

Program with Abstracts: Muskoka 2016

36th Canadian Tectonics Group Workshop



**Toby Rivers
Fried Schwerdtner
Dennis Waddington**

**October 21 to 23, 2016
Bracebridge, Ontario, Canada**

Cover photo

Rock cut on Gravenhurst Parkway, just north of Reay Road intersection. West facing, up-dip view of amphibolite-facies, mafic-rich orthogneiss, in the western marginal zone of the Germania lenticular structure. The gneisses are migmatitic with abundant leucosome and have a highly strained fabric with mesoscopic structures such as late-stage pegmatite dikes and an extensional fault-propagation fold on the other face of the outcrop. Relict granulite-facies assemblages are preserved in some mesoscopic boudins within the pervasive high-strain fabric defined by amphibolite-facies mineral assemblages.

Schedule: 36th CTG Workshop (Muskoka 2016)

Friday, October 21, 20

- 2:00 p.m. Rock walk tour of town**
- 2:00 p.m. Start poster set-up in Pine conference room**
- 2:00 p.m. Check-in and payment of registration fees in Pine conference room**
- 7:00 p.m. Poster set-up in Cedar and Pine conference rooms**
- 7:30 p.m. Meet and Greet in Cedar and Pine conference rooms**
- 8:15 p.m. Welcome and briefing in Cedar conference room**
- 8:30 p.m. Toby Rivers and Fried Schwerdtner: an introduction to the Ottawa River Gneiss Complex (ORGC) and the Muskoka Region**
The ORGC as a giant metamorphic core complex: field evidence, regional significance and tectonic implications for the collapse of the Grenville Orogen

Saturday, October 22, 2016

- 7:00 a.m. Group breakfast in dining room**
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- 8:30 a.m. Brief remarks to open the Oral Session: Cedar conference room**

SCHEDULE OF ORAL PRESENTATIONS (* indicates presenter)

SESSION I: chaired by Phil Simony

- 8:45 a.m. Zoe Braden*, Laurent Godin, John M. Cottle, and Dawn A. Kellett**
Segmentation and rejuvenation of the Himalayan crystalline core in western Nepal
- 9:00 a.m. Renaud Soucy La Roche*, Laurent Godin, John Cottle**
Abrupt along-strike variations in the P-T-t-d evolution of the Himalayan middle crust: insights from western Nepal klippen
- 9:15 a.m. D. Grujic*, K.T. Ashley, M.A. Coble, I. Coutand, D.A. Kellett, and N. Whynot**
Inverted temperature fields: peak metamorphic and deformational temperatures across the Lesser Himalayan Sequence

9:30 a.m. **Isabelle Coutand*, David M. Whipp Jr., Djordje Grujic and Kyle Landry**
Late Neogene tectonically driven crustal exhumation of the eastern Himalaya (Sikkim and Bhutan) derived from inversion of low-temperature multithermochronologic data

9:45 a.m. **Raymond Price**
The Paleogene transition from dextral transpression to dextral transtension in the southern Canadian Cordillera

10:00 a.m. **Coffee/Tea, discussion, poster viewing: Cedar and Pine conference rooms**

SESSION II: **chaired by Caroline Gordon**

10:30 a.m. **Willem Langenberg**
Why are only a few Transverse Faults mapped in the Canadian Rockies?

10:45 a.m. **Jürgen Kraus* and Paul F. Williams**
The Emperor's New Clothes – the Discrepancy between Observation and Interpretation in the Canadian Rocky Mountains

11:00 a.m. **Christie Rowe**
Insights into earthquake rupture and recovery from paleoseismic faults

11:15 a.m. **Catherine Ross*, Christie Rowe and M. Swanson**
A Comparison Between Modelling of Coulomb Stress and Field Observations of Off-Fault Strain around Pseudotachylyte Fault Veins, Norumbega Fault System, southern Maine

11:30 a.m. **Alan Dickin*, Jacob Strong, Gabriel Arcuri, Annika van Kessel and Lucia Krivankova-Smal**
A new model for the crustal structure of the SW Grenville Province, Ontario, Canada

11:45 a.m. **Jacob Strong* and Alan Dickin**
Three-dimensional visualization of the major lithotectonic boundaries in the SW Grenville Province, Ontario

12:00 Noon **Poster Session I (see program below): Cedar and Pine conference rooms**

12:30 p.m. **Lunch: Cedar conference room**

SESSION III: **chaired by Shoufa Lin**

2:00 p.m. **Henry Halls**
Crustal shortening across the Grenville collisional orogen from paleomagnetic evidence

- 2:15 p.m. Carol-Anne G n reux* and Bruno Lafrance**
Structural evolution in the South Range of the Sudbury Structure
- 2:30 p.m. Deanne van Rooyen* and David Corrigan**
Structural domains in the Kuujjuaq – Tasiujaq area of the Paleoproterozoic new Quebec Orogen; effects of orthogonal compression and dextral transpression
- 2:45 p.m. David Corrigan**
Persistence of Archean SCLM through time and its effect on collisional tectonics
- 3:00 p.m. Ian Chappell**
Relative Timing and Structural Controls of Gold deposition at the Black Fox and Grey Fox deposits along the Porcupine-Destor Deformation Zone
- 3:15 p.m. H.L. Gibson, Bruno Lafrance*, J.A. Ayer and P. Thurston,**
The science behind Metal Earth

3:25 p.m. Coffee/Tea, discussion, poster viewing: Cedar and Pine conference rooms

SESSION IV: chaired by Laurent Godin

- 4:00 p.m. Qihang Wu**
A material-point method formulation for incompressible linearly viscous geological flow
- 4:15 p.m. Nathan R. Clevn**
Tectonic architecture of the Opinaca and La Grande subprovinces: synthesis of structural interpretations and alternative geophysical treatments
- 4:30 p.m. Joe White*, I. Zibra and L. Menegon**
Fracture in the Midst of Flow - Deformation processes along the Moyagee Fault, Western Australia
- 4:45 p.m. Pierre-Yves F. Robin*, Chris R.J. Charles, Don W. Davis and Phil J.A. McCausland**
Chondrule shapes and fabric in a CR2 chondrite
- 5:00 p.m. Poster Session II: Cedar and Pine conference rooms**

6:00 p.m. Cash Bar: (location TBA)

7:00 p.m. CTG Dinner: (location TBA)

8:30 p.m. GAC/CTG-SGTD business meeting: Cedar conference room

10:00 p.m. Final take-down of posters

Sunday, October 30, 2005

7:00 a.m.	Group breakfast in dining room:
8:00 a.m.	Pick up box lunches for the CTG field trip
8:30 a.m.	Departure for CTG field trip: participants gather in front of main entrance to the Quality Inn to make sure everyone has a ride.
4:00 p.m.	Field trip ends

THAT'S ALL FOR THIS YEAR – HAVE A SAFE TRIP HOME EVERYONE

LIST OF POSTER PRESENTATIONS (* indicates presenter)

Mark Ahenda*, Laurent Godin, Djordje Grujic And Ross Stevenson
Early Cenozoic evolution of the Gurla Mandhata core complex, NW Nepal Himalaya

Samantha Carruthers*, Christie Rowe and Sean Mulcahy
Deformation of Blueschist and Eclogite Blocks at Depth

Kelian Dascher-Cousineau* and James Kirkpatrick
Evolution of Fault Slip Surfaces with Increasing Displacement

Dylan Jamison
Deformation History of the Black Bay Fault

Katia Jellicoe* and Shoufa Lin
Structural History of the Goudreau Lake Deformation Zone and Island Gold Deposit in the Superior Province, Ontario

Jamie Kirkpatrick
Fault surface geometry as a record of deformation processes

Iris Lenauer* and Ulrich Riller
Did trishear deformation overturn the South Range of the Sudbury Igneous Complex?

Jiangyu Li
Mapping Project in Liuyuan, Beishan, North China

LIST OF POSTER PRESENTATIONS (cont'd)

Lucy X. Lu* and Dazhi Jiang

Mechanics of Oblique Convergence of Plates and Continental Tectonics

Svieda Ma

Preliminary observations on the style and timing of deformation along the Bathurst Fault, western Nunavut

Noah Phillips

Melt Present Deformation in a Hot Lower Crustal Shear Zone: The Lower Fish River Onseepkans Shear Zone, Namibia

Mengmeng Qu*, Dazhi Jiang, Lucy X. Lu, Ivan R. Barker and Desmond E. Moser

A comparison between multiscale simulation results of quartz lattice preferred orientations and EBSD data from the Shangdan tectonic zone of the Qinling orogenic belt, China

Tasca Santimano*, Matthias Rosenau and Onno Oncken

Accretionary wedge evolution seen as a competition between minimum work and critical taper

W.M. Schwerdtner*, Toby Rivers and Scott Robertson

Map patterns and shape-fabric signatures of km-scale cross-folds in Archean and Proterozoic gneisses, parautochthonous part of the Ottawa River Gneiss Complex, Grenville Province of Ontario

Caroline Seyler

Mixed rheological behavior of a subduction plate boundary fault beneath the seismogenic zone

Erik Young

Rheological Dependence of Slip Surface Distribution in a Shear Zone Core at the Brittle Ductile Transition

Abstracts: 36th CTG Workshop (Muskoka 2016)

Early Cenozoic evolution of the Gurla Mandhata core complex, NW Nepal Himalaya

Mark Ahenda^{1*}, Laurent Godin¹, Djordje Grujic² and Ross Stevenson³

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The Himalaya is divided into several major lithotectonic units: the Tethyan Sedimentary Sequence, the Greater Himalayan Sequence (GHS), the Lesser Himalayan Sequence (LHS), and the Siwaliks, each separated by major crustal-scale fault and shear zone systems. The South Tibetan Detachment separates the Tethyan Sequence from the underlying GHS, the Main Central Thrust separates the GHS from the underlying LHS, and the Main Boundary Thrust separates the LHS from the underlying Siwaliks. These fault systems root in the Main Himalayan Thrust above the Indian Basement (Fig. 1). The Gurla Mandhata core complex is an amphibolite to granulite facies metamorphic core complex exposed in the hinterland of the Himalaya in NW Nepal. Subsequent to crustal thickening, exhumation occurred along a system of local detachment and strike-slip faults associated with a Mid-Miocene transition from dominant N-S directed compression to dominant orogen-parallel extension identifiable across the Himalayan orogen. The rocks of the Gurla Mandhata core complex have been disparately assigned to the GHS or LHS, and much of their pre-Mid-Miocene prograde tectonic history is still unknown. Previous work suggests that some LHS rocks are exposed in the dome, therefore implying significant underlying geometrical complexity. A 40 km long N-S transect through the dome was sampled in Spring 2016. Major rock units identified and sampled include occasionally migmatized metapelitic schist, augen gneiss, orthogneiss, leucogranite bodies, and marble/calc-silicate gneiss. Several E-dipping faults were identified, along with abundant top-to-the-W shear-sense indicators within the main shallow W-dipping foliation and along brittle steeply-dipping faults throughout the transect. Lithotectonic association of the metapelitic and augen gneiss units will be determined through ϵ_{Nd} / ϵ_{Sm} isotopic analysis and U-Th/Pb geochronology. Thermochronometric age determination of monazite grains in metapelites will identify major thermal pulses recorded in the rocks, and will be integrated with structural mapping and microtectonic analysis with the aim to reconstruct the prograde early Cenozoic history and subsurface geometry of the dome.

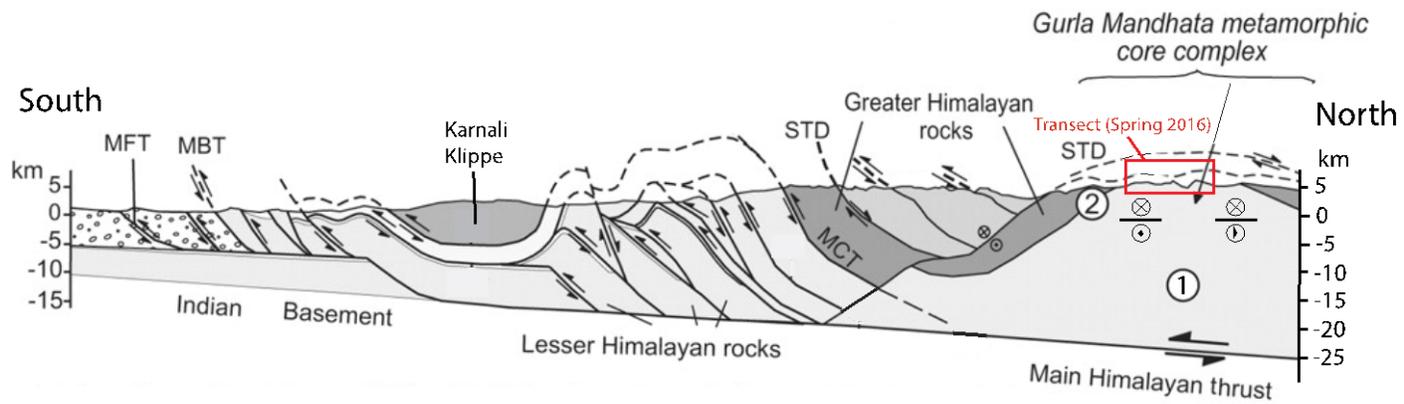


Figure 1: Schematic cross section of the Himalaya through the Gurla Mandhata core complex, showing the Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), and South Tibetan Detachment (STD). Structural elements to be studied include 1) region of possibly thickened LHS or GHS rocks, and 2) possible contact between GHS and LHS rocks in the core complex. This model assumes core complex rocks are dominated by LHS affiliation, and does not propose adequate solutions to geometrical complexity in the subsurface. (Modified from Murphy, 2007)

Segmentation and rejuvenation of the Himalayan crystalline core in western Nepal

Zoe Braden^{1*}, Laurent Godin¹, John M. Cottle², and Dawn A. Kellett³

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The Main Central thrust is a major mountain building shear zone in the Himalaya that carried the orogenic metamorphic core in its hanging wall towards the foreland during the early Miocene. It is typically seen as an in-sequence thrust that incorporates material via footwall accretion. To test the significance of lateral and across-strike variations in deformation, the hanging wall of the Main Central thrust was sampled multiple times in its transport direction in the western Nepal Himalaya. U-Th/Pb petrochronology, ⁴⁰Ar/³⁹Ar thermochronology and SHRIMP U/Pb geochronology were used to study the progression of deformation from hinterland to foreland. Despite the geographic proximity and apparent structural continuity of the sampled regions, the timing of metamorphism, melting, and cooling differ substantially. The hinterland only records more recent deformation and metamorphism at 18 Ma, and initiation of melt crystallization at ca. 14 Ma. Monazite hosted in a boudinaged kyanite-bearing leucosome from the hinterland constrains deformation to as recently as 8 Ma. In contrast, the foreland region records a protracted series of events: metamorphism began as early as 48 Ma and lasted until 18 Ma. In both areas, the timing of melt crystallization youngs down section through the hanging wall toward the base of the thrust. ⁴⁰Ar/³⁹Ar thermochronology on muscovite from two areas in the foreland yield cooling ages of ~17 Ma and 14-12 Ma, respectively. The youngest deformation recorded in the foreland of the sampled transect is ca. 18 Ma, yet rocks in the hinterland were still being actively deformed and melted ca. 8 Ma. The southern, foreland-most hanging wall rocks were consequently exhumed above the ductile-brittle transition while the northern hinterland-most hanging wall rocks were still undergoing ductile deformation and partial melting. Out-of-sequence reactivation of the crystalline core in the hinterland does not fit clearly into any current models for orogenic evolution of the Himalaya. Work done by other research groups along strike from the studied region does not show evidence of the young structural rejuvenation reported here. Our results suggest lateral variation in the evolution of the crystalline core is significant, and under-represented in current models of the orogeny.

Deformation of Blueschist and Eclogite Blocks at Depth

Samantha Carruthers*, Christie Rowe and Sean Mulcahy

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Subduction zones produce large earthquakes and tectonic tremor, and the dynamics of these plate boundaries control the rates of plate tectonics. However, the stress conditions at depth cannot be directly observed, so are poorly understood. Blueschist and eclogite form at depths of >30 km in the subduction zone, and if exhumed, can be used to study stress and temperature conditions close to the plate interface. Due to subduction depth it is impossible to study this in an active environment, so we rely on exhumed rocks from the Franciscan Complex. By developing a detailed deformation history tied to the metamorphic assemblages, I aim to identify when and where the subducting slab deformed and tie that to stress conditions on the deep subduction interface. These blocks have been well-characterized in metamorphic studies, but since they occur in mélangé terranes, past researchers have not made use of structural information. To our knowledge, this will be the first study to use high grade blocks from the Franciscan to research the structural aspects of subduction dynamics.

I will conduct fieldwork in two locations: Tiburon Peninsula and Jenner Headlands, CA. The blocks are composed of blueschist and eclogite, some bearing garnet and lawsonite that have been dated using Lu-Hf geochronology (Mulcahy et al., 2009; 2014). The individual blocks cannot be connected spatially, however if they deformed under the same P-T conditions we will be able to determine that they show us equivalent parts of the subduction system. I am developing a novel mapping method using a unique internal reference frame for each individual boulder to reveal 3-D rotations in the strain ellipse within each reference frame. I will build 3D models from 100s of field photos using AGIsoft Photoscan Pro software. I will use georeferenced orthophotos projected from the 3D model to create a unique reference frame for each of the boulders to document the structural fabrics. In order to relate the measured strain to paleo-stress along the Franciscan subduction zone, I will measure yield strength of my samples in the rock mechanics lab at Lamont-Doherty Earth Observatory. If we are able to successfully study these samples with our new approach, it will create opportunities to obtain structural data and information from mélanges.

Relative Timing and Structural Controls of Gold deposition at the Black Fox and Grey Fox deposits along the Porcupine-Destor Deformation Zone

Ian Chappell

Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada

The Timmins-Porcupine gold camp is located within the Southern Abitibi Greenstone Belt. It produced in excess of 72 M Oz. of gold since mining began over a century ago. Over 98% of these mines occur on the north side of the Porcupine-Destor deformation zone (PDDZ). The PDDZ stretches over 450 km and includes the prolific Timmins-Porcupine camp. This endowment in gold has spurred many studies in an effort to build a framework for the emplacement of gold mineralization with respect to the stratigraphic, structural and chronological evolution of the camp. Four regional deformation events have been identified; D1 regional uplift, D2 imbrication of south over north thrust sheets, D3 left lateral strike slip movement with the formation of an echelon folding, D4 right lateral strike slip movement. Although these studies provide great insights on the deformational history of the Timmins-Porcupine camp, most segments of the PDDZ between the Timmins-Porcupine and Val d'Or gold camps have received less intense scrutiny.

Eighty kilometers east of Timmins along Highway 101 aptly named "the Golden Highway" is Hislop Township. This Township hosts the Black Fox mine, Grey Fox property, and past producing, Hislop, Gibson and Ross mines which collectively produced over 1.1 M Oz. of gold. The latter three deposits are located south of the PDDZ whereas the Black Fox mine occurs along the PDDZ. These deposits host two distinct vein and sulphide hosted mineralization styles.

The Grey Fox property consists of largely undeformed variolitic pillowed to massive volcanic rocks which have undergone multiple stages of brittle deformation and, brecciating. Gold is present in polyphase quartz-carbonate breccia veins and in quartz-carbonate crustiform veins surrounded by hematite-albite-sericite-pyrite alteration haloes.

The Black Fox mine differs from the Grey Fox property by the strong ductile deformation of the host rocks and the emplacement of gold mineralization during this deformation. Four major deformation events are observed at the Black Fox Mine. A penetrative and continuous S1 fabric formed during D1. It is associated with south-over-north drag folds (F1) with an axial planar cleavage. These folds and S1 fabric are folded by open F2 folds with an axial planar cleavage S2, which formed during a D2 event. D3 brittle south-over-north reverse faults overprint these structures. Gold was observed within quartz-carbonate veins interpreted as syn-D1 as they contain wallrock fragments with S1 fabric. Breccia and crustiform veins similar to those at the Grey Fox property are deformed parallel to S1 suggesting that this style of mineralization predate the PDDZ and the Black Fox mineralization. This sequence of deformation differs from that observed in the Timmins-Porcupine gold camp by the prevalence of dip-slip movement over strike-slip movement.

Tectonic architecture of the Opinaca and La Grande subprovinces: synthesis of structural interpretations and alternative geophysical treatments

Nathan Cleven

Université Laval, Québec, QC, Canada

Current designations of subprovince boundaries in the Superior Province are litho-tectonic contacts separating regions of surface geology that have fundamental differences. The La Grande volcano-plutonic subprovince and the Opinaca metasedimentary subprovince share a long boundary with a complicated tectonic history. In this contribution we present custom treatments and re-interpretations of provincial and federal government magnetic and gravimetric survey data that offer insights into the nature and underlying architecture of the Eeyou Istchee Baie-James region. Various edge detection treatments of gravimetric surveys help to delineate major structural boundaries that extend to depth, and to identify potential deep crustal structures with no direct surface expression. Pseudogravimetric treatments of long- and short-wavelength components of detailed magnetic survey data allow us to visualize how the organization of the deeper crust relates to structural expressions in shallow and surface geology. We will present igneous and detrital geochronology results along with preliminary structural analyses that depict how the progressive development of major regional structures affected the boundary between the Opinaca and La Grande subprovinces. Their influence on the opening and subsequent tectono-metamorphism of the Opinaca basin will be discussed.

Persistence of Archean SCLM through time and its effect on collisional tectonics

David Corrigan

Geological Survey of Canada, Ottawa, Ontario, Canada

Most of Laurentia was assembled as a result of Proterozoic accretionary and collisional tectonics around Archean nuclei, which began with the Slave-Rae plate interaction at about 2.02 Ga and ended with the final assembly of Rodinia about 1.0 Ga ago. A simplified reconstruction of the accretion and collision history suggests that tectonic assembly occurred in three phases characterized by: *i*) amalgamation of a “Slave-Rae-Hearne-Wyoming-Sask-Meta Incognita-North Atlantic” continental mass during the interval 2.2-1.83 Ga, *ii*) collision the Superior craton with the above collage at about 1.83-1.78 Ga, and *iii*) migration of convergence to the southeastern margin of Laurentia in a Cordilleran-type framework during the interval 1.78-1.20 Ga, followed by Grenvillian (1.20 – 1.00 Ga) reactivation of part of that margin. Tectonic assembly during this protracted period involved accretion of both evolved and juvenile crust and mantle, as well as magmatic addition. 3D imaging and characterization of the bounding Proterozoic orogenic belts (mobile belts) suggests that although a substantial amount of juvenile material was either tectonically or magmatically added during the Paleo- and Mesoproterozoic, a greater proportion than previously recognized is actually represented by recycled Archean crust. Orogen-scale cross sections along the volumetrically dominant Trans-Hudson Orogen, constrained by deep seismic, magnetotelluric, geochronologic and tracer isotope data, suggest that in general, the middle and lower crust is dominated by Archean age rocks whereas juvenile Proterozoic crust is more commonly (with exceptions) preserved by thrusting in upper crustal levels. This has important implications for quantitative models of continental growth through time and suggests that production of perhaps thicker and more buoyant lithospheric mantle during the Archean may have favored preservation of Archean versus younger crust. This is especially the case for Proterozoic and younger accretionary orogens that were succeeded by continent-continent collision.

Late Neogene tectonically driven crustal exhumation of the eastern Himalaya (Sikkim and Bhutan) derived from inversion of low-temperature multithermochronologic data

Isabelle Coutand^{1*}, David M. Whipp Jr.², Djordje Grujic¹ and Kyle Landry¹

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Both climatic and tectonic processes affect bedrock erosion and exhumation in convergent orogens, but determining their respective influence remains a challenge. A requisite first step is to quantify long-term ($\sim 10^6$ yr) erosion rates. In the Himalaya, past studies suggest long-term erosion rates varied in space and time along the range front, resulting in numerous tectonic models. A large set of new cooling ages including apatite and zircon fission-track and (U-Th)/He data have been collected along three > 150-km-long North-South oriented transects across the orogen in the Sikkim and Bhutan Himalaya. Interestingly, the pronounced patterns of observed cooling ages do not correlate with topography, rainfall distribution and the locus of deeply fluvially incised “tectonic” windows, indicating that tectonic processes are mainly responsible for their spatial distribution. Inversion of this thermochronometric data set was performed using a modified version of the 3-D thermo-kinematic model PECUBE, with parameter ranges defined by available geochronologic, metamorphic, structural and geophysical data to evaluate the impact of the basal décollement geometry and kinematics, duplex development, and relief growth on the evolution of the thermal structure of the eastern Himalaya during the last 12 Ma. Our main results 1) indicate that models involving significant relief growth do not show a substantial influence of the topographic evolution on low-temperature cooling age distribution in this region, and 2) attest that the lateral variation of the geometry and kinematics of the Himalayan basal décollement locally associated with duplex formation exert a leading influence on lateral variations of middle to upper crustal long-term exhumation rates documented along the strike of the Himalaya.

Evolution of Fault Slip Surfaces with Increasing Displacement

Kelian Dascher-Cousineau* and James Kirkpatrick

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Fault slip surface roughness determines fault strength, friction and dynamic fault processes. Wear models and field observations suggest that roughness decreases with cumulative displacement. However, measurements have yet to isolate the effect of displacement from other possible controls, such as lithology or tectonic setting. We present an unprecedentedly large fault surface dataset collected in and around the San-Rafael Desert, S.E. Utah, United States. In the study area, faults accommodated regional extension at shallow 1 to 3 *km* depth and are hosted in the massive, well sorted, high porosity Navajo and Entrada sandstones. Existing detailed stratigraphic throw profile provide a maximum constraint for displacement. Where cross-sectional exposure is good, we measure exact displacement imparted on slip surfaces using offset in marker horizons. Thereby, we isolate for the effect of displacement during the embryonic stages of faulting (0 to 60 m in displacement). Our field observations indicate a clear compositional and morphological progression from isolated joints or deformation bands towards smooth, continuous and *mirror-like* fault slip surfaces with increasing displacement. To quantify these observations, slip surfaces were scanned with a white light interferometer, a laser scanner and a ground based Lidar. Together these instruments resolve more than eight decades of spatial bandwidth (from less than μm 's to *m*'s in scale). Preliminary results indicate that roughness decreases with displacement according to a power law. Roughness measurement associated with only maximum constraints on displacements corroborate this result—for a given displacement, minimum roughness is bounded by the later smoothing trend. In addition, we find that the maximum roughness is fixed—bounded a by a primordial roughness corresponding to that of joints surfaces and deformation band edges. Our results build towards a coherent model of fault wear robust to ambiguities associated to displacement estimates, spatial scaling and geological context.

A new model for the crustal structure of the SW Grenville Province, Ontario, Canada

Alan Dickin*, Jacob Strong, Gabriel Arcuri, Annika van Kessel and Lucia Krivankova-Smal

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The Grenville Province forms the exhumed remnants of a 1.1 Ga collisional orogeny that telescoped an older continental margin. Terranes with distinct crustal formation ages can be mapped using Nd isotopes, revealing a ramp-flat thrust structure. The ramp is identified by the presence of retrogressed eclogites, and its trajectory is refined using Nd model ages. The main allochthon is locally overlain by the Parry Sound klippe, but is also underlain by a tectonic duplex. NW-directed nappes represent remnants of a corrugated thrust sheet, but a ring-shaped remnant was also preserved where the thrust sheet was down-buckled under Parry Sound domain.

Structural evolution in the South Range of the Sudbury Structure

Carol-Anne G n reux* and Bruno Lafrance

Mineral Exploration Research Centre, Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario

The Sudbury Igneous Complex (SIC) is the remnant of a deformed impact crater, which formed at 1850 Ma. The location and shape of the SIC are closely related to three major tectonic features: the boundary between the Superior and Southern provinces, the intersection of two major fault systems, and the Grenville Front tectonic zone. Some of these features formed prior to the impact whereas others postdate it, but the amount of ductile deformation that can be attributed to post-impact versus pre-impact events is still a matter of debate. For example, a roughly 400 m wide mylonite zone overprints the contact between the granitic rocks of the Superior Province and metasedimentary rocks of the Huronian Supergroup. This mylonite zone displays horizontal shear sense indicators that correspond to dextral shearing. A strong, steeply dipping stretching lineation is also recorded within the mylonite and across the township within all rock types including Sudbury Breccia. One possible interpretation is that the mylonite formed as a result of a single, progressive transpression event, as proposed for the South Range Shear Zone, which has a similar orientation and also displays vertical stretching combined with dextral shearing. However, the mylonite zone also aligns with the Creighton fault to the east, which is thought to have originated as an extensional fault during sedimentation and to have been reactivated during subsequent orogenic events. This suggests that the dextral displacement and the stretching lineation could alternatively have formed during two separate reactivation events, rather than during a single, progressive dextral transpression event.

The science behind Metal Earth

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Metal Earth is a multidisciplinary, \$104 million project led by the Mineral Exploration Research Centre of Laurentian University. The main goal of the project is to characterize the processes that resulted in preferential metal-endowment of the crust. The project comprises three main activities: (1) Geophysical and geological transects, (2) Craton-scale compilation studies, and (3) Thematic research. The transect activities will involve reflection seismic, magnetotelluric, and gravity surveys along transects across major deformation corridors in the Abitibi and Wabigoon subprovinces, concurrent with structural and stratigraphic mapping integrated with radiogenic and stable isotope tracer studies, to investigate the pathways for the upward migration of magmas and hydrothermal fluids from the mantle to the crust. Craton-scale geochemical, isotopic and geophysical compilations, supplemented by new U-Pb radiometric ages and isotopic data, will be done to understand the 4D architecture of the Superior craton. The data will be used to produce time-slice maps that track the assembly and evolution of the craton and will identify regional, deep mantle-crustal paths for mineralizing fluids, magma, and heat. Thematic studies will seek to answer fundamental questions about the features and processes that result in metal endowment by understanding: (1) the subcontinental lithospheric mantle and crustal-scale fluid pathways, (2) fluid and metal sources, and (3) Archean tectonics and metallogeny.

These activities will identify key geological, geochemical and geophysical differences between metal endowed and less endowed areas. These differences will establish a “fingerprint” for ore systems, which will define areas of endowment based on newly recognized patterns of measurable data, and will determine the processes and controls on metal endowment. Innovative technologies, modeling algorithms, software tools and techniques will be developed to aid exploration by predicting the metal endowment of greenstone belts and cratons.

Inverted temperature fields: peak metamorphic and deformational temperatures across the Lesser Himalayan Sequence

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To explain the formation of an inverted metamorphic sequence we performed a study, which combined geothermometry with the thermochronology. The data were evaluated through thermokinematic forward and inverse modelling to constrain the ranges of important geological parameters such as fault slip rates, the location and rates of localized crustal accretion, and the thermal properties of the crust. The case study was performed along a transect across the Lesser Himalayan Sequence (LHS) of the eastern Bhutan. The geothermometry included the Raman spectroscopy of carbonaceous material (RSCM) to determine the peak metamorphic temperatures and Ti-in-quartz thermobarometry to determine the deformation temperatures. The thermal kinematic modelling was performed with PECUBE software and as thermochronologic constraints we used apatite and zircon U-Th/He and fission-track data and ⁴⁰Ar/³⁹Ar dating of muscovite. The spatial pattern of peak temperatures across the LHS, acquired by RSCM indicates that there are two temperature field sequences separated by a major thrust. Internal temperature sequence shows an inverted temperature field gradient of 12 °C/km; in the external one the peak temperatures are same with the structural sequence. Thermo-kinematic modelling shows that the thermochronologic and thermobarometric data can be well fit by a two-stage evolutionary scenario: an Early-Middle Miocene phase of overthrusting of a hot hanging wall over a downgoing footwall and inversion of the synkinematic isotherms, followed by the formation of the external duplex developed by basal accretion. To reconcile our observations and the experimental data we suggest that the pervasive ductile deformation within the upper LHS and along the Main Central thrust zone at its top stopped at ~11 Ma when the deformation shifted and focused until after ~6 Ma within the external duplex.

Crustal shortening across the Grenville collisional orogen from paleomagnetic evidence

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The Grenville orogen is thought to be mainly the result of collision between Laurentia and another continent, possibly Amazonia, from about 1.09 to ~1.0 Ga

The orogen is characterized by a parautochthon that runs the length of the Grenville Province and which is separated from allochthonous terranes to the SE by the Allochthon Boundary Thrust (ABT). SE of the ABT the terrane has been metamorphosed during the Ottawa phase of the collision at about 1.09 - 1.02 Ga and between the Grenville Front and the ABT the rocks appear to have been deformed and metamorphosed at about 1.0 Ga during a late phase of the collisional orogen known as the Rigolet, which appears to have affected rocks both NW and SE of the ABT.

Paleomagnetic results from metamorphosed Sudbury dykes and from a meta-gabbro anorthosite about 2.47 Ga old, define a direction of magnetization (shallow down to the ESE) that characterizes the parautochthon, and which differs profoundly in direction from the neighbouring allochthonous terrane which carries a steep up magnetization to the WNW. These magnetizations are thought to represent the result of metamorphism and cooling following, respectively, late and early stages of the Ottawa orogen.

A model is presented, suggesting that the uplifted allochthonous terrane was carried NW on the ABT and a succession of progressively deeper thrust faults for several thousand kilometers¹. Since the allochthonous terrane is considered to be part of Laurentia, a possible implication is that Laurentia was shortened by several thousand kilometers¹ in a NW direction, as a result of the Ottawa orogen. If true, the shape of Laurentia prior to the orogen may have been sufficiently different from what it is today, to impact pre-1.1 Ga continental configurations.

¹ Halls, H.C. 2015, *Geology*, v. 43, p.1051-1054

Deformation History of the Black Bay Fault

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The Black Bay Fault (BBF) is a major northeast-southwest trending crustal feature transecting the South Rae province of the Canadian Shield. Extending from northern Saskatchewan (SK), the BBF trends 100's of km northward into the Northwest Territories (NWT), though the full extent of the fault remains unknown. Little is known about the fault, with only a few small scale studies completed in the vicinity of Uranium City, SK. Disagreement over the fault's tectonic driver remains. In the NWT, the fault has primarily been traced from aeromagnetic lineaments, and becomes more complex, with a large change in orientation of fault trace with an undulating NW trend.

As a part of the GSC's GEM2 South Rae project, in collaboration with the NWT Geological Survey, the BBF's continuation into the NWT was examined to better understand the deformation history over the course of two field season. The 2015 field season focused on the continuation of the fault into NTS 75B where the lineaments are well defined, whereas the 2016 field season focused on NTS 75G and H where the trace of the fault becomes more complex. Additionally, outcrops described in previous studies around Uranium City were revisited to examine the along strike variation of deformation.

Overall, the BBF is observed to be a steep west-dipping structure, separating domains with different tectonometamorphic histories, the Ena and McCann from the Firedrake. The fault is defined by a strong NE/SW fabric overprinting regional E-W fabrics proximal to the fault. Deformation primarily ranges from ductile to brittle-ductile, with a dextral shear sense with pervasive moderately-plunging SW lineation commonly observed. A rare ductile sinistral component is observed in regions with a large degree of strain heterogeneity, likely indicating early sinistral motion was subsequently overprinted by younger dextral reactivation. Shallow NE-plunging lineations were commonly observed in outcrops with sinistral kinematic indicators, along with rare tonalitic L-tectonites.

Due to exposure and access, minimal examination of the change in fault orientation has been completed; however, the NW trending section is associated with shallowly-plunging NW lineations and an uncommonly observed sinistral shear sense. Deformation along the offset boundary was laterally constrained compared to the NE/SW fabrics seen along the main aspects of the BBF.

During deformation of the BBF differential uplift appears to have occurred, with a shift from a brittle-ductile regime characterized by mylonitic rocks around Uranium City towards a ductile regime dominated by augen and straight gneisses in the north of 75B. Additionally, late stage quartz-filled tensions gashes and fluid alteration observed in the south are absent in the north. A reemergence of the shallower crustal deformations resembling the deformation around Uranium City was observed where the fault returns to a NE/SW trend. A late normal south-side down component appears to have preserved the lower level of deformation in the north.

Structural History of the Goudreau Lake Deformation Zone and Island Gold Deposit in the Superior Province, Ontario

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The Goudreau Lake Deformation Zone (GLDZ) is located within the Michipicoten Greenstone Belt of the Superior Province in northern Ontario. It lies to the southeast of the Hemlo gold camp and has been proposed as the western extension of the Abitibi Greenstone belt. The GLDZ cuts through two volcanic assemblages and hosts multiple gold deposits, notably the Island Gold deposit. The structural controls on mineralization and the history of the deformation zone are still poorly understood.

At least two generations of deformation in the GLDZ have been recognized. Subhorizontal folds plunging shallowly to both the East and West have been documented. The west-plunging folds are locally associated with dextral shear sense indicators. Stretching lineations defined by elongated feldspar within intermediate quartz-feldspar-porphyrific tuff plunge steeply to the East and were observed to both the North and South of the ore zone. Petrographic analysis is being used to determine the shear sense of deformation during the development of this fabric.

The Island gold deposit is located within intermediate to felsic volcanic rocks and consists of a southern and northern parcel. The southern parcel is the main economic focus and includes the Island Gold, Island Deep, Lochalsh, and Extension 1 and 2 zones which lie along the same, roughly 60°, strike. Mineralization occurs in anastomosing ore zones of smoky grey quartz veins within a silicate and sericite alteration package that dip steeply to the South. Within the southern parcel, a preliminary sequence of deformation has been recognized within the ore zone which involves the extension of major ore veins, resulting in pinch-and-swell and boudinage structures, followed by thrust-faulting accompanied by shallow, en echelon veins which cross-cut the ore zones. The northern parcel contains the Goudreau Zone, which is hosted by both the intermediate to felsic volcanic rocks and dioritic intrusions. It consists of tightly folded horizontal ore veins plunging shallowly to the East with a variably moderate to nonexistent surrounding alteration package.

The trondhjemitic Webb Lake Stock, which is mineralized and roughly follows the GLDZ to the North of the Island Gold deposit, and a late, cross-cutting intrusion have been sampled for U-Pb dating to better constrain the absolute upper- and lower limits on timing of mineralization.

Fault surface geometry as a record of deformation processes

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Fault slip surfaces, where displacement is localized during earthquakes, exert a primary control on fault strength, stability, off-fault stresses and rupture characteristics. Slip surfaces are non-planar, or rough, and although distinct features can be identified on the surfaces at outcrop scale they have characteristic geometry, regardless of the tectonic setting or rock type. The self-affine scaling of the surface geometry is controlled by fracturing of the rock during slip, and is direct evidence for scale-dependent strength of rocks. However, at the extremes of observational length scales, the scaling behavior changes. At length scales of tens to hundreds of micrometers or less, the roughness is isotropic, marking a change in wear mechanism. Analysis of the reflector corresponding to the Costa Rica subduction zone megathrust in 3-D seismic data also suggests a transition to isotropy at several km. This dimension matches the spacing of horsts and grabens on the oceanic plate, and indicates processes external to the fault impact the mechanical behavior. These insights highlight the importance of fault geometry to fault mechanics and show how faults can be used to constrain the physical controls on slip.

The Emperor's New Clothes – the Discrepancy between Observation and Interpretation in the Canadian Rocky Mountains

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Quantitative cross section construction techniques have been applied to shallow fold-thrust belts for more than 50 years. They are based on a very simplified view of deformation, a limited variety of structures, and many assumptions that may not all apply. Based on these principles, three fold-thrust scenarios (“ramp-flat folds”), described as end members, are used in cross section construction and seismic subsurface interpretations: detachment fold, fault-propagation fold, and fault-bend fold (Fig. 1) They are considered to be the product of thrusting and appear in every current structural geology textbook.

Fault-propagation fold and fault-bend fold have no syncline in the immediate footwall and particularly the former is frequently applied to seismic interpretations of the Foothills (and other areas). In contrast, outcropping footwall synclines appear to be the rule in the Front Ranges; these cannot be explained by any currently accepted fold-thrust model. Such synclines typically disappear with depth in a cross section with no further data available.

The current fold-thrust models are obviously not exhaustive in describing the observed structures and they are also kinematically unrealistic. We therefore give two unifying models that explain all structures observed and show that folds in shallow fold-thrust belts like the Rockies are not always the product of thrusting. We further extend the standard models and view them in a progressive deformation with stages from detachment fold through fault-propagation fold to fault-bend fold. (Fig. 1)

It is concluded that balancing cross sections is based on the “reverse argument” that only structures are admitted that legitimize the technique even though such structures may be rare in nature. The technique should therefore only be used as a first approximation.

(Kraus and Williams, cont'd)

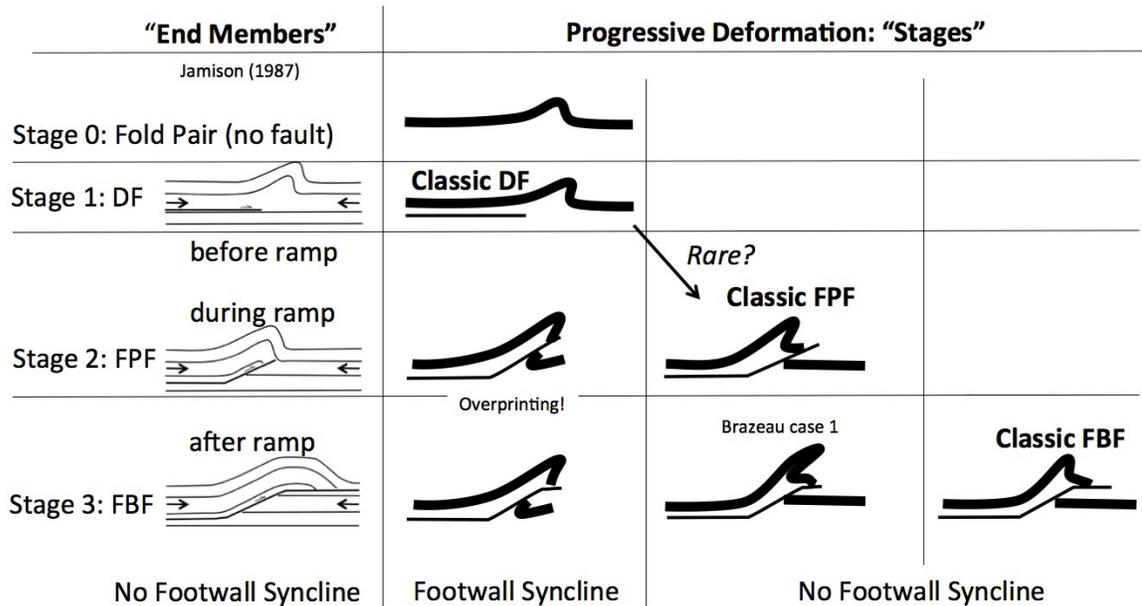


Figure 1: Extension of the currently accepted fold-thrust scenarios from the unrealistic "end members" of Jamison (1987) to more meaningful "stages" in a progressive deformation: anticline/syncline pair → detachment fold (DF) → fold-propagation fold (FPF) → fault-bend fold (FBF). Folds can initiate at any of these stages.

REFERENCE

Jamison, W.R., 1987, Geometric analysis of fold development in overthrust terranes: Journal of Structural Geology, v. 9, p. 207–220.

Why are only a few Transverse Faults mapped in the Canadian Rockies?

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In recent years the use of geothermal energy for both electricity and heating has been growing rapidly through the implementation of low temperature geothermal production systems in Europe and the United States. Geothermal energy is unobtrusive and emission free, available 24/7 and operational costs are low and stable. The use of the Earth's heat is therefore increasingly considered in future renewable energy strategies in these countries and it seems logical that Canada will follow their lead.

Engineered Geothermal Systems (EGS) for deep wells is a promising development in converting heat into electricity. The production of hot water is similar to the production of petroleum and therefore, horizontal drilling and fracking will play an important role. These applications ask for extensive knowledge in temperature and pressure modeling, geomechanics and structural geology. Folds, faults and fractures will define exploration plays and will be more important than ever in a world which is subject to changing supply of energy in our society.

This paper will discuss the various faults and fractures of the Alberta Rockies. Transverse faults of the Crowsnest Pass, Banff, Nordegg, Jasper and Grande Cache areas will be discussed. It will be shown that there are many more transverse faults present than represented on most published geological maps. Off sets along those faults range from kilometers to a few meters. Relationships with fracture fabrics will also be discussed.

Did trishear deformation overturn the South Range of the Sudbury Igneous Complex?

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The Sudbury Igneous Complex (SIC), Canada, is an impact-induced layered sheet of crystalline rocks deformed into an asymmetrical fold basin, the Sudbury Basin. The geometry and deformation of the southern SIC, the South Range, have long been subject to debate. Trishear deformation may serve as a plausible mechanism for the present geometry of the South Range SIC as the Sudbury Basin shows the following structural characteristics: (1) presence of several distinct thrust faults imaged in seismic lines accomplishing localized deformation, whereas deformation at surface is mostly distributed, (2) large angular discordance between upper and lower SIC contacts, (3) gradient in foliation dips and strain magnitude, (4) along-strike thickness variations of the SIC, (5) variable relative thicknesses among individual SIC layers, (6) uplifted and south-facing Huronian rocks south of the SIC, and (7) correspondence of the South Range Shear Zone to high strain in the central portion of the trishear zone. Collectively, these characteristics are not fully explained by previously invoked deformation models, such as folding of the SIC followed by thrusting on SE-dipping faults, pure folding of the SIC, or pure translation and shearing of the South Range SIC on the South Range Shear Zone.

A main characteristic of trishear deformation is the transfer of localized displacement on a basal thrust fault to distributed deformation and associated displacements within a triangular zone, the trishear zone. At the top of the trishear zone, local displacement magnitude equals the hanging wall slip, whereas there is no slip at the base of the trishear zone. This gradient in shear direction and slip magnitude results in a change in layer thickness and layer dip during progressive trishear deformation and depends on position within the trishear zone. Field structural data, namely foliation surfaces, igneous layering and lithological contacts, in combination with forward kinematic modelling constrain deformation parameters of trishear deformation such as displacement, propagation-to-slip ratio, trishear angle. Backward kinematic modelling of trishear deformation is used to restore the shape of the igneous sheet and provides information on the initial geometry of, and the strain distribution within, the Sudbury Igneous Complex.

Trishear deformation at Sudbury indicates that local steep dips of the basal SIC are spatially confined to the trishear zone. The hanging wall, composed of Huronian rocks and the SIC Norite, are mainly translated and show little internal deformation by shearing or rotation. The highest shear strain magnitudes are present in rocks of the Granophyre and adjacent Onaping Formation, subjected to maximal tectonic thinning in the South Range, indicating that the South Range Shear Zone may be the surface manifestation of a trishear deformation zone.

Mapping Project in Liuyuan, Beishan, North China

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The Beishan Orogenic Collage (BOC) is located in the southernmost part of the Central Asian Orogenic Belt (CAOB), at the junction of the Tarim block to the west, the North China Craton to the east and the Siberian Craton to the north. In order to understand the accretionary process of the southern BOC, field mapping was carried out in Liuyuan, Beishan, North China. The mapping area is mainly composed of ophiolitic mélange including trondhjemite, gabbro, pillow basalt, diabase dykes, pyroclastics, tuffaceous sandstone and turbidites. Thrust and imbricated deformation is commonly developed in this area. Pillow basalt with chert reflects marine environment, such as mid-ocean ridge. Moreover, the Permian turbidites including conglomerate and sandstone come from an arc-related basin or forearc basin. Two deformation phases are identified: D1 is characterized by E-W striking isoclinal folds F1 and E-W transposition foliation. D2 is characterized by tight to open folds F2, which strike in NE. In terms of the contact relationship, conformity, non-conformity and fault contact are recognized in mapping. Granitic intrusions and volcanics crop out along the boundary of shear zone. Permian sediments juxtapose along shear zones against quartz schist and basalt. Different units are separated by faults. The presence of bimodal volcanic rocks refers to an extension-related volcanism. Combining the field observation and literature sources, the interpretation of the geology in mapping area is very significant to build the last stage of the accretion in BOC.

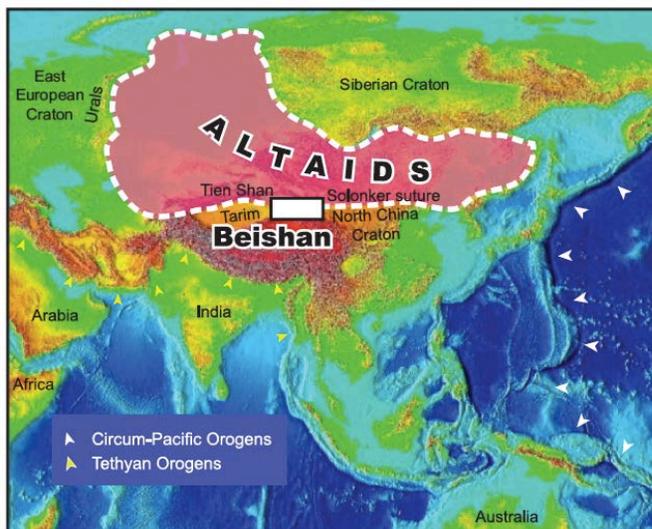


Figure. Topographic map showing the location of Beishan. Altaiids is also known as Central Asian Orogenic Belt (CAOB) (Xiao et al., 2010).

Mechanics of Oblique Convergence of Plates and Continental Tectonics

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Oblique convergence between lithospheric plates or blocks leads to transpression. To date, a large number of works have focused on the finite strain patterns, the rotation and strain path of fabric elements in transpressional high-strain zones. However, most of the previous models are kinematic and do not address directly the mechanics of oblique plates margin deformation. Although some continuum mechanics models have been developed, they do not account for the mechanical interaction between the high-strain zone and country rocks. Natural convergent boundaries commonly consist of a broad deformation belt and one or more tabular high-strain zones. Deformation arising from the oblique convergence between the North American and Pacific Plates is distributed over 200 kilometers, including the San Andreas Fault and a broad country rock deformation zone. The convergent boundary between Australian and Pacific Plates consists of the Alpine Fault and a 100 km wide diffused deformation belt to the east of the fault.

We develop a new approach to transpression modeling considering the entire convergent system. The strain and stress partitioning, as well as the mechanical interaction between high-strain zone and surrounding country rocks, are all integrated into a fully mechanical model. The model is based on an extended Eshelby theory on inclusions. The ductile lithosphere subjected to plate motion is considered as an infinite power-law viscous material. The tabular high strain-zone is regarded as a tabular inclusion embedded in the lithospheric matrix. The extended Eshelby theory already developed provides an effective approach to relate the interior and exterior flow fields of the inhomogeneity and to the far-field imposed flow. In this way, the velocity field and stress field of the entire convergent boundary can be obtained from the plate motion. Application to two obliquely convergent plate boundaries (South Island, New Zealand and Central California) shows a consistency among velocity fields and stress fields, suggesting that this extended Eshelby theory based model is valid for the mechanics of oblique convergence and continental tectonics.

Preliminary observations on the style and timing of deformation along the Bathurst Fault, western Nunavut

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The Bathurst Fault is a NNW-trending crustal-scale structure that transects through the eastern Slave craton and left-laterally displaces the Thelon tectonic zone by up to 140 km. Though there is no geochronological constraint on the timing of fault motion, early studies suggest that the fault initiated in response to Slave-Rae convergence and then reactivated in the Paleo- to Meso-proterozoic. The Bathurst Fault is a prospective structure associated with known uranium occurrences in the Proterozoic Kilohigok and Thelon basins. The close relationship between fault zones, which often behave as pathways and depositional sites for U-bearing fluids, and Proterozoic basins are well recognized targets of exploration in Canada.

This M.Sc. study aims to constrain the style and timing of deformation along the Bathurst Fault zone to construct a temperature-deformation history of fault reactivation. The temporal relationship between the Bathurst Fault and the Slave-Rae collision, Thelon orogen, and nearby uranium mineralization in Proterozoic basins will be established with age-dating (⁴⁰Ar/³⁹Ar thermochronology and U-Th/Pb geochronology) paired with microstructural observations and quartz petrofabrics.

In July 2016, field observations and samples from two transects across the fault at detailed sites were collected. The Bathurst Fault is manifested as a zone of high strain rocks in the central transect and as discrete brittle lineaments in the northern transect. Field observations in the central transect reveal a suite of high metamorphic-grade and variably strained granitoid rocks in the fault zone and east within the Thelon tectonic zone. These are juxtaposed against less resistant metasedimentary and metavolcanic rocks of the Slave craton west of the fault. Deformation fabrics (e.g. mylonite and L-tectonite) are parallel to the Bathurst trend and strain is localized within mica- and amphibole-rich horizons of quartz syenite to monzonite rocks. Mineral lineations, defined by oriented hornblende and flattened alkali-feldspar grains, in the fault zone are steeply plunging and where shear sense indicators are present, show top-to-the NW shear. Preliminary petrographic observations indicate pervasive intracrystalline deformation textures in abundant feldspar and quartz grains. In feldspars, intracrystalline microstructures suggest a range of deformation mechanisms active from low temperature (e.g. microfaulting, bent twins) to medium-high temperature (e.g. subgrain development). In the northern transect, quartz arenite samples from the base of the Kilohigok Basin will be utilized to test for the presence of a strain gradient adjacent to this brittle section of the Bathurst Fault. Overall field relationships suggest that early ductile mylonitic fabrics, likely Thelon-related, are overprinted by Bathurst-related ductile shearing evolving to late brittle fracturing.

Upcoming work will include U-Th/Pb dating of monazite to constrain the early ductile phase of fault motion. ⁴⁰Ar/³⁹Ar dating of hornblende and muscovite will provide a cooling history that will be correlated with deformation temperature as revealed by quartz petrofabrics and feldspar microtextures.

Melt Present Deformation in a Hot Lower Crustal Shear Zone: The Lower Fish River Onseepkans Shear Zone, Namibia

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How do lithologic contrasts in lower crustal shear zones affect shear localization and overall strength? We examine a lower crustal shear zone from Namibia to investigate this question.

Key Points:

1) The Lower Fish River Onseepkans Shear Zone (LFROSZ) has been previously mapped as a low angle thrust, yet detailed mapping at key localities shows that the area has been overprinted with extensional structures (steeply dipping foliations, down-dip lineations, normal shear sense indicators).

2) Field observations of partial melting, microstructures, and pseudosections show that deformation occurred during prograde metamorphism, at ~700 °C and 600 MPa in the presence of partial melt.

3) The relative strength of units has been determined through detailed mapping of the distribution and contact geometries of lithologically and structurally distinct units on meters-km scale in several outcrops of the LFROSZ.

4) Partial melting of metapelites and metapsammities changes the distribution of strain and the relative strength of rocks.

Short Term: The melt has no shear strength and dramatically weakens samples at low melt volumes (7%).

Long Term: The melt forms a relatively strong unit compared to the restite, a biotite and sillimanite dominated schist.

The Paleogene transition from dextral transpression to dextral transtension in the southern Canadian Cordillera

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In the southern Canadian Cordillera both the late Cretaceous-Paleocene (~75 – 55 Ma) contractional deformation and the early and middle Eocene (~55 – 40 Ma) extensional deformation were linked northwestward to dextral continental transform faulting in the northern Cordillera.

The transition from dextral transpression to dextral transtension evidently involved a comparatively minor change in relative motion between the Cordilleran accreted terranes and ancient 'North America' (aka "Laurentia", "Laurasia", etc.). However, this minor change in relative motion abruptly and profoundly transformed the tectonic evolution in the southern Canadian Cordillera.

The more or less SW to NE convergence component of transpression that had induced crustal shortening and thickening, and thereby, lateral gravitational spreading of the foreland thrust-and-fold belt, plus related subsidence and lateral spreading of the foreland-basin; was replaced by the more or less E – W divergence component of transtension that induced inhomogeneous crustal stretching and thinning, asthenospheric upwelling, and crustal-scale boudinage, above a much (~ 25 km) shallower and relatively flat Moho. The dextral en echelon Monashee, Valhalla, and Priest River metamorphic core complexes include 35 – 40 km thick boudins of Paleoproterozoic-Archean continental crystalline crust. The boudins have been exhumed along listric, east-dipping, extensional (abnormal? normal) faults that extend into (or under) the 35-40 km thick layer of Paleoproterozoic-Archean continental crystalline crust that underlies the Cordilleran foreland thrust-and-fold belt of the southern Canadian Rockies and part of the northern Purcell Mountains. The intervening area between the 'core complex' boudins and the 35 km and 40 km thick autochthonous 'North America' crystalline basement is a zone of extensional necking in which the thickness of the crystalline continental crust decreases from between 35 km and 40 km to as little as 15 km. During the westward extensional exhumation of the Monashee, Valhalla, and Priest River metamorphic core complexes/boudins, the Mesoproterozoic, Neoproterozoic, and Paleozoic supracrustal strata of the Kootenay arc and Purcell anticlinorium subsided into this zone crust necking.

One of the tectonic implications that emerge from this 'conceptual process model' is that the onset of crustal thinning at the beginning of the transition from transpression to transtension marks the termination of the tectonic convergence, and of the combination of crustal thickening, and lateral gravitational spreading that created the foreland thrust-and-fold belt. Metamorphic geobarometry and thermochronometry within the metamorphic core complexes shows that transtensional extensional exhumation was rapid ("near isothermal") and that it had begun at ~55 Ma; and accordingly, that thrust faulting and thrust-fault related folding in the southern Canadian Rockies terminated by ~55 Ma.

The Ottawa River Gneiss Complex as a giant metamorphic core complex: field evidence, regional significance and tectonic implications for the collapse of the Grenville Orogen

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It has become commonplace to cite the Grenville Province as an example of a large hot orogen (LHO) of Himalaya-Tibet style with an orogenic plateau in its hinterland underlain by double thickness crust. However, the implications this architecture imposes on the ensuing tectonic evolution are less widely recognised. Heating due to prolonged burial of deep crust to upper mantle depths leads to profound thermal and melt weakening, such that collapse of the thick crust on its weak base is inevitable. In this presentation we highlight features of the hinterland of the Grenville Province that point to widespread and profound gravitationally-driven orogenic collapse and suggest it provides an unparalleled archive for the demise of a LHO.

Duration of orogeny, width of orogen, temperature of peak metamorphism: On the basis of metamorphic ages from ~1090-980 Ma, the Grenvillian Orogeny lasted for over 100 Ma. In the orogenic hinterland, ~40-50 Ma of crustal thickening and prograde metamorphism during the early Ottawan orogenic phase were followed by an equivalent duration of post-peak exhumation and retrogression. In terms of size and metamorphic grade, reconstructions suggest the Grenville Orogen was at least 1000 km wide and that it includes extensive high-grade terranes underlain by Ottawan mid-P (~1000 MPa) granulite-facies rocks, all features consonant with a LHO.

Core complex architecture: Very large metamorphic core complexes, including the Ottawa River Gneiss Complex (ORGC) with a core diameter >200 km, have been recognised in the Grenville Province, and are juxtaposed against upper crustal remnants known as the Ottawan Orogenic Lid (OOL). The geologic record of high-grade Ottawan metamorphism and deformation in the core (ORGC), but lack of Ottawan metamorphism and ductile deformation in the adjacent OOL, attests to mechanical detachment of the hot core from the cool cover. Evidence from the ORGC, where the ~7 km-wide detachment zone consists of highly flattened amphibolite-facies straight gneiss with km-scale lenticular low-strain granulite-facies remnants preserved as foliation megaboudins, attests to formation of the detachment from rocks derived from the core after the metamorphic peak, and to strain heterogeneity on the km scale.

Transtensional cross-folds and FPFs: The detachment zone in a metamorphic core complex is the site of extensional shear. In the ORGC, it is also the site of trains of multi-order buckle cross-folds with axial traces at high angles to the orogenic front. The cross-folds range from upright to recumbent and are stretched parallel to their sub-horizontal hinge lines, features diagnostic of formation in an extension-dominated transtensional setting, implying strain in the detachment was triaxial, involving wrench as well as shortening and extensional components. Late m- to dm-scale extensional fault-propagation folds (FPFs), many occupied by pegmatite dykes, are common structures in the ORGC, individually documenting modest horizontal extension as the gneissic rocks in the core complex cooled through the brittle-ductile transition, with the pegmatite dykes recording the presence of pockets of water-rich magma at depth.

In summary, the widespread presence of Ottawan mid-P granulite-facies rocks in the ORGC adjacent to the OOL, together with the record ~60 Ma of post-peak retrogression, exhumation, transtension and crustal thinning during slow cooling, terminating with brittle-ductile structures and late pegmatite, provides an unrivalled archive of orogenic collapse we are just beginning to understand.

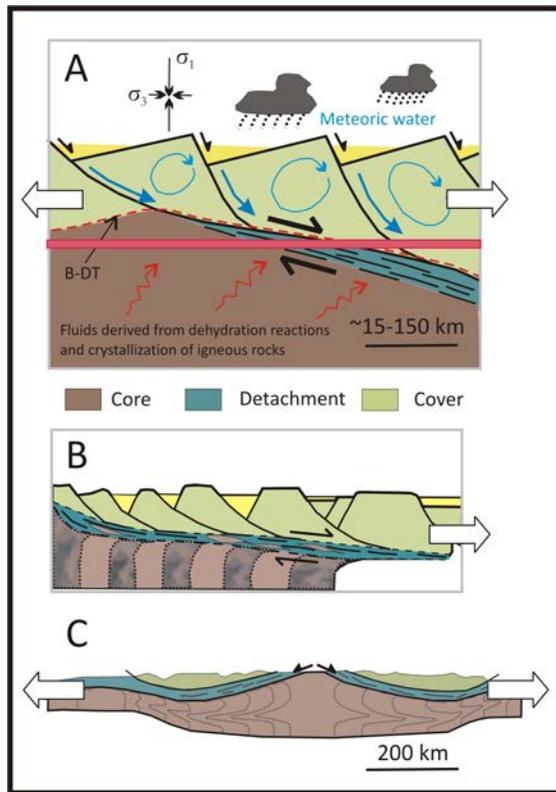


Figure 1. (A) Schematic figure of a continental metamorphic core complex. Horizontal red line represents the approximate level of exposure of the ORGC and OOL in the southwest Grenville Province. (B) Schematic figure with flow lines showing vertical flattening strain at the top of the core leading to formation of the detachment zone. Note preservation of granulite-facies megaboudins in the detachment zone. (C) Regional setting of crustal-scale core complex in a collapsed hot orogen, showing megaboudinage of the upper crust and flow of the ductile mid-crust into the boudin neck region forming extensional bending folds during crustal-scale extension.

From Rivers and Schwerdtner (2015)

Rivers, T. and Schwerdtner, W.M. 2015. Post-peak evolution of the Muskoka domain, western Grenville Province: ductile detachment zone in a crustal-scale metamorphic core complex. *Geoscience Canada*, **42**, 403-436. <<http://www.dx.doi.org/10.12789/geocanj.2015.42.080>>

Chondrule shapes and fabric in a CR2 chondrite

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The approximately spherical shapes of meteoritic chondrules is attributed to surface tension acting on ca. 1-mm melt droplets in the microgravity field of the solar nebula. However, chondrules shapes commonly depart significantly from spherical. Shape measurements of 109 chondrules in a CR2 chondrite (NWA801) imaged by X-Ray Computed Tomography show a clear impact of some axial compaction in the host chondrite (Fig. 1). But the eccentricities of many individual chondrules significantly exceeds that of the compaction strain and must have preceded their accretion onto the parent body (Fig. 2). We propose that these shapes result from fast rotation of the melt droplets prior to, and during their solidification, similar to what has been convincingly argued to explain the shapes of tektites.

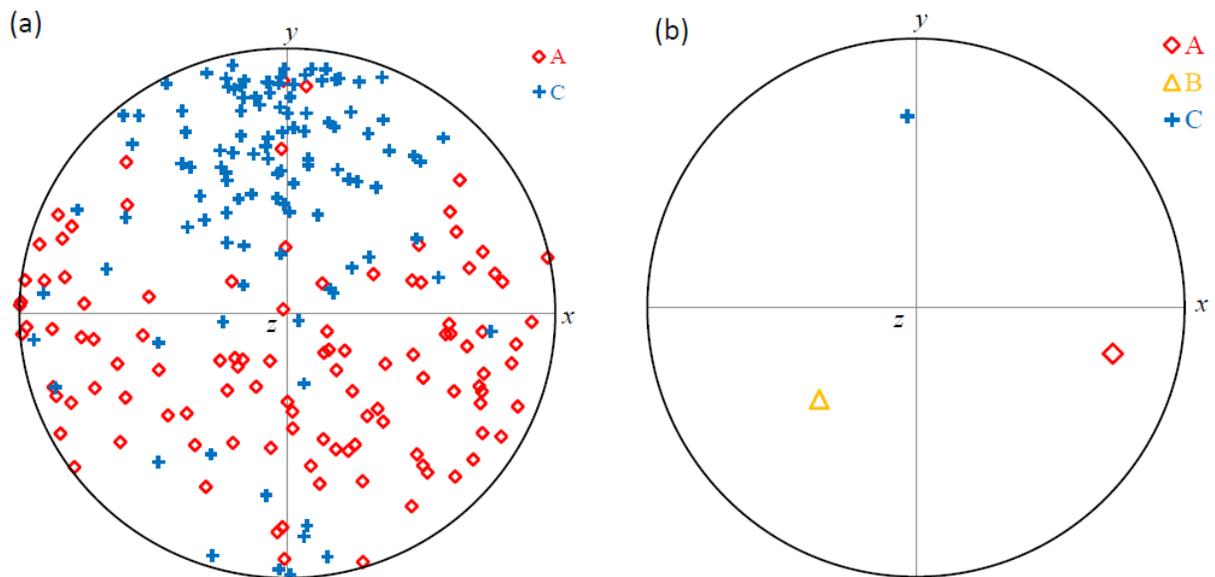


Figure 1: (a) Equal-area plot of long axes (square diamonds) and short axes (+) of 109 chondrules. (b) The 'average chondrule ellipsoid' is oblate with $A/B = 1.018 \approx 1$, $A/C = 1.14$. That ellipsoid can be interpreted as a modest compaction strain.

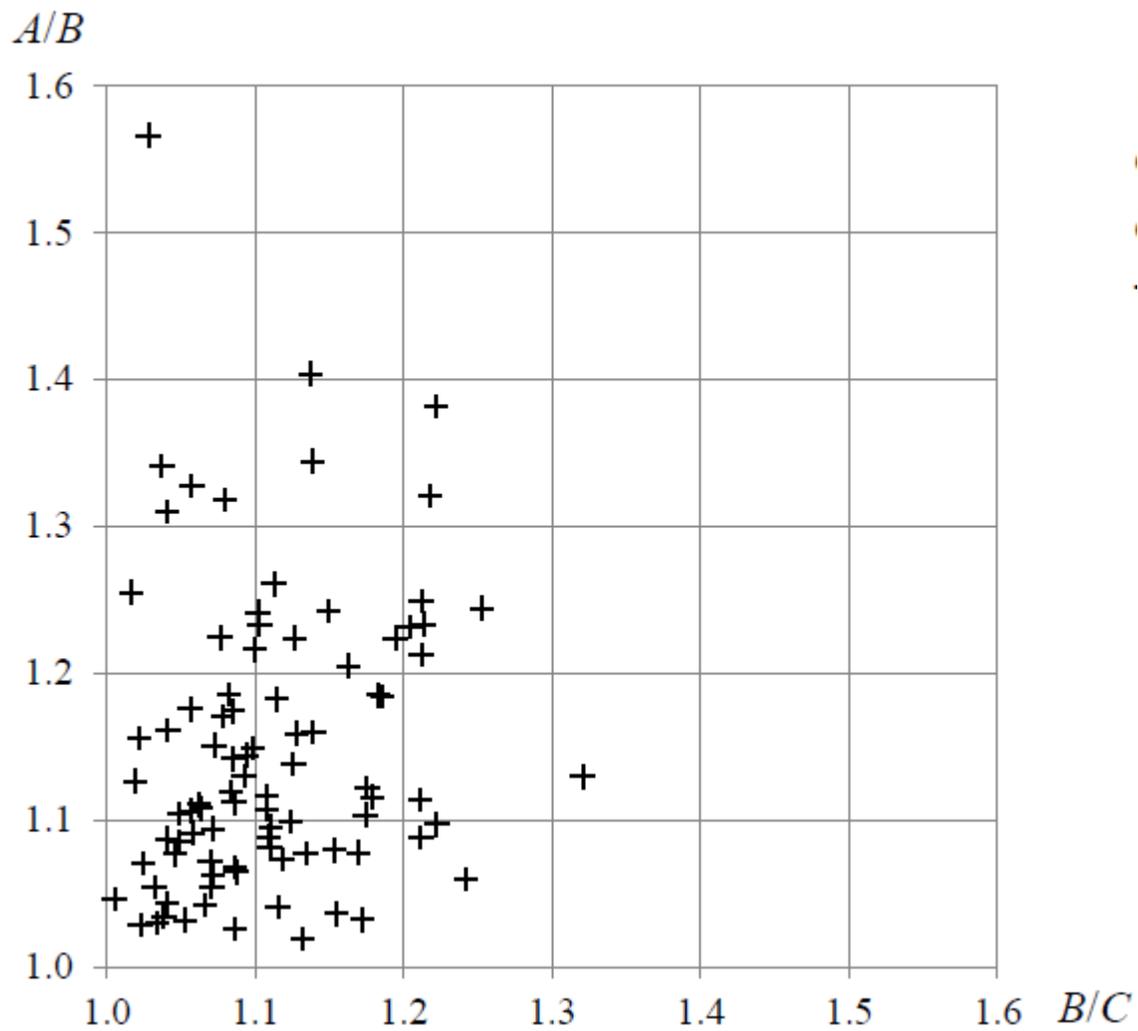


Figure: 2. Flinn plot of the 109 'decompacted' chondrule shapes. The shapes of most chondrules can clearly not be modelled by the compaction.

A Comparison Between Modelling of Coulomb Stress and Field Observations of Off-Fault Strain around Pseudotachylyte Fault Veins, Norumbega Fault System, southern Maine

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Static stress changes caused by fault motion may be of significant magnitude around fault bends, ends, and intersections, and have been shown to partially explain aftershock distributions (Poliakov et al., 2002). In the brittle-ductile transition zone, these stress concentrations may be relaxed after earthquakes by ductile flow. Small-scale deformation features adjacent to pseudotachylyte-filled fault veins may record deformation in response to static stress changes in the wallrock caused by slip on non-planar or intersecting fault surfaces.

Starting from an existing pseudotachylyte map of the Fort Foster Brittle Zone in Kittery, Maine (Swanson, 2013) we mapped the deformation structures in detail at several selected sites of the outcrop surface. High-resolution photographs and field measurements were taken where pseudotachylyte fault veins bend and there were associated near-fault small-scale deformation features. A ~5 m² area of outcrop was selected for Coulomb3 stress modelling. It was observed that the deformation between two pseudotachylyte veins was characterized by a simple pattern: when one fault bends away from the other, the deformation in between the two is characterized by mm- to cm-scale pseudotachylyte injection veins; where the faults are parallel to each other, the deformation style is characterized by ductile features such as kink and bend drag folds.

The pseudotachylyte photo-mosaic was then used as a basemap in Coulomb3 software in order to build an idealized fault model. The rake and slip of the earthquakes which formed the pseudotachylytes are not known, so we assumed that the shear zone is primarily dextral, and we use the average scaling of normal earthquakes to make estimates of the slip. The predicted stress change orientation and magnitude distribution were produced by Coulomb3. We compare the stress change distributions from the models to the distribution of small near-fault structures mapped in the field. The distribution of stresses is similar to the distribution of shortening and extensional strain measured in the wallrock, therefore we conclude that static stress changes were accommodated plastically in the compressional region where the two faults propagated parallel to each other and in a brittle manner in the extensional region behind the rupture tip in the post-seismic time interval. This suggests that damage occurs over the entire fault by more than just the propagating tips and also suggests that the type of deformation is heavily influenced by the geometry and heat diffusion of the pseudotachylytes.

Insights into earthquake rupture and recovery from paleoseismic faults

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Ancient faults preserve evidence of past earthquake rupture, aseismic creep, and interseismic healing, but our ability to read the record is incomplete. There are two key differences between earthquake slip and creep that have the potential to be preserved in rocks. First: the slip velocity is sufficiently high that the frictional heat production on the slip surface is faster than the conductive heat dissipation, resulting in a net temperature rise. If the slip is sufficiently localized and the normal stress is high enough, this temperature rise can dissociate hydrous minerals, cause rapid maturation of organic compounds, and melt fault rock, producing pseudotachylytes. These reactions are recorded in fault rock mineralogy and composition and can be used to estimate coseismic temperatures from <250°C up to > 1400°C. A second difference between seismic and aseismic slip on faults is that seismic slip is *dynamic*, that is, that the slipping area expands in size at rates comparable to the shear wave velocity in the rocks (~ 3 km/s), which results in extreme stress gradients in the wall rock at the rupture tip. The stressing rate exceeds the speed at which fractures can propagate through the wall rock, resulting in distinctive patterns of very closely spaced and branching fractures, and sometimes pulverization. In some faults, these fractures are the dominant form of off-fault damage and may cause permeability spikes through the fresh fracture networks. With these fossil earthquake signatures in hand, we can identify ancient seismic rupture planes and use these to map out the geometry of earthquake ruptures at the outcrop scale (10^{-3} - 10^3 meters), which is below the resolution and location uncertainty of earthquake seismology in most active faults. Using an example from the Norumbega Shear Zone in Maine, I will show that earthquakes can rupture multiple parallel and non-parallel surfaces simultaneously. This discovery is consistent with recent deconvolutions of multiple rupture planes from earthquakes with a large non-double couple component in their focal mechanisms, suggesting that this may be a common phenomenon. Outcrop studies may be able to elucidate the consequences for slip distribution and help explain spatial variations in fracture energy and stress drop that are barely resolvable in seismic data.

Accretionary wedge evolution seen as a competition between minimum work and critical taper

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The critical taper theory and the minimum work concept independently best explain the mechanics of an accretionary wedge. However, natural wedges cannot always be at critical taper because the formation of thrusts and work done by the wedge cannot always be minimum due to fluctuations based on the external work acting on the wedge. To test the applicability and interplay of both concepts we compare an analogue (sand) accretionary wedge that grows with varying styles of deformation i.e. frontal accretion and underthrusting to a self-similar growing analytical wedge which grows by adding material homogeneously to its surface and that has a constant and always critical taper over time while performing minimum work. We describe the change in geometry and the work done through accretion cycles of the “real” analogue wedge in relation to the ideal self-similar wedge (SSW). At the beginning of every accretionary cycle the analogue wedge transitions from a critical taper wedge (in particular from the peak friction envelope to the static friction envelope) to a minimum work wedge. Over time, the wedge progresses towards an ideal state that is a balance between the two models. Overall the analysis shows that deformation in accretionary wedges is a competition between minimizing work and reaching the critical taper. The critical taper theory defines the preferred geometry of the wedge and the minimum work concept determines the path of deformation the wedge adopts to keep work at a minimum.

Map patterns and shape-fabric signatures of km-scale cross-folds in Archean and Proterozoic gneisses, parautochthonous part of the Ottawa River Gneiss Complex, Grenville Province of Ontario

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The Ottawa River Gneiss Complex (ORGC) overlies the Grenville Front Tectonic Zone in the western Grenville Province of Ontario and western Quebec, and is subdivided into a lower parautochthonous part and an overlying allochthonous part separated by the Allochthon Boundary (AB). In the Ontario segment, the parautochthonous part is largely composed of metaplutonic and metasedimentary gneisses that have yielded Archean and Proterozoic model ages and are interpreted to represent redeformed in-situ parts of pre-Grenvillian Laurentia and its complex southeast margin. In contrast, the allochthonous part is composed of imbricated, mostly Mesoproterozoic orthogneisses transported from the orogenic hinterland and assembled into a 1090-1050 Ma (early Ottawan) thrust-sheet stack, which subsequently experienced ductile collapse and gravitational spreading during the late-Ottawan (~1050-1020 Ma). At an early stage of the collapse process, the assemblage of allochthonous and underlying parautochthonous gneisses was transformed into a system of north- to northwest- to west-trending, upright to inclined, markedly noncylindrical, multi-order buckle cross-folds, geometrically similar to those comprising J.G. Ramsay's types 1-2 fold interference patterns. In the Georgian Bay region of the ORGC, the axial traces of some very large (first-order) cross-folds pass from the allochthon into the underlying parautochthon, giving rise to the wavy trace of the intervening folded AB surface. In the North Bay region of the ORGC, however, the trace of the AB surface is straighter and it is decorated with abundant remnants of eclogite, coronitic metagabbro and meta-anorthosite, rendering its origin as a major ductile décollement zone more readily interpreted.

In much of the ORGC, moderately- to highly-strained, retrogressed and decompressed orthogneisses exhibit prominent L-S shape fabrics defined by deformed and partly or wholly recrystallized igneous megacrysts, strained amphibolite-facies mafic clots after granulite-facies precursors and distorted plagioclase-rich pseudomorphs after garnet porphyroblasts. Cross-folds in these orthogneisses deform the retrogressed/decompressed gneissic layering and contain S>>L shape fabrics in the limbs and L>>S shape fabrics in the hinge zones. Based on the results of kinematic and dynamic numerical modelling of single-layer and multi-layer buckle folds, we explain the L-S shape-fabric pattern of the cross-folds by late-orogenic regional buckling during retrogression and exhumation of the ORGC in a regime of inclined, heterogeneous, pure-shear-dominated, ductile transtension (Fig. 1).

This poster summarizes structural and petrological results of our recent field work in the Ontario segment of the parautochthonous part of the ORGC. Based largely on geological maps by S.B. Lumbers published by the Ontario Geological Survey and our own field observations, we suggest that the map patterns of the Bonfield, Cosby, Mulock and Powassan granitoid 'batholiths' (actually, approximately tabular concordant sheets) and their prestrained host rocks are consistent with an origin of multi-order cross-folding during late-Ottawan, regional ductile transtension.

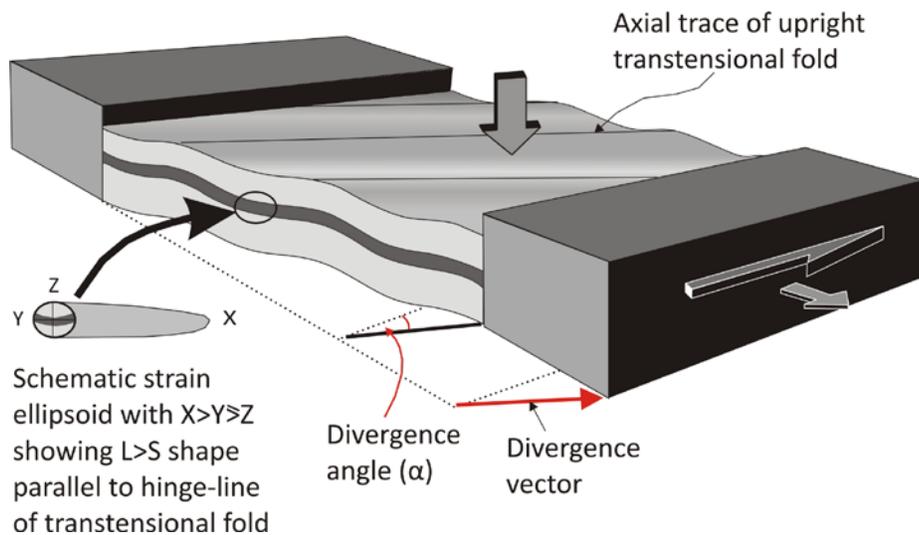


Figure 1: Block diagram showing set-up used to model ductile transtension, with two vertical-sided rigid blocks bordering an intermediate ductile region with passive horizontal layering that undergoes first-order transtensional folding. Prolate strain ellipsoid with X-axis parallel to the hinge line of the cross-fold is shown. Modifications to this idealized model are used to explain the distribution and orientations of cross-folds in the ORGC.

Mixed rheological behavior of a subduction plate boundary fault beneath the seismogenic zone

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Recent observations of episodic tremor and slow slip in subduction zones suggest aseismic slip and brittle shear fracture occur concurrently in the transition at the downdip limit of the seismogenic zone. Geophysical observations indicate that the transition zone is characterized by anisotropic seismic velocities, indicating foliated rocks, and near-lithostatic pore fluid pressure, but there are few insights from the rock record. We investigate the Leech River Fault on Vancouver Island, a paleo-plate boundary where an oceanic large igneous province was subducted beneath an accretionary wedge unit to explore the structures that form in the transition zone. Previous analyses of the mineral assemblages in the juxtaposed Leech River schist and Metchosin metabasalt indicate peak metamorphic conditions of ~350 MPa and 500-600°C in the schist and > 300°C in the metabasalt, comparable to estimated temperatures of ~525-650°C downdip of the seismogenic zone in Cascadia. A mylonitic shear zone, developed in both units, defines the fault. Shear fabrics, folding and boudinage, and a steeply plunging stretching lineation record both flattening and noncoaxial deformation. A disjunctive foliation is evident in both units and forms an S—C fabric that is locally deflected by C' surfaces, consistent with overall kinematics of sinistral-oblique subduction. In the schist, interconnected, anastomosing layers of muscovite, chlorite, biotite, and graphite define the foliation. In the metabasalt, chlorite dominates the cleavage domains. Phyllosilicates are likely deformed by basal glide. Asymmetric pressure shadows and phyllosilicate tails are developed around garnet and amphibole porphyroclasts. Amphibole porphyroclasts are deformed by rigid grain rotation and pressure solution mechanisms. Quartz is dynamically recrystallized by grain boundary migration and shows evidence for pinning between phyllosilicate sheets. Discordant quartz veins are present in both units and represent discrete fracture events that channelized fluid flow at depth. Veins are sheared into sigmoidal shapes, isoclinally folded, and boudinaged in two directions. Planar, folded, and refolded veins show that vein formation was contemporaneous with ductile deformation. Quartz within the veins varies from relatively undeformed to recrystallized by grain boundary migration mechanisms, where the degree of quartz recrystallization is dictated by the abundance of second phases: monomineralic quartz veins show a greater degree of recrystallization compared to domains with a higher abundance of phyllosilicates. Bulk deformation was therefore accommodated by distributed shear, largely partitioned into aligned phyllosilicate domains, accompanied by localized fracture likely assisted by high pore pressure or high stress or strain rate perturbations.

Abrupt along-strike variations in the P-T-t-D evolution of the Himalayan middle crust: insights from western Nepal klippen

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The Himalayan metamorphic core, exposed between two opposite sense shear zones, is locally preserved in a series of klippen that form its foreland-most exposure. The Karnali and Jajarkot klippen in western Nepal Himalaya are investigated to decipher the tectono-metamorphic history of the apparent leading edge of the exhumed middle crust. Both klippen are east-west trending doubly-plunging synforms underlain by a folded reverse-sense shear zone. They comprise upper greenschist to amphibolite metamorphic facies rocks in contact with overlying weakly to non-metamorphosed sedimentary rocks along a folded normal-sense shear zone.

Despite similar first order structural architectures and across-strike positions, phase equilibria modelling (Perple_X) combined with multi-equilibrium thermobarometry (THERMOCALC avPT mode using a permutational approach with TC_Comb) suggests significant contrasting metamorphic evolution between the two klippen. Migmatitic schists (Ky + Grt + Bt ± Ms ± St) in the Karnali klippe are characterized by chemically homogenised garnet and yield peak metamorphic conditions of 600-750 °C at 800-1000 MPa with clockwise P-T paths. In contrast, Grt + Bt + Ms ± Chl schists in the Jajarkot klippe are characterized by garnet with preserved growth zoning and yield peak metamorphic conditions of 550-600 °C at 900-12000 MPa with hairpin P-T paths. Garnet isopleths thermometry in the Jajarkot klippe suggests an increase in pressure during garnet crystallization, which is locally associated with deformation along the bounding shear zones. Higher temperatures of deformation in the Karnali klippe (600-750 °C) compared to the Jajarkot klippe (500-600 °C) are also supported by quartz crystallographic <c>-axis preferred orientation fabrics.

Timing of metamorphism was assessed by in-situ LASS-ICPMS monazite and xenotime geochronology combined with trace element acquisition. In the Karnali klippe, protracted prograde metamorphism between ca. 45 and 30 Ma was followed by retrograde metamorphism and exhumation between ca. 30 and 20 Ma. In the Jajarkot klippe, peak metamorphic conditions were prevailing around 25 Ma, but rare monazite and xenotime inclusions suggest that metamorphism may have started as early as 45 Ma. Retrograde reactions producing xenotime were dated at ca. 18 Ma in the Jajarkot klippe.

The most striking difference between the two klippen is the absence of migmatites affected by protracted high temperature metamorphism at medium to low pressure in the Jajarkot klippe, which also contrasts with any other mid-crustal section exposed further north. This implies that part of the middle crust was either (1) tectonically excised, or (2) pinched out southward and eastward towards the Jajarkot klippe. Partial tectonic removal of the middle crust requires unrealistic geometries of the bounding shear zones. Alternatively, partially molten mid-crustal material may not have extruded as far south as the Jajarkot klippe. Because of their marked tectono-metamorphic differences, an important structure must separate the two klippen. A lateral ramp in the Himalayan basal detachment, possibly caused by an inherited basement cross-structure, could explain the present day geometry. Transfer zones in the foreland fold-thrust belt and significant changes in topography previously recognized in western Nepal suggest that such a structure may have influenced the Himalayan orogen throughout its evolution.

Three-dimensional visualization of the major lithotectonic boundaries in the SW Grenville Province, Ontario

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SketchUp® is computer software that was developed to construct 1:1 real-world structures in three-dimensional space. Using this software the three-dimensional subsurface structure of the major lithotectonic boundaries can be visualized in the SW Grenville Province of Ontario. The structures and their trajectories are constrained by Nd isotope mapping and lithological boundaries at the surface and by geophysical surveys below the surface. The lithotectonic boundaries that will be depicted include the Grenville Front, Allochthon Boundary Thrust, Algonquin duplex boundary, Parry Sound shear zone and Central Metasedimentary Belt boundary.

Structural domains in the Kuujuaq – Tasiujaq area of the Paleoproterozoic New Quebec orogen; effects of orthogonal compression and dextral transpression

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The New Québec orogen (NQO) is a Paleoproterozoic belt in the southeastern Churchill Province of the Canadian Shield made up of autochthonous rocks deposited adjacent to the Archean Superior craton, tectonically overlain by allochthonous metavolcanic and metasedimentary assemblages accreted to the cratonic margin. The NQO is bound by two Archean cratons, to the west by the Superior craton, and to the east by the Core Zone. Current models infer early terrane accretion to the Superior margin at ca. 1.82 Ga, followed by terminal collision with the previously amalgamated Core Zone – North Atlantic Craton block, in a bulk dextral transpressional regime at ca. 1.80 Ga. In general orthogonal shortening in the orogen decreases from north to south, leading to a widening of the orogenic belt towards the south. The combination of orthogonal compression with dextral transpression formed a complex association of structures in the NQO, and several distinct structural domains can be identified in the orogen, here presented from west (foreland) to east (hinterland) for the Kuujuaq – Tasiujaq area of the orogen. The Kaniapiskau Supergroup which comprises mainly rift-to-drift supracrustal sequences intruded by mafic to ultramafic sills, tectonically overlies the Superior margin on the western edge of the orogen. It is characterized by thrust stacking reflecting a dominantly compressional deformation regime, and overprinted by a strong transpressional component which is well expressed in stacked and folded iron formations. Part of the Rachel-Laporte zone may represent accreted continental back-arc basinal sequences and is characterized by tight folding and increasingly steep foliations towards the eastern part of the zone. The Olmstead domain is a zone of Archean rocks of uncertain affinity which most likely represent the suture between the Core Zone and marginal sequences accreted to the Superior craton. It is characterized by pervasive, steep, transposition foliations overprinted by steep to moderately SW-plunging lineations. The Archean domains east of the accreted Paleoproterozoic sequences have a very different structural style. The Gabriel domain is characterized by steep NW trending foliations in the north and south of the study area, with a zone of E-W trending structures in the central area. The Leaf Bay domain is characterized by subhorizontal foliations, and broad, open folds with long wavelengths (10s of km) that have broadly E-W trending, vertical axial planes. This domain is interpreted as a crystalline nappe thrust over the more westerly domains, folded in the SE-directed dextral transpressional deformation. In the central part of the study area there are three Archean inliers, described as “domes”. We interpret these as stacked basement slices of the Superior margin that are imbricated as a result of dextral transpression along the craton margin. Current work is targeted at deciphering the timing of shift from orthogonal to transpressional shear and to link specific mineral assemblages and fabrics to these events. This may assist in providing a context for current exploration for orogenic gold in the region.

Fracture in the Midst of Flow -Deformation processes along the Moyagee Fault, Western Australia

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Within the Archean Yilgarn Craton of Western Australia, crustal scale shear zones accompanied emplacement of crustal batholiths. The dextral transpressional Cundimurra Shear Zone (CMSZ) was active for >20 Ma, during the incremental emplacement of the Cundimurra Pluton. Displacement along the CMSZ continued after pluton assembly, during the syndeformational cooling and exhumation of the granite-greenstone system. The Moyagee Fault occurs within the northern portion within the NE-trending segment of the CMSZ during the latter stages of pluton emplacement. The fault network comprises sequentially developed discrete shear fracture, cataclasis and ductile shear localized along pre-existing zones of high ductile shear. The distinct deformation components have been examined by SEM, TEM and EDSB in order to establish the grain-scale deformation processes.

Discrete fault/shear zone segments are highlighted by ultra-fine-grained tourmaline having all the aspects of pseudotachylyte that requires at least thin sectioning for definitive identification. In the earliest stages of fault development, tourmaline veins are a common, but not ubiquitous component consistent with stress-driven, as opposed to fluid-pressure driven, rupture. Subsequent displacement occurs by cataclasis that transitions rapidly into ductile flow and formation of ultramylonite. The ultramylonite is dominated by tourmaline, plagioclase and K-feldspar with grains only rarely largely than 1µm. All mineral phases are heavily dislocated with evidence of dynamic recrystallization. During this phase of deformation, the presence of tourmaline is critical to establishing a polyphase material in which grain size pinning and grain boundary sliding enable substantive macroscopic strain. Overall, the grain-scale fabrics demonstrate the complexity and possibility of multiple brittle-ductile transitions throughout the continental crust.

A material-point method formulation for incompressible linearly viscous geological flow

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Material-point method is a mixed Lagrangian-Eulerian method. The method utilizes Lagrangian particles to advect physical properties and solves partial differential equations on an Eulerian grid. The method avoids the degradation of accuracy caused by mesh distortion in a Lagrangian formulation. On the other hand, it enables the tracking of material deformation history, which would be difficult in an Eulerian formulation. Since mass, momentum and physical parameters are carried by particles throughout the modelling process, numerical diffusion by repeated grid-particle interpolation is minimized. In our implementation, we solve the continuity and momentum equations on a 2D modelling domain under Type I (Dirichlet) boundary condition with a linearly viscous (Newtonian) constitutive relation. Convective and transient terms in the momentum equation are neglected, resulting in a quasi-steady-state formulation and a linear set of equations. The particles sample the physical domain by Dirac delta function (i.e. for each particle, information is represented at a discrete point within the particle). Within each time step, information from the particles are interpolated by bilinear shape functions to the computational grid, where the governing equations are subsequently solved by a finite element formulation for velocity and pressure. The velocity is then interpolated back to the particles, by which particles are advected in an explicit manner and the stage is set for the next time step. Where strong velocity gradient is present, an adaptive refinement scheme is applied to split the particles in order to improve the accuracy of the integration. The code is benchmarked by a classic lid-driven cavity flow and the results are comparable with solutions obtained by other classic numerical methods under same conditions. Potential improvement of the code in terms of accuracy and the application of this method to anisotropic geological flow is discussed.

Rheological Dependence of Slip Surface Distribution in a Shear Zone Core at the Brittle Ductile Transition

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A heterogeneous assemblage of sheared lithologies at brittle-ductile transitional conditions within an exhumed continental strike-slip fault contains evidence for compositionally controlled strain partitioning at both map and micro-scale. The spatial distribution of strain within the shear zone core is observable on a map scale and a high resolution 1:8 map of the area has been produced. This distribution can be observed as compositional and grain size heterogeneities which define different strength materials. It is hypothesised that weaker planes in the fault characterised by preserved pseudotachylite textures within mica-rich ultramylonites occurring along the interface between different materials are preserved earthquake slip surfaces. These surfaces contain evidence for both brittle and plastic deformation in an area where primarily plastic deformation is observed. Relative strength distribution within the fault is estimated based on lithology and used to assess the dependence of possible earthquake slip-surface distribution on the nature of surrounding materials. Following this, a numerical representation of the interfacial relationships found within the Pofadder Shear Zone will be used to test the reproducibility of these elastic and plastic cycling along the interface of sheared materials. The project aims to quantify the distribution of preferentially strained surfaces related to compositional diversity in order to estimate the spatial heterogeneity of fault strength and seismicity at brittle-ductile transitional conditions.
