

Raymond A. Price
Geology of the Fernie Map-area (82G)

W.M. Schwerdtner and Dan Landa
Cylindrical S/Z folds as indicators of a shear component: new examples from the Grenville Orogen in Ontario

Guido Serafini, P.-Y. F. Robin and Nadia Haider
The Northbrook-Kaladar Formation: a microcosm of the Mazinaw Domain (Composite Arc Belt, Grenville Province)

Deborah Spratt and Malcolm Lamb
Fracture patterns at Turtle Mountain, S.W. Alberta

Glen S. Stockmal, Chris Beaumont, Mai Nguyen and Bonny Lee
Dynamical numerical models of thin-skinned thrust-and-fold belts: linkages between structural style and foreland deposition

Deanne van Rooyen, Sharon D. Carr, Alana Hinchey and James K.W. Lee
U-Pb geochronology and ^{40}Ar/^{39}Ar thermochronology studies in the vicinity of Thor-Odin dome, southeastern British Columbia to test tectonic models and characterize the behaviour of ^{40}Ar/^{39}Ar systematics in migmatite terranes: A Ph.D. thesis proposal

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Sunday 15 October

07h00 **Breakfast**

08h00 **Load bus for field trip**

18h00 **Arrive at airport in Calgary**

Layering attitudes in southwestern Candor Chasma from HRSC image data and stereo-derived DTM

F. Fueten[a], R. Stesky[b], P. MacKinnon[a], E. Hauber[c], K. Gwinner[c], Scholten, F.[c],
T. Zegers[d], G. Neukum[e] and the HRSC Co-Investigator Team

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Layered deposits occur widely within the chasmata of Valles Marineris, but their origin and mechanism of formation are uncertain. Recent geochemical data indicate the presence of sulfates in some of the deposits. Less is known about their internal geometry and structural setting, properties that may give clues to their formation process. High resolution imagery and stereo-derived digital terrain models (DTMs) from the High Resolution Stereo Camera (HRSC) experiment on the Mars Express orbiter can provide this information, by allowing the attitudes of observed layering to be calculated at various locations throughout the image. This study focused on the deposits in southwestern Candor Chasma which had already been mapped by Lucchitta as units of Hesperian or Amazonian age.

A multispectral image (12.5 m/pixel) and DTM (50 m/pixel) calculated from HRSC data collected during orbit 2116 represent a significant increase over previously available data. Pangaea Scientific's software ORION was used to sample the image and calculate the layering attitudes. Overall, attitudes of the new data agree with attitudes measured using lower resolution data. However, it now possible to distinguish a number of features that could not be resolved using the older data. Analysis of the new data suggests the following:

1) Massive competent units dip primarily gently to the E-SE.
2) The massive units have most likely been displaced by faulting.
3) These massive units are unconformably overlain by thinner, less competent units.
4) The attitudes of the thinner units are consistent with draping.
5) The unconformity documented using the lower resolution data is an unconformity between thin units, indicating that at least two unconformities are present.

Hence, analysis of the newer, higher resolution data suggests that the structural history of this part of Valles Marineris was more complex than previously thought.

Reexamination of Eocene extension in the southeastern Canadian Cordillera

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The Okanagan Valley-Eagle River fault system (OVF) is thought to have accommodated, in part, the extensional collapse of the southeastern Canadian Cordillera. It is constrained to be Latest Paleocene to Eocene in age (ca. 56-45 Ma) as provided by data acquired from variably deformed and cross-cutting granitoid bodies and sheared rocks within the fault zones. Most of the data that directly constrain the time of motion on these faults were obtained more than two decades ago via ID-TIMS on zircon and monazite, K-Ar on micas and hornblende, and fission track on apatite. Although the data precisely constrain when extension ended, there are very few analyses that provide insight into the syn-tectonic timing of this extensional episode, and virtually none that pin down the earliest movement on these structures. The main reasons for a paucity of syn-extension time constraints are: 1) In polydeformed terrains it is very difficult to isolate and date individual deformation events. To sort out the complex structural hierarchy, microstructural analysis is often required. However, two decades ago the micro-scale geochronology needed to date micro-scale structural features was generally not available. 2) The geochronologic techniques used typically entailed analyzing minerals separated from crushed and ground rock, resulting in loss of textural information linked to specific structural or metamorphic features.

Fortunately, various *in situ* geochronologic techniques (e.g. SHRIMP, LA-ICPMS, EMP) are now widely available that preserve textural information observed at the micron-scale. This provides the best opportunity to link age constraints directly to structural and metamorphic events. With careful *in situ* analyses coupled with a bottom-up approach, we should be able to better address the difficult question of, "When did extension along the OVF really begin?". Answering this question has significant implications with respect to modeling the tectonic evolution of the southern Canadian Cordillera. For instance, some workers have suggested that during the peak of the Cordilleran orogen the southern Canadian Cordillera may have undergone Channel Flow. In this model, a channel of weak, melt-laden lower crust begins to flow at higher velocities than rocks both above and below the channel. Implicit in this model is the synchronous development of oppositely verging extensional and compressional structures along the upper and lower boundaries of the channel, respectively. A key to testing the viability of this model is to compare the timing of extension versus compression. Most importantly, do they overlap, if so, by how much time? Currently, the Eocene time constraints for the OVF provide only a small window of time that would overlap with compressional events within the southern Canadian Cordillera that ended ca. 50 Ma. This in turn suggests that if there was Channel Flow, it would barely have had time to initiate, i.e. a nascent channel. However, if extension was ongoing prior to 56 Ma, this would support an argument for longer-lived Channel Flow. To this end, we have started two projects whose objectives, in part, are to better constrain the early history of the OVF and its potential role in Channel Flow, and whether or not Channel Flow in the southern Canadian Cordillera is a viable model.

The motion of porphyroclasts in mylonites: deformation mechanism and rheology information from microstructures

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Deformation of the composite material made of one phase (variably called inclusion, object, clast, particle, impurity or inhomogeneity in the literature) dispersed in another continuous phase (called matrix) has been a subject of research in the broad field of materials science for over a century. Many rock types in Earth's lithosphere resemble this composite material, such as porphyroclast-bearing mylonites, porphyroblast-bearing metamorphic rocks, conglomerates, igneous rocks containing enclaves, xenoliths, or clasts, and the melt-crystal mesh at the late stage of magma crystallization. There are two theories for the deformation of such a composite material. Where the inclusions are rigid and the matrix is linearly viscous, G. B. Jeffery's (1922, Proceedings of the Royal Society of London, A102, 161-179) theory applies. Where the inclusions are deformable, J.D. Eshelby's (1957, Proceedings of the Royal Society of London, A241, 376-396) theory applies.

Microstructures of porphyroclast-bearing mylonites suggest two distinctive rigid porphyroblast behaviors. One type of porphyroclasts shows geometrical relationship between clast orientation and flow field that agrees with the prediction based on Jeffery's theory. In this case, elongate rigid clasts develop a stable orientation when their aspect ratio exceeds a critical limit which depends on the kinematic vorticity of the flow, while less elongate grains rotate continuously, although with oscillating angular velocity. The long axes of such stable clasts are synthetically orientated with respect to the mylonitic foliation. Another, commonly fish-shaped, type of porphyroclasts, such as mica fish, shows a strong shape-preferred orientation with the long axes of the clasts inclined at a small antithetic angle with respect to the main mylonitic foliation. This geometrical relationship between rigid clast orientation and flow field contradicts with the prediction of Jeffery's theory. However, it can be remarkably well explained by Eshelby's theory for *deformable* clasts. The "effective" viscosity ratio of the porphyroclast to the matrix, best-fitted for natural data, is between 0 and 3. Therefore to form the preferred orientation presented by fish-shaped rigid porphyroblasts, there must have existed a thin low-viscosity material wrapping around the porphyroclast at the time of deformation. The low-viscosity material decouples the clast from the matrix and essentially turns the inclusion mechanically into a low viscosity one whereas the rigidity of the clast maintains the inclusion shape. The angular velocity of such a porphyroclast is governed by Eshelby's theory and the shape does not change in the course of deformation. The ultra fined-grained material derived from dynamically recrystallization or cataclassis of the clast and/or the presence of metamorphic fluid at the clast-matrix interface may constitute the low-viscosity material wrapping around the clast.

Constraints on the rheological behaviour of migmatites: Preliminary work from the Atnarko Metamorphic Complex, BC

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The Atnarko Metamorphic Complex (AMC) consists of polydeformed intermediate plutonic and volcanic rocks ranging from Jurassic to Tertiary in age. Most rocks have a gneissic fabric with migmatites exposed in the core of the complex. Thrust faults and folds verge to the southwest. Large northwest and north striking, dextral mylonite zones crosscut the main gneissic fabric, as do smaller sinistral and dextral east striking ductile shear zones. At least three phases of folding are documented; F1 and F2 folds are southwest verging, tight to isoclinal with coplanar fold axes and folds and F3 folds are open to closed with east to southeast plunging fold axes.

The migmatites in the AMC are of the stromatic type. They consist of leucosomes and melanosomes, both of which are commonly folded. Several observations were made regarding the geometry of leucosomes: 1) The folded and layer-parallel leucosomes are apparently highly strained yet show little evidence for internal strain - probably because of the presence of partial melt during deformation, 2) The folded leucosomes appear to control the wavelength of folds, and it can be demonstrated that the leucosomes are more competent than the amphibole-rich melanosomes, 3) Discordant leucosomes and granitic dykes are in apparent continuity with foliation-parallel leucosomes, and may represent interconnected melt channels such that melt was present throughout the migmatite evolution and that the entire network underwent final crystallization at the same time.

We measured fold parameters (wavelength and amplitude) by grid mapping in the field to calculate the viscosity contrast of the melanosomes and leucosomes and determined that most folds exhibit a competence constrast of above 250. Recent experimental work by Rutter et al (2005) shows that with a melt fraction of 30%, and at 700°C, a granitic material will have a flow strength of ~ 10 MPa. If the leucosomes control the fold wavelength, and if this indicates that it is mechanically stronger than the melansomes, the amphibolite must be deforming, at the time of folding, by a mechanism other than dislocation creep. An alternative scenario is that the folding occurred prior to partial melting and the melt essentially followed a pre-existing geometry.

Impact of erosion on dynamics, internal structure and exhumation in accretionary wedges: insights from analogue modelling

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We studied the effects of erosion on fault propagation and exhumation history in accretionary wedges by experimental and geological approaches. Different parameters are tested (basal friction, rate and angle of erosion, presence of décollements and subduction window). A model Coulomb wedge is submitted to erosion under flux steady state conditions. The volume of eroded material remains equal to the volume of newly accreted material, maintaining a constant surface slope during shortening. The material is exhumed along a series of inclined (20°–50°) thrusts in the rear of the high-friction wedge with critical taper 8°. Presence of a low-friction décollement layer in the accreted series of high-friction wedge (erosion slope 6°) allows underplating of basal thrust units and developing of an antiformal stack in rear part of the wedge like a dome-shaped structure. The growth and exhumation of the structure is favored by major back thrust at the final stages of shortening. The basal material is transferred to the surface along a series of high-angle (60°–70°) thrusts. Above the décollement, the upper thrust wedge is thickened mainly by frontal accretion with formation of paired thrust faults (typical mechanism for low-friction wedge). The coupling of the thrust faults in the upper wedge at the final stages of shortening leads to formation of a compressed synformal ‘‘klippe’’ completely detached from the basal layers of the model. Presence of two décollement layers in the accreted series changes the fault propagation in thrust wedge inducing development of independent system of thrusts above each décollement. The formed dome-shaped antiformal structure is wider, no major backthrust occurs, and exhumation of basal layers is less pronounced occurring along less steeper thrusts (35°- 40°) if compared to the one-décollement wedge. The upper wedge above décollement layers is nearly completely eroded. If steeper slope of erosion (8°) is applied to the high-friction thrust wedge with two décollement layers, a smallest extent of basal material exhumation is observed, and the upper wedge remains preserved. Presence of subduction window in eroded low- and high friction thrust wedges induces the development of a major long-lived out-of-sequence thrust fault that controls transfer of material across the wedge toward the window. The former accreted material is transferred to the subduction window along curve-shaped trajectory, never being exhumed. The later accreted material is transferred to the surface in front of the out-of-sequence thrust fault. The two-times slower surface erosion applied to high-friction thrust wedge allows to faster vertical growth of the wedge at early stages of shortening, thus the area of major exhumation is shifted from rear to the middle part of wedge in the final model. Observed model structures provide constraints on the internal thrust wedge dynamics as a function of certain parameters leading to better understanding of fault geometry, kinematics, material transfer and fluid flow localization in fold-thrust orogenic belts.

The transition between the Kootenay Arc and the mid-Paleozoic Eagle Bay basin at Upper Arrow Lake, southeastern Canadian Cordillera, British Columbia

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Twelve weeks of detailed 1:20 000 scale mapping in the southern Canadian Cordillera south of Revelstoke, B.C. were conducted as part of the Geological Survey of Canada's Southern British Columbia TGI-3 program. The mapped area spans the northern margin of the Middle Jurassic Kuskanax batholith from the Kootenay Arc (Cambrian-Ordovician(?) Lardeau Group) westward to strata at Upper Arrow Lake that have recently been correlated with the Eagle Bay basin.
The Devonian Chase Formation, a calcareous quartzite, has recently been traced from the Eagle Bay assemblage, which contains an extensive Devonian-Mississippian supracrustal sequence in the North Okanagan-Shuswap region, easterly to the present study area at the western limit of the Kootenay Arc. In the Kootenay Arc, only Mississippian and younger units have been recognized overlying the Lardeau Group. The presence of Chase quartzite in a sequence previously correlated with the Mississippian Milford Group (and therefore, the Kootenay Arc) suggests the possibility of a stratigraphic link between Eagle Bay basin strata and Milford and/or Lardeau Groups. The nature of the transition has a bearing on geologic models of the Paleozoic and Mesozoic southern Canadian Cordillera. Current models involving terrane accretion postulate a major fault between Kootenay Arc rocks and Paleozoic strata to the west. Interdigitation of the basins may be a viable alternative.

Preliminary results of field work include recognition that an assemblage of metamorphosed volcanic, siliciclastic and carbonate units previously interpreted as part of the Mississippian Milford Group (McHardy Assemblage) and the Permian Kaslo Group conformably (?) overlies the Chase Formation and is interlayered at its top with a distinctive sequence of greenstone, white marble, green and grey phyllite, grey limestone, and white quartzite previously mapped as part of the Lardeau Group. This sequence therefore overlies Devonian (and younger?) units and should not be correlated with the lower Paleozoic Lardeau Group. The 'new' assemblage can be traced southeastward nearly to Trout Lake. Its relationship with type Lardeau Group to the east has not yet been established.

Origin of the Sudbury Breccia in the North Range of the Sudbury impact structure

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The ca. 1.85 Ga Sudbury impact structure straddles the boundary between the Archean Superior Province and the Paleoproterozoic Southern Province. It consists of a crystallized impact melt sheet (Sudbury Igneous Complex, SIC), concentric and radial dioritic dykes that extend from the SIC into the impacted rocks, and suevitic breccias and fall-back breccias of the Onaping Formation, which directly overlie the SIC. The most conspicuous, outcrop-scale, impact-related structures are shatter cones and large irregular bodies of Sudbury Breccia. These structures are superimposed on pre-impact Kenorean structures in the Superior Province and on Blezardian to Early Penokean structures in the Southern Province. They are overprinted by post-impact regional folds and reverse shear zones of the South Range Shear Zone system along the south rim of the Sudbury impact structure.

Because of its apparent annular distribution around the SIC, the Sudbury Breccia is interpreted as a pseudotachylitic breccia that formed during comminution and possibly frictional melting along rim-collapse normal superfaults during gravity-driven modification of the impact crater. We mapped the distribution of the Sudbury Breccia and the orientation of Archean structures in the Archean Levack gneiss complex along the north rim of the SIC. Archean ductile structures in the Levack gneiss can be grouped into three generations of folds and foliations that have consistent orientation patterns across the map area. The Sudbury Breccia increases in abundance towards the SIC contact but otherwise shows no concentric concentration nor does it coincide with major contact-parallel fault planes. Trace element and major element geochemistry shows that the matrix of the breccia is a mixture of comminuted tonalitic and dioritic Levack gneisses. These observations suggest that the breccia bodies did not originate along superfaults but rather formed by in situ comminution and possibly frictional melting of the Levack gneiss during the excavation and uplift of the transient crater floor as coherent blocks that were bounded and transected by fractures.

Initiation of the Turtle Mountain Thrust, Crowsnest Pass, Alberta

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The initiation of the Turtle Mountain Thrust is investigated. In the Foothills and Front Ranges of Alberta folding and thrusting appear to operate simultaneous. However, in the case of the Turtle Mountain Thrust it appears that folding predates thrusting during initial shortening. The thrust-ramp in the competent carbonates is localized by a buckling instability in the layered succession in an early stage of shortening and buckle-folding. The thrust fault ramped through the fore-limbs of the Turtle Mountain Anticline (initially a detachment fold) and defines a fault-propagation fold in a later stage of the buckle-folding process. The Turtle Mountain Thrust has a prominent Footwall syncline, which fit the fault-propagation model. Consequently, the prominent process in these layered strata is buckling, whereby thrust faults initiate at buckling instabilities. The Turtle Mountain example will be compared to structures in the Lewis, Rundle and Nikanassin thrusts.

Buckle folds can be modified by fault-bending at a later stage, after thrust faults formed. After the initiation of these types of thrusts, large displacements along these thrusts could be accommodated. The evidence of initial folding might have moved a long way from the location of the ramp, leaving only evidence of later fault-bend folding or showing no folding at all. The McConnell Thrust shows examples of this type of behavior.

The importance of differentiating ductile slickenside striations from stretching lineations and variation of shear direction across a high-strain zone

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Rocks in high-strain zones are generally foliated and/or lineated, and foliation and lineation data have played a very significant role in kinematic interpretation of these zones. Two principal types of foliations and two corresponding types of lineations are commonly developed in high-strain zones. The foliations are generally called S- and C-surfaces. S-surfaces are close to the local $\lambda_1\lambda_2$ principal strain plane (where $\lambda_1>\lambda_2> \lambda_3$ are three principal strain axes) and the stretching lineation within them (Ls) is approximately parallel to the λ_1 direction of the finite strain ellipsoid. C-surfaces are planes (or more precisely, narrow zones) of high shear strain parallel to the main high-strain zone boundary. striations of the "ridge-in-groove" type (Lc), a product of ductile deformation, may be present on C-surfaces and they form parallel to the shear direction.

A key task in kinematic interpretation of many high-strain zones is to determine their shear directions. Traditionally this is done using Ls with the assumption that they indicate 'transport' (strictly 'shear') direction and thus have a kinematic significance similar to that of Lc, especially where the strain is high. However, this long-held assumption is based on the simple shear model, and recent developments in the study of high-strain zones show that it is generally not applicable to high-strain zones of non-simple shear (e.g. transpression and transtention zones). This is especially true in high-strain zones with triclinic kinematic framework where no simple relationship exists between stretching lineations and shear directions. On the other hand, the ductile slickenside striations (Lc) *are* parallel to the local shear directions. It is therefore very important in determining the shear direction of a high-strain zone to differentiate Lc from Ls. Although both S- and C-surfaces are commonly present in high-strain zones, Lc data are much less commonly reported than Ls data. Our experience is that Lc are much more common than reported in the literature. It is very likely that many field geologists do not differentiate the two types of lineations, either because of a lack of appreciation of the importance of differentiating the two or because of the difficulty of doing so. Both types of lineations may have been simply reported as 'stretching lineations'.

In this presentation, we first review the recent development in the study of high-strain zones, emphasizing a triclinic model and the common deviation of Ls from the shear direction. We then discuss how to recognize Lc and differentiate them from Ls. Finally, we present the description of a natural high-strain zone and show how differentiating the two types of lineations can lead to recognition of new phenomenon as well as kinematic insights into a high-strain zone.

A new look at "Andrew Lake thrust" and "Waugh Lake Group" in the Alberta portion of the Taltson orogen

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"Andrew Lake thrust", was postulated to have transported high-grade rocks of the Taltson basement complex at least 10 km to the northeast on top of the "Waugh Lake Group", a volcano-sedimentary sequence deposited in a small intra-arc basin near the eastern periphery of the Taltson magmatic zone (McDonough et al., 2000). The inferred age of deposition for the Waugh Lake "Group" is 2.02-1.97 Ga, hence slightly younger than the 2.13-2.09 Ga age of deposition inferred for the Rutledge Group of the Taltson foreland basin. The "Waugh Lake Group" unconformity was interpreted to be masked by the ca. 1.97-1.96 Ga Andrew Lake-Colin Lake granitoid suite. "Andrew Lake thrust", the only thrust zone ever invoked in the Taltson orogen, has been kinematically linked to the ca. 1.93 Ga mid-crustal evolution of major strike-slip shear zones, well-documented in the central and western Taltson magmatic zone.

"Andrew Lake thrust", traced in most part through Andrew Lake and a bog at its northern end, disappears south of Andrew Lake, cannot be correlated with any tectonic feature to the north in N.W.T. and is nowhere closer than 2 km to the "Waugh Lake Group". The few outcrops along the its trace do not show any strain gradient, the commonly subvertical foliation within and across the postulated thrust zone displays ambiguous or dominantly strike-parallel and oblique kinematic indicators, similar to those observed throughout the Taltson basement complex.

"Waugh Lake Group" records high non-coaxial strain under low-grade metamorphic conditions with variably northerly trending, steeply-dipping layering or foliation and with many exposures of gradational transition from massive plutonic to layered rocks. On either side it grades through strain gradients into granitoids. At least some textures previously interpreted as sedimentary (e.g., quartz-pebble conglomerates, polymictic conglomerates, rhythmic and cross-bedded horizons) could be derived from adjacent igneous rocks through polyphase deformation, strain partitioning and hydration near the brittle-ductile transition of a shear zone. A granitoid pod from the Waugh Lake assemblage yielded a preliminary U-Pb zircon age of ca. 1.973 Ga (analyses by L. Heaman), within the range of ages that define the Taltson plutons adjacent to the west. $^{40}Ar/^{39}Ar$ dates of sericite in four phyllonite samples from the typical steeply-dipping layers of the Waugh Lake assemblage range from 1.84 to 1.82 Ga (analyses by O. van Breemen), consistent with shearing at shallow structural levels in a transcurrent tectonic setting.

The Waugh Lake lithotectonic assemblage previously described as an isolated outlier in NE Alberta, has been followed along strike to the southeast into Saskatchewan where it joins a ca. 25 km long by 1 km wide belt of low-grade rocks mapped southward to lat. 59°45'N (Koster, 1971); to the north, it projects into one of the belts of low-grade rocks of the Tazin Group that have been mapped at least 90 km to 60°43'N (Mulligan and Taylor, 1969). This extensive set of relatively narrow anastomozing belts of subvertical low-grade metamorphic tectonites records late transcurrent tectonics along the elusive eastern periphery of the Taltson magmatic zone, and may have limited or no stratigraphic significance.

The nature and significance of deformation within the Lewis thrust sheet at Crowsnest Lake: A meso-scale perspective

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Extensive fresh road cuts along Highway #3, on the south side of Crowsnest Lake, provide an outstanding cross-sectional display of meso-scale deformation of the Upper Devonian lime mudstones of the Palliser Formation, the dark shales and the cherty and argillaceous limestones and minor shale of the Mississippian Banff Formation, and the intervening thin black shale of the Devonian-Mississippian Exshaw Formation. This orthogonal transect crosses the lower part of the sheet within a lateral-ramp zone in which the Lewis thrust cuts up-section in its hanging wall from an extensive bedding detachment zone deep within Mesoproterozic rocks of the Belt-Purcell Supergroup in the region to the south to another extensive bedding detachment zone within the Palliser Formation in the region to the north. The unusually intense deformation along this hanging-wall lateral ramp may also reflect the fact that the transect lies within the zone of transition between the dominantly northwest-striking thrust faults and folds that characterize the thrust and fold belt SW of the Crowsnest Pass and the dominantly north-trending structures that characterize it here and in the region to the north.

Abundant polished bedding surfaces, many with ENE trending slickenlines, record pervasive shear displacements along bedding surfaces in the carbonate rocks, even in the normally massive lime mudstones of the Palliser Formation. The stratigraphic section has been tectonically thickened by numerous thrust faults, some with associated fault-bend and fault-propagation folds. Most thrust faults are contraction faults (they produce shortening in the plane of the bedding) that generally intersect the bedding at low angles (< 30 degrees). They commonly emerge from and merge with bedding-parallel (interstratal) shear zones (bedding detachment zones). Thrust duplex structures of various sizes and types are common. Most thrusts are synthetic contraction faults (they have the same sense of shear as the Lewis thrust), but some are antithetic contraction faults. Displacements on the thrusts/contraction faults, as recorded by slickenlines, are generally ENE - WSW and range from < 1cm to many metres (and perhaps kms). Extension faults produce stretching in the plane of the bedding; they also are widespread, but less abundant than the contraction faults. They have much lower displacements (<10m), and generally intersect the bedding at high angles (> 60 degrees). A third class of faults comprise transverse, generally steeply dipping, shear surfaces that appear to be tear faults that form lateral ramps between thrust faults and/or bedding detachment faults. Calcite veins and calcite-coated fractures also are common; many are mineralized joints (extension fractures?) but some are shear surfaces and some veins comprise calcite deposited in the lee of asperities on fault surfaces, including bedding detachment fault surfaces. Localized dissolution and precipitation of carbonate minerals occurred during thrusting.

Deformation of these rocks has some of the basic attributes of cataclastic flow: The distortion within the thrust sheet during large-scale translation and rotation has been accommodated mainly by comparatively small relative displacements and rotations among metre-scale to cm-scale blocks of rock, within which there generally has been little or no significant internal distortion.

From the tightly constrained perspective of the steep road cut along Highway #3, it is not obvious which of the numerous faults and bedding-parallel shear surfaces seen in the road cut are significant faults at the scale of Sentry Mountain. However, the view to the north across Crowsnest Lake at the south slope of Crowsnest Ridge provides a broader perspective. In this natural section through the lower part of the Lewis thrust sheet the overall structure of the thrust sheet is clearly displayed. The sequence of stratigraphic units (Palliser, Exshaw, Banff and Livingstone Formations) is essentially homoclinal, but there is evidence of variable internal thickening within formations. A comparable natural section is available in the view south toward Sentry Mountain from the microwave tower that is located north of the lake on the Crowsnest Ridge.

Fernie Map-area (82G): Nature and significance of profound change along the Cordilleran foreland belt

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Fernie map-area (114°–116°E, 49°–50°N) spans most of the Cordilleran foreland thrust-and-fold belt. It extends westward from the authochthonous east-dipping Paleocene foreland basin deposits of the Porcupine Hills Formation that overlie the "triangle zone" in the west limb of the Alberta syncline, across the Canadian Rockies and the Rocky Mountain trench, into the allochthonous Mesoproterozoic rocks of the Aldridge Formation in the Purcell anticlinorium. It also spans the transition between the northwest-trending thrusts and folds of the northern U.S. Rockies of Montana and the north-trending structures of the southern Canadian Rockies. This latter transition is manifested along the eastern margin of the foreland thrust and fold belt as the Crowsnest Pass deflection: a smooth southward change from north-trending structures to northwest-trending structures; however, it is part of the Crowsnest Pass cross-strike discontinuity (CPCSD). In British Columbia, the CPCSD involves a 220-km sinistral offset of the northeastern margin of the Paleozoic Cordilleran miogeocline from central Canadian Rockies near Sparwood B.C. to the vicinity Jumpoff Joe fault west of Chewelah in northeastern Washington. This offset is associated with two major, transverse, northeast-trending, dextral reverse faults (Moyie-Dibble Creek fault and St. Mary-Lussier River fault). These two faults follow the locus of older structures that controlled patterns of erosion and deposition during the Meosproterozoic (Belt-Purcell Supergroup), Neoproterozoic (Windermere Supergroup), and Cambrian to Triassic (Cordilleran miogeocline). The older structures were aligned with a major Paleoproterozoic crustal suture (the Vulcan zone) that has been outlined in the crystalline basement of southern Alberta by magnetic and gravity anomaly maps, drilling, and LITHOPROBE seismic imaging. The changes in stratigraphy between the Cordilleran miogeocline, on the northwest side of the CPCSD, and Montania, the Neoproterozoic-Paleozoic cratonic platform that developed above the Mesoproterozoic Belt-Purcell basin on the southeast side of the CPCSD, are responsible for the profound changes in the orientation and style of structures within the Main Ranges of the Rockies, the Rocky Mountain trench and the Purcell Mountains across the CPCSD.

This part of the Cordilleran foreland thrust-and-fold belt formed during Jurassic to Paleocene convergence behind northeast-dipping ocean-margin subduction zones. Supracrustal rocks were scraped off the under-riding North American crystalline basement and accreted to the over-riding tectonic collage of oceanic terranes that makes up most of the southern Canadian Cordillera. Thick (10-20) prisms of sediment that had accumulated in the intra-continental Belt-Purcell basin (1500-1400 Ma) and in the Cordilleran miogeoclinal continental terrace wedge (540-200 Ma) were detached from their underlying basement and displaced up to 220 km northeastward, over the flat surface of the North American craton. The resulting tectonic inversion of the two superimposed deep sedimentary basins generated the tectonic relief (and topographic relief) that energized complex lateral gravitational spreading and the formation of variably oriented critical-taper thrust-and-fold wedges. The orientations of the inverted sedimentary wedges were inherited from the orientations of the margins of the sedimentary basins. The margin of the Belt-Purcell basin was northwest-trending; the margin of the Cordilleran miogeocline was northeast-trending along the CPCSD, but north-trending north of the CPCSD; hence the change from northeast-verging to east-verging structures between the northern U.S. Rockies of Montana and the adjacent Canadian Rockies north of the CPCSD, and also, the local southeast-verging thrusting and folding in the Fernie area, where the north-trending and northeast trending margins of the Cordilleran miogeocline meet.

Measuring a fabric ellipsoid from planar fabric elements using the Sorted Vector Addition (SVA) Method

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The anisotropic fabric of some rocks is sometimes associated with preferred orientation of planar fabric elements, such as flat sedimentary pebbles, platy metamorphic minerals or igneous feldspar laths. In some cases, such fabric may be too weak to be evaluated by mesoscopic inspection, and thus require some detailed objective petrographic method. But even when foliation and lineation directions can be readily assessed in the field, it can be useful to measure it quantitatively and thus to be able to map with confidence the variation of its intensity and orientation over a field area.

The Sorted Vector Addition method provides a simple way to obtain a sectional fabric ellipse from planar markers; three or more sectional ellipses can then be combined to obtain a best-fitting fabric ellipsoid. The principle of the SVA method is best understood by first considering a rock in which the orientation of planar markers is statistically isotropic. The line segments observed in a planar section of these markers are also isotropically oriented within the section plane. After having measured the orientations of these line segments, they can be sorted according to their orientation angles. These sorted segments can be treated as unit vectors, which can be progressively added to each other. For an isotropic distribution, the successive vector sums delineate an approximate half circle. (By then adding the same vectors after a change in sign, the half-circle can be extended into a full circle.) When the planar markers are not isotropically distributed, sectional SVA yields an elongate centro-symmetric curve which can often be approximated as an ellipse.

Practical aspects of SVA include the method of measurements of the sectional line segments, which can be manual or automated, the sorting method, and the careful translation of sectional measurements to three-dimensional orientation angles.

We illustrate the use of SVA – and of the ellipsoid-fitting program ELLIPSOID – with the measurements of a biotite flake fabric in samples of the Northbrook Tonalite. The Northbrook Tonalite is a metatonalite / metagranodiorite metamorphosed and deformed by a strong and regionally extensive transpression event. Fabric anisotropy is clearly visible in the field, and the lineation in particular can be measured with confidence from shapes of loose mafic aggregates. The mesoscopic foliation, on the other hand, is more difficult to measure. We therefore used isolated biotite grains to quantify that fabric. These biotite flakes are metamorphic and are not likely to have behaved as passive markers during the deformation. We may thus only describe the ellipsoid measured as that of a 'virtual strain'. Nevertheless, we interpret the variations of that virtual strain as reasonable relative indicators of variations in the intensity, shape and orientation of real tectono-metamorphic strain. (See poster by Serafini, Robin and Haider).

Shear zone geometry and rheology: insights from physical modeling

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The geometry of ductile strain localization phenomena such as shear zones and folds depends on the rheology of the deformed rocks. Thus, geometries of natural shear zones have been used to deduce rheological properties of the affected materials both qualitatively and quantitatively. But we observe finite structures in the field. They typically reflect a complex deformation history. Hence, meaningful data can only be derived if the regarded shear zone features a well-constrained temporal evolution under approximately constant PT-conditions with a simple rheology.

This work aims at better understanding the relation between shear zone geometry and the rheology of the sheared materials by physical modeling of shear zones in a simple shear box with various analogue materials. We employ different materials with characteristic rheological properties: viscous Newtonian and non-Newtonian, viscous non-linear with either strain hardening or softening, elasto-visco-plastic and frictional Mohr-Coulomb. The experiments are observed with a Particle Image Velocimetry system that allows the determination of displacement and velocity fields at high spatiotemporal resolution. The evolution of shear zone width, transversal strain distribution, displacement distribution, and maximum and mean shear strains are investigated and related to the rheologies of the applied materials which have been measured independently with a controlled-stress rheometer.

Incremental and cumulative deformation histories differ significantly in spite of time control and high observational resolution. Nevertheless, some materials (e.g., strain hardening and highly strain-softening fluids) show specific cumulative patterns. Hence, at least qualitative rheological constraints can be derived from finite structures in the field.

Cylindrical S/Z folds as indicators of a shear component: new examples from the Grenville Orogen in Ontario

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Except in deformation zones dominated by high-magnitude *simple shear,* the orientation and S/Z style of cylindrical buckle folds are supposed to indicate, respectively, the direction and sense of a shear component tangential to the fold-enveloping surfaces (see textbooks of structural geology). But as shown by W.F. Brace many years ago, the shear-induced monoclinic symmetry of cylindrical S/Z forms depends on a finite-magnitude strain rather than the type of overall deformation. Moreover, the S/Z style qualifies as a shear-component indicator only if the cylindrical axis parallels a principal strain direction, on the scale of individual fold pairs or fold trains. This does not hold true for the *oblique folds* of simple-shear-dominated deformation zones, even if the cylindrical axis has become subparallel to elongated cm-scale inclusions defining a linear shape fabric (*stretching lineation*).

The use of single-generation, open S/Z folds is straight forward, particularly within non-metamorphic sedimentary sequences or low-grade metamorphic rocks. The situation can be much more difficult, by contrast, in ductilely deformed *metasedimentary* gneisses. Repeatedly folded, *metaplutonic* gneisses are commonly replete with distorted pseudomorphs after igneous megacrysts, relict mafic clots, or dm-scale xenoliths whose linear-planar shape fabrics pertain to the total rock strain. The hinge zones of quasi-cylindrical, superimposed folds in strained lithologic contacts and a concordant mineral-shape foliation typically lack axial-planar schistosity but exhibit purely linear or dominantly linear shape fabrics parallel to the cylindrical axis. Such linear fabrics can be explained by passive superposition of a folding strain on dominantly planar shape fabrics. Examples of strongly to purely lineated fold-hinge zones abound in metaplutonic gneisses of the Georgian Bay-Muskoka region, Grenville Orogen (Ontario), on length scales ranging from 10 cm to 10 km. Throughout the region, three generations of imposed folds (F2, F3 and F4) have been recognized in earlier studies. F2 and F3 structures in the gneissic layering or main foliation are coaxial and transverse to the Ontario segment of the Grenville Orogen. Depending on size and interlimb angle of the gentle or open F4 structures, whose hinges tend to be subnormal to the linear shape fabrics, F2 structures with S style are now quasi-cylindrical or moderately noncylindrical.

In parts of the Georgian Bay-Muskoka region, amphibolite units contain quasi-cylindrical F2 structures with three-dimensional gauges of the folding strain; flattened feldspathic pseudomorphs after large garnet porphyroblasts. The pseudomorph fabric conforms to the F2 axial plane, and has a weak linear component parallel to the cylindrical axis. Results of ongoing field work show that SE-plunging, m-scale F2 structures with S style abound also at the basal-detachment surface of the Composite Arc Belt (southeastern Ontario). In the companion abstract, we consider possible tectonic implications of the orogen-parallel distributed shear inferred from the sum of our field evidence collected to date.

Folding of Grenville gneisses under orogen-parallel sinistral-normal shear on the kilometre scale

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It is widely believed that in central and southeastern Ontario, NW- and SE-directed simple shear dominated the ductile deformation during the 1090 – 1050 Ma Ottawan and 1010 – 990 Ma Rigolet orogenies. However, the regional prevalence of strongly foliated and weakly lineated (S>>L) metaplutonites casts doubt on the merit of plane-strain scenarios. Northeast of Georgian Bay (Lake Huron), ca. 1430 Ma, *single-cycle* metaplutonites tend to have simple S>>L mineral-shape fabrics rather than a composite foliation with tight rootless folds. Form and orientation of open to close buckle folds (F2) in lithologic contacts and the mineral-shape foliation of meta-igneous and metasedimentary rocks attest to an orogen-parallel shear component possibly associated with an orogen-perpendicular stretching component (NW-directed extrusion flow). In brief, our field data (2006) indicate that the Ottawan and Rigolet strains are truly triaxial, and probably a net result of repeated ductile shearing, shortening and stretching of deeply buried rocks.

In the Georgian Bay region and northwestern parts of southeast Ontario, contacts between rock units and the concordant mineral-shape foliation seem to have been folded several times. Various linear-shape fabrics (*stretching lineations*, L) are parallel to the hinge lines of coaxial, multi-order, F2 and F3 structures. All linear-shape fabrics are typically bent across the N-S to E-W trending hinge lines of F4 structures, whose inter-limb angles are commonly >120°. We focused attention on the F2 structures, and tried to assess their orientation and S/Z style before refolding and triaxial boudinage of the long fold limbs. Detailed observations were made in well-exposed wall segments of two lithotectonic interfaces, (1) the folded Allochthon Boundary and (2) the basal-detachment surface of the Composite Arc Belt. In such wall segments, quasi-cylindrical parts of F2 structures commonly plunge to the east or southeast, and have S forms whose short limbs are thrown into parasitic M folds. Questions remain to be answered as to the evolution of the parasitic M folds, and their temporal relationships to the hosting S folds. But we consider all quasi-cylindrical segments of easterly to southeasterly plunging S folds as evidence for pre-F4, northeasterly directed, sinistral-normal shear accumulated at an advanced stage of Ottawan ductile deformation. Details about our lines of reasoning are provided in the companion abstract for the poster presentation.

The Northbrook-Kaladar Formation: a microcosm of the Mazinaw Domain (Composite Arc Belt, Grenville Province)

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Detailed mapping of a few square kilometres (< 2.5 km^2) along the southern contact of the Northbrook Metatonalite documents a geographically compact record of igneous, sedimentary and tectonometamorphic events which appears to echo much of the geological evolution of the much broader Mazinaw Domain.

The oldest rock in the area is the Northbrook Metatonalite (NM, although commonly metagrano-dioritic in composition). Its crystallization age has not been measured but Corfu and Easton (1995) suggest the same, ~ 1,250 ± 10 Ma age as that of the neighbouring Cross Lake Pluton to the north. Along its southern margin, the N Metatonalite was unconformably overlain, in the western half of the map area, by what we interpret to be a mafic volcanic edifice (VE). Its rocks consist of mafic to intermediate amphibolites containing distinctive intermediate to large equant hornblende grains. We interpret these equant hornblende crystals as pseudomorphs after coarse igneous pyroxene grains crystallized either within a volcanic edifice or in thick flows. On the east half of the map area, the NM is unconformably overlain by what we call the Northbrook-Kaladar formation (NK Fm). Further south from the Northbrook contact, the NK Fm also overlies the mafic metavolcanic complex. The NK Formation consists of metamorphosed thin mafic volcanic flows, arkose, polymictic and arkosic conglomerate beds, and eventually pelitic rocks.

The tonalite, volcanic edifice and NK Formation were all jointly affected by a tectono-metamorphic event leading to strong NE-SW horizontal extension and a corresponding vertical flattening foliation that grades southward into a reverse, south-over-north component of strain. The large horizontal extension can best be accounted for by horizontal transpression, but no convincing sense for the horizontal shear was found in the map area. The meta-igneous rock units (NM, VE) and the lower part of the NK Fm were initially relatively anhydrous, and their metamorphism is mostly a hydration event, forming epidote and amphibole. Further south, the prograde pelitic assemblage includes quartz, muscovite, and staurolite breaking down to sillimanite, garnet and biotite. There is no indication of two stages of metamorphism, and the minerals, although they have a strong shape fabric, exhibit no significant intracrystalline strain. A small circular stock of undeformed leucocratic granite punctures the rocks of the NK Fm. It does not seem to imprint any contact metamorphism on its host, and it is best interpreted as emplaced during the last – still hot but tectonically quiet – stage of the main metamorphic event. Immediately to the south, the 1,245 Ma (Van Breemen and Davidson 1988) Addington Granite, which was also metamorphosed and stretched horizontally at high temperature, is thrust over the NK Formation. While none of the rocks have been dated, we might correlate the NK Fm with the Flinton Group (described in a narrow trough of metasediments to the west of our area) as others have done, and ascribe the strong transpression under medium-grade metamorphic conditions to the 1090-980 Ottawan orogeny. That transpression, common to much of the Mazinaw domain, would thus postdate the accretion of that domain to the Composite Arc Belt, but yet appears to be restricted to that domain.

Fracture patterns at Turtle Mountain, S.W. Alberta

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Mississippian limestones are exposed in an east-verging anticline with an overturned forelimb in the hanging wall of the Turtle Mountain Thrust. As part of the Turtle Mountain Monitoring Project, a 61.3 m deep borehole was drilled on top of Turtle Mountain, 100 m from the Frank Slide surface, and digital televiewer images were acquired to determine the nature and orientation of discontinuities beneath the surface. The goal was to identify fractures that potentially connect to the large open cracks observed at surface and statistically analyze the fracture population to determine which orientations are most likely to be involved in future mass wasting events. In the process, it was also possible to distinguish sets related to folding and faulting, and sets that remain open due to gravitational effects or situ stresses.

Bedding was consistently oriented over the logged interval, with a mean dip direction and dip of 294°/37°, indicating that the borehole intersected only the west-dipping limb of the Turtle Mountain Anticline. Several large open fractures with apertures of more than 1 cm are seen in the image logs and are potentially long enough to connect to fractures observed at the surface. The most frequent dip directions of the major fractures are to the northeast (toward the Frank Slide surface) and east (toward the town of Hillcrest), and most of the dips are steeper than 60°. One major fracture dips WNW, subparallel to bedding; another dips south along the ridge. 151 other fracture surfaces, with apertures <1 cm (commonly ≤1 mm), were also identified and measured in the image logs. Their orientations are more variable, but the larger sample size provides more statistically valid results. The three most frequently encountered orientations dip WNW (subparallel to bedding), ESE and ENE.

Since the 40.5 m long borehole logs sampled only a limited portion of Turtle Mountain, the results were compared to surface data to determine that they are representative of a wider area than the borehole itself. Comparing the surface data to the borehole data we see that the three most frequent orientations in both datasets are the NW-dipping steeper-than-bedding set, the set dipping steeply NE toward the Frank Slide surface, and the set that dips ~30°SE toward Hillcrest. The two main differences between the plots are the lack of vertical beds measured in the borehole due to the low probability of intersecting surfaces sub-parallel to the borehole. The fewer azimuths represented in the surface data may be due to human bias - the tendancy to look for patterns and sets rather than measuring every orientation. Fractures and cracks measured in outcrops on Turtle Mountain include Stearns' (1967) Type 1 and Type 2 extension and shear fractures, but several additional sets are observed. The variety is likely due to Turtle Mountain's position in the middle of the Crowsnest Deflection where surface structures trend N-S to the north and NW-SE to the south of the deflection, within the Vulcan Low on the aeromagnetic map of basement, and in an area of uncompensated topography on the isostatic residual gravity anomaly map. The 050° compression direction at the time of thrusting was deduced from the hundreds of measurements of slickenside orientations made in the region by Don Norris. It is oblique to both the local fold axis orientation and the bedding strike in the vicinity of the borehole. Type 1 dextral shears and Type 2 extension fractures are the most abundant, and there are significant numbers of fractures perpendicular to the local fold axis (*ac* fractures) and others sub-parallel to local bedding.

Dynamical numerical models of thin-skinned thrust-and-fold belts: linkages between structural style and foreland deposition

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The sedimentary records of foreland basins reflect the structural and geodynamical evolution of the adjacent orogenic belts. For example, changes in mass distribution due to thrusting cause changes in lithospheric flexural response, which in turn cause changes in slope and accommodation space across the foreland basin. In addition, syndeformational sedimentation can profoundly influence structural style, as well as the timing and magnitude of motion on individual thrusts. These feedback relationships, i.e., structure influencing sedimentation and sedimentation influencing structure, are essential elements of the coupled thrust belt / foreland basin dynamical system.

We examine aspects of this coupled system using an arbitrary Lagrangian-Eulerian finite element approach to model the mechanics of thin-skinned thrust-and-fold belts (TFBs). Model faults are represented by narrow zones of high shear strain, yielding structural styles very similar to natural TFBs. Under appropriate mechanical conditions, syndeformational surface processes (erosion and sedimentation) may result in the proximal portion of the flexurally subsiding foreland basin achieving critical taper, without internal deformation. This causes the tip of the TFB to step out into the foreland, incorporating the proximal foreland basin as a piggyback basin, which may then be shortened by out-of-sequence thrusts. Continued convergence and repeated accretion of piggyback basins leads to a structural style characterized by broad, little-deformed synforms, separated by more strongly deformed antiforms, similar to features in the Alberta Foothills and elsewhere. Although syndeformational sediments have been erosionally removed across the Foothills, the structural characteristics of dynamical feedback between deformational style and surface processes remain.

U-Pb geochronology and $^{40}Ar/^{39}Ar$ thermochronology studies in the vicinity of Thor-Odin dome, southeastern British Columbia to test tectonic models and characterize the behaviour of $^{40}Ar/^{39}Ar$ systematics in migmatite terranes: A Ph.D. thesis proposal

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This Ph.D. project is designed to carry out detailed mapping, U-Pb geochronology and $^{40}Ar/^{39}Ar$ thermochronology studies in the vicinity of the Thor-Odin dome to characterize thermotectonic history of different structural levels, and address the significance of the apparent boundaries between them. The Thor-Odin dome, of the southern Monashee complex, is the deepest exposed structural level in the southern Omineca belt. It comprises Paleoproterozoic basement rocks, infolded with Proterozoic and/or younger metasedimentary rocks that have all undergone penetrative deformation and anatexis in the Paleocene – Eocene and were rapidly exhumed in the Eocene. The Thor-Odin dome is surrounded by medium to high-grade rocks to the west and south that show Late Cretaceous to Paleocene deformation and metamorphism, and by rocks, to the east, that were deformed in the Middle Jurassic and generally cooled by the Jurassic or Early Cretaceous.

Unresolved problems in the area include: i) lack of information about timing of metamorphic history (e.g. P-T paths), particularly across the southern flank of the Thor-Odin dome; ii) the location and nature of the boundaries between areas of different metamorphic grade; and iii) the mechanisms and processes responsible for the current tectonic configuration of the area. Different models include: i) crustal thickening due to thrusting followed by Eocene extensional exhumation; ii) Eocene diapirism; iii) channel flow and channel flow with extrusion; iv) channel flow and fold interference causing doming; v) localized nascent channel flow within a crystalline thrust sheet; vi) unconformities between different domains; and others. One way to discriminate between tectonic models is to address and characterize the cooling histories of different domains in conjunction with structural studies. This project will build on previous studies and characterize timing of deformation and cooling along transects through adjacent domains. The transects will cover basement in the Thor-Odin dome, structurally intermediate rocks of the Gold Ranges, to the south, and structurally highest rocks to the east, in the hanging wall of Columbia River Fault, with a focus on their apparent boundaries. (For example, is there a boundary with significant displacement at Cariboo Alp between the Thor-Odin dome and overlying rocks? Is there significant displacement on the Columbia River fault system?) Samples will be collected as part of an integrated U-Pb geochronology (monazite and zircon) and $^{40}Ar/^{39}Ar$ thermochronological (hornblende, biotite and muscovite) study. The thermochronological study, in particular, will be specifically targeted at gaps in the data set and at the boundaries between domains in order to characterize their cooling histories. This will make it possible to determine the nature of each boundary; for example, cooling of a premetamorphic boundary will have a different $^{40}Ar/^{39}Ar$ profile than that of an extensional fault. The first phase of field work has been completed, covering the south-western flank of Thor-Odin at Cariboo Alp and the high and low grade metamorphic rocks south of the dome.

This study will also address the behaviour of argon systematics in migmatite terranes. Previous studies have yielded an apparent contradiction between cooling and deformation ages as obtained from $^{40}Ar/^{39}Ar$ thermochronology and U-Pb geochronology in migmatite terranes (e.g. in Thor-Odin and the Bergen arc of Norway), with $^{40}Ar/^{39}Ar$ dates being older than dates obtained with U-Pb methods. This study will determine whether these apparent contradictions are possible in such terranes or are analytical artifacts.

Kinematic vorticity number and shear zones

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The kinematic vorticity number has been used to determine whether or not there is normal convergence of shear-zone boundaries. The results indicate convergence which in some cases is extreme. It is argued here that the method is fallacious and suggested that dragfolds are probably more useful from this point of view. Abundant dragfolds in a shear zone are an indication that there has been a time in the shear-zone history when convergence was not significant. Dragfold development is favoured by divergent conditions.