# 2012 CTG Fall Meeting

***October 27 & 28, Ottawa***
***Geological Survey of Canada, 615 Booth Street, Ottawa, Ontario***

*Photo: View of the Eardley Escarpment, marking the main northern boundary fault to the Ottawa–Bonnechere Graben northwest of Ottawa. The Gatineau Hills, part of a dominant physiographic feature in eastern Canada—the Laurentian Highlands—form the high ground on the right of this panoramic view towards the northwest. The uplifted highlands expose c. 1.0-1.3 Ga crystalline basement rocks of the Grenville orogen, a deeply eroded ancient mountain belt along the south-eastern edge the Canadian Shield. The broad Ottawa Valley, visible on the left, is underlain by relatively flat-lying Cambro-Ordovician sedimentary rocks of the Ottawa Embayment of the St. Lawrence Platform. Fault offset on the Eardley Fault, down-dropping the Ordovician strata underlying the valley, is of the order of 500 m (from Bleeker et al., 2011, GAC Fieldtrip Guidebook; pdf available on request).*

## Preliminary Program

### Friday, Oct. 26:

- Arrival in Ottawa, with many out-of-town participants staying in the Best Western Hotel (Best Western Macies), 1274 Carling Avenue, not far from the Booth Street complex.
- Evening get-together at Monkey Joe's Bar & Grill (across the road from the Best Western, on Carling Avenue), 1265 Carling Avenue, Ottawa, Ont. K1Z 8S9, Tel: (613) 725-2992.

### Saturday, Oct. 27:

- Fieldtrip around the Ottawa area, from Grenvillian basement to faulted graben floor, all-day starting at 8:00 am from Booth Street and finishing around 5:30 pm. Lunches and drinks provided.
- Beer and dinner at The Heart & Crown Pub on 353 B Preston Street, tel: (613) 564-0000, starting at about 5:30 - 6:00 pm.
- Canadian Tectonics Group (CTG) business meeting at 8:15–9:00 pm, at the Heart & Crown.

### Sunday, Oct. 28:

- Oral presentations and posters, Gamble Hall, in lobby of the 615 Booth Street building, starting 8:00 am. Lunches and coffee will be catered. Parking is free in the parking lot across the road.
- Departure(s) at about 4:00 pm.

# List of Participants

| | | |
|---|---|---|
| Nicole Allen | Queen's University | nk_allen@hotmail.com |
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*First author but not present at meeting.

## Program for Saturday, October 27

### Fieldtrip (8:00 – 17:00):

| | |
|---|---|
| 08:00 - 08:15 | Getting together on Booth Street |
| 08:15 - 09:00 | Drive to Lac Beauchamp (…via Tim Horton’s if time permits). |
| 09:00 - 09:30 | Unconformity: Nepean Sandstone on Grenville basement |
| 09:30 - 09:50 | Drive to Val-des-Monts quarry |
| 09:50 - 10:30 | Typical "Grenville Series" granulite-grade gt-bio-sill paragneiss, relict bedding, incipient melting |
| 10:30 - 11:00 | Drive to Buckingham |
| 11:00 - 12:00 | "Buckingham volcanics" and carbonatite intrusions, Grenville dyke |
| ***12:00 - 13:30*** | ***Travel and Lunch, Coffee and P-Stop*** |
| 13:30 - 14:30 | Outcrop, to be determined (optional), Champlain Lookout |
| 14:00 - 14:30 | Travel |
| 15:00 - 17:00 | Stittsville Fault, section through complex normal (or “not so normal”, see Fig. 1 below) fault system in hanging-wall of main Hazeldean Fault, Clark Quarry |
| 17:00 – 17:30 | Back to Ottawa |
| ***17:30 - 20:15*** | ***Beer and pub dinner, at the Heart & Crown on Preston Street*** |
| 20:15 - 21:00 | SGTD (GAC) and CTG business meeting, chaired by **John Waldron et al.** |
| ***21:00 - 22:00*** | ***R & R*** |

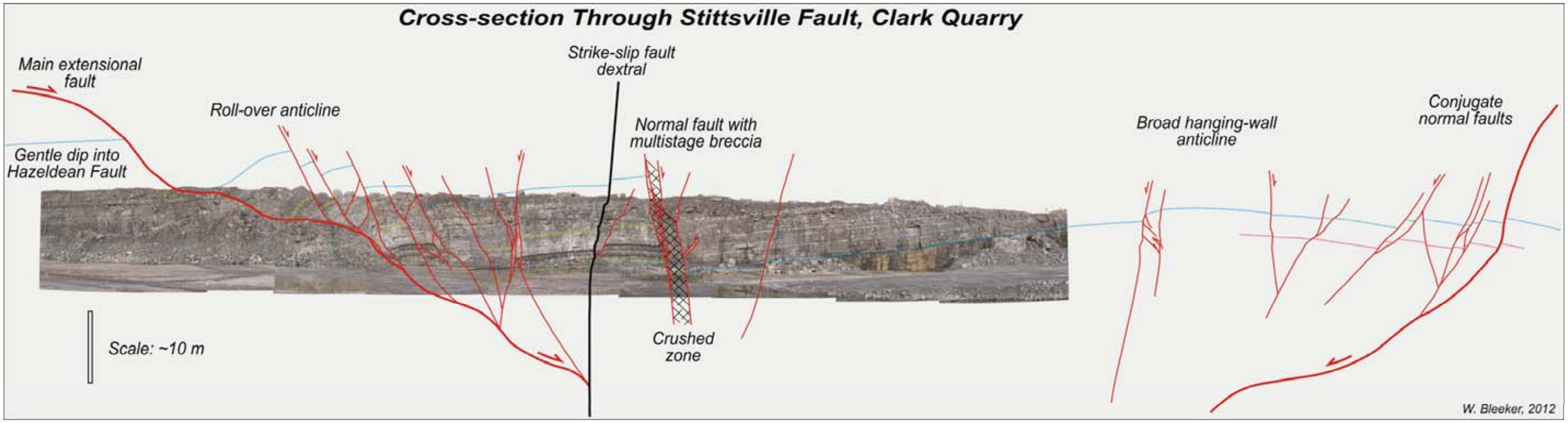

*Figure 1: Panoramic section through the "Stittsville Fault", Clark Quarry, looking towards the ENE (070°); no vertical exaggeration, although the eastern part of section (at right) is slightly foreshortened to make things fit. Displacement on this second-order extensional/normal fault of the Ottawa Embayment is relatively modest (~25-30 m, mainly S-side down). Nevertheless, the overall structure is rather complex with numerous splays or third-order faults cutting through the carbonate platform of the Late Ordovician Ottawa Group and creating cross-stratal permeability. The main event(s) are normal faults that sole into a more shallow-dipping extensional fault. In the immediate hanging wall of this fault, blocks are rotated to form a small, faulted, "roll-over anticline". Some steep second-order faults show mainly dextral strike-slip (e.g., fault plane in black). And much of the (late?) normal fault displacement is taken up by an extensive crush zone with probably several phases of brecciation. At the larger scale, the strata form a broad, open, hanging-wall anticline, which constitutes an almost perfect scale model of, for instance, the structure that hosts the Hibernia oil field. The walls of the Clark Quarry provide multiple sections through this fault, several hundred metres apart. In some walls, there is clear evidence for a thrust reactivation on the low-angle extensional fault, in one wall creating a "triangle zone". Age constraints on these various phases of faulting are currently poor, and could be summarized by "Silurian to yesterday".*

# Program for Sunday, October 28

## Oral Presentations (AM):

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|---|---|
| 08:00 - 08:20 | **Wouter Bleeker** (GSC, Ottawa)<br>*Arrival, signing in, hanging up posters and introductory remarks* |
| 08:20 - 08:40 | **Lyal Harris & Jean Bédard** (INRS, Quebec City, and GSC Quebec)<br>*Archaean Arcs Are Snarks—Structural and Geophysical Evidence against Archaean Subduction* |
| 08:40 - 09:00 | **Zsuzsanna Tóth et al.** (Laurentian University)<br>*Structural Setting of Shear-hosted Gold Mineralization in Geraldton Area, Northwestern Ontario-Preliminary Results* |
| 09:00 - 09:20 | **Kate Rubingh, Bruno Lafrance, B. & Harold Gibson** (Laurentian University)<br>*Early Thrust Imbrications within the Mcleod Road - Birch Lake Thrust Panel and Implications on Gold Mineralisation at the New Britannia Mine, Snow Lake, Manitoba* |
| 09:20 - 09:40 | **Andy Parmenter & Paul Williams** (U. of New Brunswick)<br>*Mantle Dynamics and the Suprastructure-Infrastructure Association: Global View and an Example from the Thor-Odin Dome in Southeastern British Columbia* |
| 09:40 - 10:00 | **Borja Antolin et al.** (Queen's University)<br>*Late Deformation Stages in the Eastern Himalayas (NW Bhutan) by Means of Pyrrhotite Remanences* |
| ***10:00 - 10:30*** | ***Coffee Break, and Posters*** |
| 10:30 - 10:50 | **C. Birnie[1], F. Fueten[1], R. Stesky[2] & E. Hauber[3]** ([1]Brock University, [2]Pangaea Scientific, [3]German Aerospace Center)<br>*Underlying Structural Control of Small-Scale Faults and Fractures in West Candor Chasma, Mars* |
| 10:50 - 11:10 | **Elena Konstantinovskaya et al.** (INRS, Quebec City)<br>*Geometry and Differential Emplacement of Duplexes in the Joly - St. Flavien Gas Storage Area, Southern Quebec Appalachians: Implications for the Reservoir Lateral Continuity* |
| 11:10 - 11:30 | **Willem Langenberg** (University of Alberta)<br>*The Understanding of the Structural Geology of the Crowsnest Pass Transect From 1903 Till 2012* |
| 11:30 - 11:50 | **John W.F. Waldron[1], Sandra M. Barr[2], C.E. White[3] & Jim Hibbard[4]** ([1]U. of Alberta, [2]Acadia U., [3]Nova Scotia Dept. of Natural Resources, [4]North Carolina State U.)<br>*Strike-Slip Faults and the Mid-Paleozoic Reconfiguration of the Appalachians in Atlantic Canada* |
| 11:50 - 12:10 | **Richard Ernst & Wouter Bleeker** (Carleton University, GSC Ottawa)<br>*Constraints on Pre-Pangean Supercontinent Reconstructions from the LIP Barcode Record and Associated Giant Dyke Swarms: An Overview of the Lips and Supercontinent Project* |
| 12:10 - 12:30 | **Katherine Boggs** (Mount Royal University)<br>*Google Earth Models; Purcell Thrust and Grotto Creek; Canadian Cordilleran Geological Map Project* |
| ***12:30 – 13:00*** | ***Lunch: Grab a sandwich, stretch your legs*** |

13:00 – 13:30 Lunch, discussion while you munch away. **Boggs et al.**
*Google Earth applications, examples and discussion*

## Poster Presentations (PM):

13:30 - 15:00 Posters (about 8 posters, ~10 minutes each), see list of titles below

## Posters:

**Nicole Allen[a], Danielle Brown[a], Laurent Godin[a], Daniel Gibson[b]** ([a]Queen’s University, [b]Simon Fraser University)
*Microstructural Analysis and* $^{40}Ar/^{39}Ar$ *Thermochronology of the Okanagan Valley Fault System, British Columbia*

**Nils Backeberg & Christie Rowe** (McGill University)
*Sub-Parallel Flattening Fabrics and Way-Up Indicators in the Finlayson Lake Greenstone Belt, Western Superior Province, Ontario: Testing the Structural Geometry of a Mesoarchean Greenstone Belt*

**Katherine Boggs** (Mount Royal University)
*Google Earth Models; Purcell Thrust and Grotto Creek; Canadian Cordilleran Geological Map Project*

**Sharon Carr** (Carleton University) **& Philip Symony** (University of Calgary)
*Cretaceous to Eocene Evolution of the Southeastern Canadian Cordillera: Continuity of Rocky Mountain Thrust Systems with Zones of "In-Sequence" Mid-Crustal Flow*

**Nathan Cleven** (University of Waterloo)
*The Hongliuhe Fold-And-Thrust Belt: Evidence of Arc-Arc Collision after the Early Permian in the Beishan Orogenic Collage, Northwest China*

**Rohanna Gibson & Laurent Godin** (Queen's University)
*Along-Strike Strain Partitioning in the Himalayan Metamorphic Core, Central Nepal: A Proposed Study*

**Lyal Harris & Jean Bédard** (INRS, Quebec City and GSC Quebec)
*Fossil Mantle Rift Controls on Deformation and Mineralization in the Quebec Abitibi*

**Ben Melosh[1], Christie Rowe[1] & Louis Smit[2]** ([1]McGill U., [2]University of Cape Town)
*Seismicity and Strain Partitioning Recorded in a Differentially Exhumed Continental Transform Shear Zone: Pofadder Shear Zone, Namibia and South Africa*

**Joycelyn Smith et al.** (Brock University)
*Measuring Planar Features Using CTX Images and Digital Terrain Maps: Searching for Evidence of Faulting in Coprates Chasma, Valles Marineris, Mars*

**Lindsay Waffle[1*], Laurent Godin[1] & Lyal Harris[2]** ([1]Queen's University, [2]INRS, Quebec City)
*Effects of Basement Highs on Orogen-Parallel Strain Partitioning: A Case Study of the Faizabad Ridge in Northern India Using Centrifuge Analogue Modelling*

# Titles and Abstracts

(Listing alphabetic by first author.)

## Microstructural Analysis and $^{40}Ar/^{39}Ar$ Thermochronology of the Okanagan Valley Fault System, British Columbia

Nicole Allen[a], Danielle Brown[a], Laurent Godin[a], Daniel Gibson[b]

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This study focuses on the Okanagan Valley fault system (OVfs) and its footwall in the southeastern Canadian Cordillera, between Sicamous and Revelstoke, British Columbia. The OVfs formed due to a change from transpression to transtension on the western margin of North America in the Eocene, and resulted in extension-accommodated exhumation of the southern Shuswap metamorphic complex [1, 2]. Normal faults occur approximately 40 km west of the Monashee Décollement and 55 km west of the Columbia River Fault and have been proposed to have up to 30 km of horizontal displacement [2]. The OVfs exhibits a strong ductile deformation fabric in the >1km-thick shear zone within sillimanite-grade footwall gneisses, partially overprinted by brittle deformation textures. We utilize a multi-faceted approach combining microstructural analysis and $^{40}Ar/^{39}Ar$ thermochronology to critically examine two possible modes of exhumation in the OVfs: normal ductile and channel flow systems. Structural measurements and samples were collected along a sixty kilometer ENE-WSW oriented profile across the fault system. Microstructure analysis of brittle and ductile fabrics in high and low temperature regimes, together with crystallographic-preferred orientation (CPO) analysis, will be conducted using standard microscope and Fabric Analyzer techniques [3]. These analyses will provide new insights into strain partitioning and deformation temperature in the OVfs, which will be useful to interpret the thermochronological results. The $^{40}Ar/^{39}Ar$ thermochronology involves dating muscovite, biotite, and hornblende crystals from six samples across the OVfs, which have been deliberately selected from both the Cretaceous meta-sedimentary hanging-wall lithologies and the high metamorphic grade footwall granodiorite gneisses. The new cooling ages, combined with previously published $^{40}Ar/^{39}Ar$ and U-Pb zircon ages [4] and the aforementioned petro-fabric analyses will help unravel the temperature-deformation-time history of these rocks to better understand the exhumation processes linked to the OVfs.

[1] Brown, S., Gibson, H.D., Andrews, G., Thorkelson, D., Marshall, D., Vervoort, J., and Rayner, N., 2012. New constraints on Eocene extension within the Canadian Cordillera and identification of Phanerozoic protoliths for footwall gneiss of the Okanagan Valley shear zone. Lithosphere, 4, 354-377.

[2] Johnson, B. J., 2006. Extensional shear zones, granitic melts, and linkage of overstepping normal faults bounding the Shuswap metamorphic core complex, British Columbia. GSA Bulletin, 118, 366–382.

[3] Peternell, M., Hasalova, P., Wilson, C. J. L., Piazolo, S., and Schulmann, K., 2010. Evaluating quartz crystallographic preferred orientations and the role of deformation partitioning using EBSD and fabric analyzer techniques. Journal of Structural Geology, 32, 803-817.

[4] Grevais, F., and Brown, R. 2010. Testing modes of exhumation in collisional orogens: Synconvergent channel flow in the southeastern Canadian Cordillera. Lithosphere, 3, 55-75.

# Late Deformation Stages in the Eastern Himalayas (NW Bhutan) by Means of Pyrrhotite Remanences

**B. Antolín [a,b*], E. Schill [c], D. Grujic [d], S. Baule [b], X. Quidelleur [e,f], E. Appel [b], M. Waldhör [b]**

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In NW Bhutan, middle to late Miocene deformation has been partitioned between conjugate strike-slip faulting, E-W extension along the Yadong-Gulu graben and kilometre-scale folding. To better understand the late deformation stages and their implications for the evolution of the eastern Himalayas, the palaeomagnetism in the erosional remnant of the Tethyan Himalayan rocks outcropping in NW Bhutan has been studied. Pyrrhotite is the carrier of the characteristic magnetisation based on 270-325ºC unblocking temperatures. The age of the remanence is ca. 13 Ma indicated by illite 40K/40Ar cooling ages. The mechanism of remagnetisation is thermal as indicated by Raman spectroscopy on carbonaceous material temperatures [1] close to and higher than 325ºC (Pyrrhotite Curie Temperature) and 40K/40Ar and 40Ar/39Ar ages. Pyrrhotite components yield a mean remanence direction of 036/36 (Declination/Inclination). Comparison of the declination with respect to the 13 Ma reference direction, yields ca. 32º clockwise rotation with respect to stable India since 13 Ma. We suggest that this clockwise rotation is related to strain partitioning between NE-directed shortening, sinistral-slip along the Lingshi fault, and east-west extension. This represents a field-based explanation and a minimum onset age for present-day eastward motion of the upper-crust of SE-Tibet and NE- Himalayas.

The site mean directions partly show small circle distribution demonstrating that the remanence was acquired before (or synchronous) with a large-wavelength folding event after 13 Ma.

References

[1] Kellett, D.A., Grujic, D., 2012. New insight into the South Tibetan detachment system: not a single progressive deformation. Tectonics 31, TC2007.

# Sub-Parallel Flattening Fabrics and Way-Up Indicators in the Finlayson Lake Greenstone Belt, Western Superior Province, Ontario: Testing the Structural Geometry of a Mesoarchean Greenstone Belt

**Nils Backeberg and Christie Rowe**

*McGill University*

Archean greenstone belts are key to understanding the evolution and tectonic framework of the oldest preserved continental fragments in the Earth's stable cratons. We present a detailed structural study of the 2.931 - 3.003 Ga Finlayson Lake greenstone belt, which is located in the south-central Wabigoon Subprovince of the Superior Province in Canada. The Finlayson belt is situated between three TTG gneiss domes of similar ages: the 3.002 Ga Marmion gneiss; the 2.982 Ma Eye-Dashwa gneiss; and the 2.936 Ga Hardtack gneiss.

Previous work documented tectonic foliation and way-up indicators with variable lithological and chronological boundary interpretations, suggesting that the Finlayson belt either forms a synformal keel between the TTG gneiss domes (Stone and Kamineni 1989), or is comprised of three fault-bounded metamorphic and chronologically different sub-belts: eastern-, central- (or Witch Bay) and western belt (Stone 2008, pers. comm. D. Stone). The dominant fabric throughout the Finlayson belt is a strong flattening foliation trending on average 048° to 058° with approximately vertical dip, indicating NW-SE shortening. Nearly all lithological boundaries and structural features in the Finlayson belt (except those on the western margin) lie approximately parallel to the eastern boundary with the Marmion gneiss.

Using stratal paleo-up indicators including graded bedding and pillows, we assessed the possibility for an overall synformal geometry for the greenstone belt. We see predominantly northwest facing indicators in the western belt with steeply plunging fold axes and vergence to the southeast (towards the central belt). Southeast facing indicators are consistent across the entire central belt and together with the steeply plunging fold axes in the western belt do not conform to the synformal keel structure of the belt as presented by Stone and Kamineni (1989). The transition from western to central belt is poorly exposed, therefore fold or fault relation between the two sub-belts is still poorly confined. The clearest evidence for separation of three different belts within the Finlayson Lake greenstone belt is the variable metamorphic mineral assemblage and different age dates reported by Stone (2008, 2010). With newly collected structural data we aim to further test the structural context of the Finlayson Lake greenstone belt. We show variations in the regional fabric between the three belts and have been able to define two sets of compressional events. An older NNW shallowly plunging shortening axis is identified by rare fold structures, which has been overprinted by a sub-parallel SE shallowly plunging shortening axis. We find that the older deformation event is best preserved in the western belt and becomes more cryptic within the central belt, due to stronger overprinting fabrics. We argue that the stronger intensity of later flattening foliation fabric in the eastern belt successfully overprinted most, if not all, of the older structures. This is supported by field observations that the eastern belt lithologies have been completely retrogressed to chlorite schist coeval with the flattening foliation, whereas the prevalent metamorphic grade seen in the western Finlayson belt is lower amphibolite facies with peak epidote-hornblende mineralogy preserved.

# Underlying Structural Control of Small-Scale Faults and Fractures in West Candor Chasma, Mars

**C. Birnie[1], F. Fueten[1], R. Stesky[2], and E. Hauber[3]**

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Orientations of small-scale faults and fractures within the interior layered deposits of West Candor Chasma were measured to investigate what information about the geologic history of Valles Marineris they can contribute. Deformational features were separated into six categories based on morphology and their orientations were analyzed. The elevations at which the deformational features formed are recorded, as a proxy for stratigraphic level. Deformational features occur over a continuous range of elevations and display regionally consistent preferred orientations, indicating their formation was controlled by a regional stress regime. The two most abundant preferred orientations of ~35° and ~110° are approximately parallel to the chasma walls and the inferred underlying normal faults. The alignment of three populations of small faults at 140°, consistent with the morphology of release faults, indicates a large-scale fault underlying the southeastern border of Ceti Mensa. The preferred orientations imply these small-scale deformational features formed from a continuation of the same imposed stresses responsible for the formation of Valles Marineris, indicating these stresses existed past the formation of the interior layered deposits. The origins of a fourth preferred orientation of 70° is less clear but suggests the study area has undergone at least two periods of deformation.

References

Birnie, C., F. Fueten, R. Stesky, and E. Hauber (2012), Underlying structural control of small-scale faults and fractures in West Candor Chasma, Mars, J. Geophys. Res., 117, EXXXXX, doi:10.1029/2012JE004144, in press.

## Ottawa-Bonnechere Graben: A Neoproterozoic Rift Structure Shaped By Reactivation

**Wouter Bleeker** *(email: wbleeker@nrncan.gc.ca)*

*Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada*

The Ottawa-Bonnechere Graben (OBG), first so named by Kay (1942), forms a marked, fault bounded, rift-like structure in eastern North America, extending from east of Montreal to Lake Nipissing and beyond. It has an overall WNW trend, at a high angle to reactivated Paleozoic rift structures such as the St. Lawrence rift system. In detail it has a more complex structural plan, consisting of left-stepping *en échelon* segments, with many major normal faults typically clockwise to the overall trend. This is particularly evident in the Ottawa area where the *en échelon* structure is highlighted by the zig-zag course of the Ottawa River and the sudden termination of the prominent basement horst of the Gatineau Hills. Some of the major faults (e.g., the Hazeldean Fault) have a sigmoidal trace with maximum displacement on a central NW-trending segment, and displacement tapering off along strike in either direction.

The Lake Nipissing area presents perhaps the most complete "type section" of the rift structure, with 1) a ~30 km wide, normal fault-bounded valley; 2) exposures of major rift-parallel tholeiitic dykes ("Grenville swarm", ca. 590 Ma); 3) a subparallel but less widespread swarm of alkaline dykes (referred to here as the "Mattawa dykes", perhaps ca. 580 Ma?); 4) central alkaline intrusions along the valley floor (nepheline syenites and carbonatites, ca. 577 Ma) that must have fed several alkaline volcanoes; and 5) numerous more localized and more irregular mafic and ultramafic lamprophyre dykes proximal to the central intrusions. Similarities to the modern East African Rift are striking. Ages of magmatism, the overall trend of the graben, and the eastward convergence of the Grenville dyke swarm to a focal region east of Montreal (the Sutton plume?), support the model of a failed rift arm of latest Neoproterozoic age, related to a rift-rift-rift triple junction, breakup of Rodinia, and opening of Iapetus ocean, as proposed in early papers by Kumarapeli, and Burke (see Bleeker et al., 2011, for a recent overview).

Yet, most of the obvious normal faults and current physiographic controls of the graben are post-Ordovician in age, and if there was a Neoproterozoic graben structure, its suprastructure was removed by erosion and planed off prior to transgression of Ordovician platform sediments across the area. Hence Kay's original suggestion that the graben is a much younger structure. There are no Neoproterozoic rift basalts or alkaline volcanics, nor any rift clastics, preserved along the distal axis of the graben, and Grenville dykes are exposed at some depth below the paleosurface (~5 km). This argues for an elevated terrestrial graben (again similar to the East African rift) during the latest Neoproterozoic, major erosional levelling during the Cambrian, finally followed by (thermal?) subsidence and marine transgression in the Ordovician. Only afterwards did a major phase of extension and reactivation form the normal faults that now define the "graben". Reactivation along the St. Lawrence rift system was likely Mesozoic in age, during opening of the Atlantic. It is unclear, however, whether the same applies to the almost orthogonal OBG. Instead it is proposed that the major phase of normal faulting and reactivation in the OBG is Paleozoic in age, and was a response in the foreland to either the main Acadian orogeny or the later Alleghenian orogeny, when Gondwana finally collided with Laurentia to form supercontinent Pangea. Definitive testing of these various hypotheses will depend on developing novel ways to date the faults rocks.

References

Bleeker, W., Dix, G., Davidson, A., and LeCheminant, A.N., 2011. Tectonic evolution and sedimentary record of the Ottawa–Bonnechere Graben: Examining the Precambrian and Phanerozoic history of magmatic activity, faulting and sedimentation. Geological Association of Canada Annual Meeting, Ottawa 2011, Guidebook to Field Trip 1A, 98 p.

Kay, G.M., 1942. Ottawa-Bonnechere Graben and Lake Ontario homocline. Geological Society of America Bulletin, vol. 53, p. 585-646.

## Google Earth: Imagine the Possibilities for Spatial Visualization!!

**Katherine Boggs**

*Mount Royal University, Calgary, Alberta*

Spatial ability was defined by Elliot and Smith (1983) as the mental reconstruction and manipulation of visual forms and the perception and retention of visual shapes. High-level spatial cognitive skills are critical for novice students to acquire during their journey towards becoming professionals in multiple disciplines such as the geosciences (Ishikawa and Kastens, 2005; Kastens and Ishikawa, 2006; Kastens, 2009; Lee et al., 2009; NRC 2006), biology, chemistry, engineering, interior design and theatre (Boggs et al., 2011).

*1. Teaching Spatial Ability:* The spatial ability and awareness necessary for martial arts or dance, or for the above professions are much easier to acquire as a child. In academia we typically expect our students in their late teens and early twenties to acquire these spatial abilities. This is challenging for ~80% of our students. In cellular microscopy, computer reconstructions are used to assist students in visualizing the 3-D structure of cell organelles from 2-D slices under a microscope. In theatre newspaper and masking tape are used as introductory exercises when guiding novice students towards creating 3-D costumes (Boggs et al., 2011).

*2. Google Earth for Teaching Spatial Ability in the Geosciences:* But what about the multiple scale features that we have in geology? Just imagine the possible applications of Google Earth! A few are presented here, starting with virtual field trips, for example a submitted teaching activity through the Canadian Cordillera (www.carleton.edu). Using SketchUp and COLLADA to create KML files, it is possible to create custom sliders that can be used to drag vertical geological cross-sections through topography. It is also now possible to use the WxAzygy transparent interface to create in situ models in topography that are queryable via ‘cut-aways’. Or, simply draping a geological map over topography in Google Earth could be used to illustrate the ‘Rule of Vs’, while a combination of one custom slider with a draped geological map could be used to explain the difference between true and apparent thicknesses (Boggs et al., 2012).

*3. Google Earth and Navigation:* Imagine how Google Earth would have blown away maritime navigators honoured by the “Navigator” with “sextant” statue in Cobh, Ireland where millions of Irish immigrants left Ireland for the new world! Google Earth, combined with electronic charts, and GPS have erased the need for sextants in today’s maritime navigation.

# Cretaceous to Eocene Evolution of the Southeastern Canadian Cordillera: Continuity of Rocky Mountain Thrust Systems with Zones of “In-Sequence” Mid-Crustal Flow

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We document the internal geometrical development of the ~400 km wide, east-verging, retrowedge side of the southeastern Canadian Cordillera during the Cretaceous to Eocene. In the External zone, the Rocky Mountains and Foothills are characterized by three major east-verging, Late Cretaceous to Eocene, thin-skinned, piggyback thrust and fold systems, the Bourgeau – Lewis, McConnell, and Foothills systems. They root westward into a basal décollement and accommodated ~180 km of shortening. The Western Internal zone is characterized by tracts of metamorphic rocks and metamorphic core complexes (e.g. Kettle, Okanagan, Priest River and Valhalla), some of which are basement-cored domes (e.g. Frenchman Cap, Thor-Odin, and Spokane). They have a downward-younging progression of Late Cretaceous to Eocene metamorphism and deformation in infrastructural flow zones characterized by transposition foliation, migmatites, flow folds and 1-7 km thick shear zones (e.g. Gwillim Creek shear zone, Monashee décollement, Eocene basal décollement). In the Eastern Internal zone, a relict ~100-200 km wide Early Cretaceous orogen, that predated emplacement of ca. 100 Ma plutons, is nested between the External and Western Internal zones. The geology and architecture of the Internal and External zones can be explained by progressive development of major Late Cretaceous to Eocene shear zone systems in the Internal zone that can be directly linked with coeval thrust and fold systems in the External zone. The linkage was via Late Cretaceous activation and Late Cretaceous to Early Eocene reactivation of the 150-200 km-wide central portion of the Rocky Mountain basal décollement that lies beneath and translated the intervening Early Cretaceous orogen. During the latest stages of shortening, in the Early Eocene, extensional shear zone systems in the Internal zone, localized on tectonothermal culminations, were concomitant with shortening in the External zone. Motion of deep-seated Early Eocene décollements beneath some of these culminations may have contributed to their doming. Crustal shortening ended at ca.52 Ma due to a change in tectonic setting to that of a transtensional tectonic regime, coinciding with the end of thrusting in the External thrust belt and with crustal-scale extension in the Western Internal zone.

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# The Hongliuhe Fold-And-Thrust Belt: Evidence of Arc-Arc Collision after the Early Permian in the Beishan Orogenic Collage, Northwest China

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The Early Permian strata of the Hongliuhe Group are located in the Beishan orogenic collage, a tectonically significant region between the Tianshan orogen and the Southern Mongolian accretionary system, of the Central Asian Orogenic Belt. Stratigraphic reconstruction of the group show a general fining upwards sequence of rhythmically interbedded sandstones and siltstones with thick basal successions of conglomerates, all unconformably overlying a Late Carboniferous volcanic assemblage. The clast lithotypes of conglomerates successively change from being polymictic with metamorphic tectonite clasts at the base to a narrow type-distribution of granitoid clasts mid-section, showing the unroofing sequence of the arc-related provenance. The North Gongpoquan composite arc fits the clast-lithotype profile of the conglomerates, and is the most probable provenance. Hongliuhe stratigraphy experienced a thin-skinned fold-and-thrust belt style of deformation that has a consistent southward vergence. Deformation in the lower stratigraphic levels is expressed as steep, north-over-south brittle-ductile shear zones that are coupled with large-scale sheath folding, up to 15 km in breadth. The upper stratigraphic levels accommodated strain through low-angle thrust ramping, shear folding, imbricate fanning and duplexing. Therefore, the Early Permian strata of the Hongliuhe Group were syn-orogenically deposited in a fore-arc or foreland setting of the North Gongpoquan composite arc, and the dominant southward structural vergence is consistent with involvement of a north-dipping subduction system. Cross-section restoration conservatively estimates a minimum accommodation of 24% orogenic-scale shortening during this event. The timing of this collision is one of the last phases of the Beishan orogeny and provides an intermediary constraint for the final amalgamation of the southwestern Central Asian Orogenic Belt.

# Constraints on Pre-Pangean Supercontinent Reconstructions from the LIP Barcode Record and Associated Giant Dyke Swarms: An Overview of the Lips and Supercontinent Project

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The breakup history of Pangaea, Earth's most recent supercontinent, teaches us that large igneous provinces (LIPs) play a pivotal role in continental breakup, typically leaving remnants of flood basalts and their giant feeder dyke swarms on conjugate rifted margins. As was realized by Du Toit, as early as 1920 in relation to the extensive Karoo sills and dispersed southern continents, LIPs thus provide a key tool in reconstructing past continental aggregations. In the older record, many of the flood basalt sequences are no longer preserved, but their giant tholeiitic dyke swarms and sill complexes provide a rich proxy record ("magmatic barcodes") for the waxing and waning of LIP activity in deep geological time, very strongly correlating with the putative supercontinent cycle.

A detailed survey of many ancient (Archean) cratons or (Proterozoic) composite cratons shows that they are riddled with numerous giant dykes swarms that can be tracked to magmatic focal regions along cratonic margins—a picture entirely analogous to LIPs decorating the margins of modern continents (e.g., the Indian subcontinent). Discrete, short duration LIP events first weakened cratonic lithosphere and then accompanied final breakup. Reconstructing ancient supercontinents could thus be as simple as dating and matching the magmatic barcodes of all remaining large cratonic pieces (~50, both Archean and Proterozoic). In this respect, giant dyke swarms are of particular interest because 1) not only are they an integral part of LIPs, but 2) they have very large footprints (300-3000 km); 3) they were emplaced in short time pulses that can now be dated precisely; 4) they are relatively insensitive to uplift, and 5) project far back into cratonic hinterlands; 6) they contain rich geometrical and paleo-stress information; 7) they also provide superior "piercing points"; and 8) they provide the target rocks of choice for high-quality, precisely dated paleomagnetic poles ("key poles").

Thus, we have established an industry-academia-government collaborative project "Reconstruction of Supercontinents Back to 2.7 Ga Using the Large Igneous Province Record" (www.supercontinent.org). So far, our project team has obtained >100 new targeted U-Pb ages on ancient LIPs from around the world and we aim to triple that. In this talk we will present some first results and implications.

# Along-Strike Strain Partitioning in the Himalayan Metamorphic Core, Central Nepal: A Proposed Study

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Over the last half-century, structural and metamorphic studies in the Himalaya have documented significant variations in melt content, strain, age of deformation, peak pressure-temperature conditions, and cooling ages within the Himalayan metamorphic core. Yet, limited evaluations have been completed to assess and explain the along-strike variability of the orogen. For this reason, seven closely spaced N-S transects over a strike distance of 120 km were systematically sampled in central Nepal. Each 10 to 20 km transect crosses the Main Central thrust, from the upper Lesser Himalayan sequence (LHS) into the structurally overlying Greater Himalayan sequence (GHS). These cross-sections range in structural and metamorphic character from relatively undeformed biotite-grade LHS rocks to highly sheared kyanite-grade mid-crustal rocks of the GHS. Samples were collected from each transect at approximately the same eight structural levels for microstructural analysis and strain characterization (i.e. sense of shear; percentage of pure versus simple shear and temperature of deformation), including quartz crystallographic preferred orientation and vorticity analyses. These will be complemented with previously published geochronologic data, as well as with new in-situ U-(Th)-Pb monazite dating and 40Ar/39Ar thermochronology to constrain the temperature-time history of these rocks.

The seven deformation-temperature-time cross-sections will be compiled into a longitudinal cross section to quantify the along-strike variations in this part of the Himalayan metamorphic core. The ultimate goal of the research will be to build a 3D kinematic model incorporating geophysical imaging of Indian basement cross-structures, which we hypothesize might influence strain partitioning in the Himalayan metamorphic core.

# Archaean Arcs Are Snarks—Structural and Geophysical Evidence against Archaean Subduction

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> “Just the place for a Snark! I have said it twice:
> That alone should encourage the crew.
>
> Just the place for a Snark! I have said it thrice:
> What I tell you three times is true.”
>
> [*Lewis Carroll, The Hunting of the Snark, An Agony in Eight Fits*]

Bédard et al. (2012) provide geochemical, stratigraphic, and structural evidence that ‘modern’, subduction-related processes were absent in the Archaean and that Archaean arcs are akin to ‘Snarks’ − imaginary constructs with no objective existence. This presentation focuses on structural and geophysical evidence against Archaean subduction. New seismic data across the NW Yilgarn Craton in Western Australia shows no evidence for accretion of the Narryer ‘Terrane’, as previously proposed. In the central Yilgarn Craton, Archaean folds and shallowly dipping structures on seismic profiles, initially interpreted as evidence for regional thrusting and terrane accretion, resemble structures in centrifuge models developed in extension. Seismic tomography shows greenstone belts such as the Abitibi developed during extension and rifting of an older craton caused by mantle plume impingement, with no evidence for fossil subduction zones. Features on reflection seismic reflection profiles taken as evidence for ‘fossil’ subduction zones indicative of bulk shortening are interpreted instead as thrusts developed in the upper mantle (cf. numerical models of Gray and Pysklywec, 2010). Indentation of mantle wedges may aid extrusive channel flow, resulting in juxtaposition of Archaean terrains of different metamorphic grade and development of dome and keel structures in granite-greenstone belts.

In our cratonic mobilism model, once a proto-craton develops a buoyant high-viscosity keel, it would become subject to pressure from mantle currents and would drift. Immature cratons or oceanic plateaux would not have a deep keel and so would be static. We consider that Archaean cratons are not immobile nucleii along whose margins ‘mobile belts’ form by subduction-zone accretion, but that Archaean cratons were the active tectonic agents, accreting basaltic plateaux and other proto-cratons as they migrated across the planetary surface. Oblique-slip shear zones develop in the interior, reactivating rift structures that controlled initial greenstone formation, or form in oceanic plateaux ahead of older, indenting mobile cratons.

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# Fossil Mantle Rift Controls on Deformation and Mineralization in the Quebec Abitibi

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In the Abitibi Subprovince of the Superior Province in Quebec, extrusive sequences were formed in a volcanic plateau-like setting during plume-related rifting of older cratonic lithosphere at ca. 2.78-2.75 Ga. Mantle plume activity led to focussed thermal erosion, destruction and assimilation of ancient lithosphere, and formation of isotopically juvenile crust. 3D images of S-wave seismic tomographic data illustrate that the Abitibi Subprovince overlies a symmetrical rift in the sub-crustal lithospheric mantle (SCLM) of older Archaean lithosphere (N Superior Province - Minnesota River Valley domain). Enhanced aeromagnetic images of the central-northern Abitibi illustrate penetrative E-W dextral ductile shearing preceded formation of discrete, ductile to brittle-ductile, conjugate transcurrent and E-W reverse (± dextral) shear zones implying ca. N-S bulk shortening. Offset and ductile deflection of dense, mafic crust along regional transcurrent shear zones in the Abitibi Subprovince and its continuation in the Grenville Province parautochthon is apparent on short wavelength Bouguer gravity. An Archaean sinistral, NE-striking shear zone (the proto-Grenville shear zone) is identified along the SE margin of the Abitibi and Opatica subprovinces.

The displacement history and geometry of reverse and strike-slip shear zones is similar to that of structures developed during progressive lateral escape and indentation. Southward migration of the old cratonic nucleus (N Superior Craton/Hudsons Bay terrane) in response to mantle flow acting upon its deep lithospheric keel, and not subduction-related processes, led to progressive southward accretion of crustal fragments and oceanic plateaux-like segments like the Abitibi, with inversion of rift-related structures. Major epigenetic gold deposits are located above rift-bounding faults in the SCLM, suggesting that early rift structures localized deformation and hydrothermal fluid flow in greenstone sequences during ca. 2.7 Ga N-S shortening. The 1.1 Ga Desmaraisville and 0.55 Ga Otish kimberlite clusters also coincide with interpreted SCLM rift/necking features, where they are intersected by younger, NNW-striking faults. Our observations highlight the important role of ancient mantle structures on localizing deformation, hydrothermal fluid flow, emplacement of igneous bodies, and mineralization in the overlying crust.

Research was funded by Laurentian Goldfields, NSERC, Richmond Minerals, Fort Chimo Minerals, and DIVEX. Tomographic data were kindly made available by S. Godey, and the detailed aeromagnetic grid (subsequently enhanced) was provided by P. Keating (NRCan).

## Lidar Assisted Mapping and Deformation History of Crowsnest Pass, Alberta

**Sharlene Hartman and John W. F. Waldron**

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The Crowsnest Pass area, located in southern Alberta, is part of the foothills of the Cordillera Orogen. Detailed geological mapping revealed the location of map-scale structures in the Crowsnest Pass area. The use of LiDAR data increases the accuracy of geological mapping. Bare-earth-filtered digital elevation models (DEM) constructed from LiDAR data, and displayed in shaded relief images, show subtle topographic features. LiDAR-derived maps taken into the field helped to interpret inaccessible or hazardous areas. Using several “hill shade” maps, utilising different azimuths and sun angles, lineaments are manually traced. The lineaments, with field data, help with interpreting the location of geologic structures. The resulting geological map shows a number of folds that have close spatial relationships to faults. Some of these folds resemble standard fault-bend and fault-propagation folds. Many kinematic models have been proposed to describe these types of folds, each with different predicted distributions of strain and layer thickness. Several methods of strain analysis, including Fry plots and calcite strain gauge methods, have been used on the backlimbs, hinges and forelimbs to help to determine fold kinematics. In addition, the accurate geological map and cross sections reveal changes in thickness across folds. These methods are used to test the kinematic models for folds in the area. These results will be of relevance to thrust-fold relationships in other areas within the Cordillera.

# Geometry and Differential Emplacement of Duplexes in the Joly – St. Flavien Gas Storage Area, Southern Quebec Appalachians: Implications for the Reservoir Lateral Continuity

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The one- and two-levels hinterland-dipping duplexes are recognized in the parautochthonous domain at the structural front of the Quebec Appalachians in the Joly – St. Flavien area. Integration of well log analysis of 26 wells and structural interpretation of 2D (48.3 km) and 3D seismic (37.4 km2) surveys is used to reconstruct geometry and emplacement history of the duplexes. The emplacement of upper slices of the Joly duplexes was followed by the underplating of lower slices and the St. Flavien duplex reflecting hinterland to foreland sequence of thrusting. The shortening-parallel displacement is 17.2 km and 13 km for the upper and lower slices of the Joly duplex, respectively, and 11 km for the St. Flavien duplex. The long axis orientation of the duplexes in the Joly and St. Flavien areas differs at 13° that is likely related to clockwise vertical-axis rotation. The differential forward transport of the Joly and the St. Flavien duplexes was accommodated by the emplacement of minor tectonic slices in the transfer zone. Within the same structural level, tectonic slices were underplated progressively from the SW to the NE producing regular 1 km-scale slice-edge overlapping. The detachment level for the duplexes of the study area is located in the upper sandstone unit of the Theresa Formation that is likely resulted from the rheological contrast between sandstone and carbonate sequences. The SW-NE normal faults with high vertical separation in the Grenvillian basement controlled the localisation of duplex emplacement during the Taconian orogeny. The frontal uplift and the NW-SE lateral ramp in the basement created the external constraints on the geometry of thrust propagation. The sequences of the Beauharnois Formation differ in upper and lower slices and were formed in distinct paleo-locations. The fractured reservoir in Lower Ordovician dolomites of the St. Flavien duplex is correlative to the highly porous oolitic dolomite unit in the lower tectonic slice of the Joly duplex that may represent a comparable structural trap. This study is supported by Ministère du Développement Durable, de l'Environnement, et des Parc du Québec. We are grateful to Shell Canada Limited and Intragaz - Gastem for providing seismic and well log data and granting permission for publication.

# The Understanding of the Structural Geology of the Crowsnest Pass Transect From 1903 Till 2012

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Leech (1903) was in the process of mapping the Blairmore-Frank area when the Frank Slide occurred. He had recognized the Turtle Mountain Anticline from good outcrop on Drum Creek. After the disastrous Frank Slide, McConnell and Brock were instructed by Superintendent of Mines Haanel to proceed to the Crowsnest Pass and to determine the likelihood of a recurrence of similar phenomena. They failed to recognize the anticline on the east face of Turtle Mountain and represented this area as a monocline in their cross section above a steeply dipping thrust fault (McConnell and Brock, 1903).

MacKay (1933) gives a detailed description of the geology of Turtle Mountain through the use of cross sections and a map. His cross sections portray minor thrust faults in the core of the anticline, located above a thrust fault with minor displacement. Allan (1933) followed MacKay's interpretation and plane-tabled all the major fissures on top of Turtle Mountain.

Norris mapped the Blairmore West sheet in detail in 1955, but failed to recognize the Palliser Formation in the core of the Turtle Mountain Anticline. He updated the cross sections on GSC map 1829A (Norris, 1993). Price (1962) compiled the geology of the Fernie map area (which includes the Crowsnest Pass Transect). Price (1967) also documented the fracturing in this area. A balanced cross section by MacKay and Langenberg (2002) based on seismic shows the interaction of the Livingstone Thrust with the lower Burmis Thrust and the duplexes of the resulting Coleman Gas Field.

Cruden and Krahn (1973) updated the cross section through Turtle Mountain and Cruden and Hungr (1986) provided a failure mode for the collapse of the mountain. Langenberg et al. (2007) observed fault-propagation folding and documented pre-, syn- and post-tectonic fracture patterns around Turtle Mountain. Seismic lines presented by Isaac et al. (2008) allow structures in the Turtle Mountain and Livingstone thrust sheets to be tied to the Triangle Zone. Cooley (2007) documented fault-propagation folding and related fractures in the Livingstone range and tied these to the thermal and fluid evolution of the area. Stockmal (2004) describes the Triangle Zone near Lundbreck.

These studies show the evolution of understanding from the steep faults in the early 1900's to the present day large scale over-thrusts and related fracturing.

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## Seismicity and Strain Partitioning Recorded in a Differentially Exhumed Continental Transform Shear Zone: Pofadder Shear Zone, Namibia and South Africa

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The Pofadder Shear Zone (PSZ) is a dextral, NW-SE striking, ~400 km long, continental transform fault in southern Namibia and northern South Africa. We present new geologic data to test the hypotheses that, 1) the PSZ has been differentially exhumed from the base of the seismogenic zone, 2) dilational fault breccias record seismic events, and 3) changes in shear zone width and geometry record strain partitioning as the fault nears its tip. Using the relative abundance of amphibolite facies minerals (hbl-bio-plag <act) in the NW and greenschist facies minerals (act-chl-plag <hbl <bio) the SE, we estimate that the PSZ was rotated by ~5º during exhumation about a near horizontal axis. Quartz plastic, feldspar semi-brittle deformation fabrics recorded throughout the PSZ give rise to a well-developed foliation and S-C style mylonitic fabric commonly observed in mid-crustal shear zones. Foliation surfaces contain ridge-in-groove style stretching lineations and lesser brittle slicken lines. The absence of cataclasite or fault gouge precludes the possibility of continued deformation during exhumation. Right stepping dilational fault breccias cut the mylonitic foliation at low angles and contain poorly sorted, monolithologic, angular quartz-rich mylonite and ultramylonite clasts. Through geologic mapping we demonstrate that the PSZ high strain core decreases in width from 800 m in the NW to 30 m in the SE over a horizontal distance of 5 km. Over this distance the PSZ changes orientation by 30º and splays in to a series of possible horsetail shear zones. The more discrete shear zone splays contain a greater abundance of high strain ultramylonite. 30 km to the SE these splays exhibit widths of 2-3 m and contain abundant dilational breccia pods, which preserve the right stepping relationship. We interpret this change in geometry and strain intensity to be a result of strain partitioning as the fault approaches its tip rather than a later deformation event.

# Mantle Dynamics and the Suprastructure-Infrastructure Association: Global View and an Example from the Thor-Odin Dome in Southeastern British Columbia

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In simplified form, the suprastructure-infrastructure association (SIA) describes a commonly observed downward transition from steeply to shallowly-dipping tectonic fabrics which typically develop in concert with increasing metamorphic grade from greenschist to amphibolite facies conditions. Penetrative subhorizontal flow of the middle to lower crust, a characteristic feature of the SIA, is inconsistent with the classical model of plate tectonics which is based on a system of thick and rigid lithospheric plates deformable only along their boundaries and detached above a weak low viscosity asthenosphere. Instead, this contribution examines the likelihood that the SIA is a worldwide deformational phenomenon of the continental crust, developed over laterally extensive regions, and linked to mantle dynamics.

The SIA can become complicated by repeated cycles of transposition that incorporate rocks from different crustal levels, of different metamorphic grades, and (potentially) of different ages, into composite high strain zones within the high grade infrastructure. In addition, where the infrastructure is currently exposed it is commonly overprinted by steeply-dipping structures characteristic of the suprastructure.

One example of a complex SIA is found in the Thor-Odin dome in southeastern British Columbia. Here the exposed high grade infrastructure preserves evidence for Paleocene to Eocene NE-directed penetrative non-coaxial flow in the form of a well developed transposition foliation ($S_T$), persistent drag fold asymmetry, fold hingeline rotation, mineral and intersection lineation point maxima, and vein emplacement history. Independent lines of evidence suggest that the underlying North American plate was moving in a southwesterly direction during the same time interval, thus providing the link between SIA development at Thor-Odin and the drag of the flowing mantle lithosphere from below.

# Early Thrust Imbrications within the Mcleod Road – Birch Lake Thrust Panel and Implications on Gold Mineralisation at the New Britannia Mine, Snow Lake, Manitoba

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Improved understanding of the volcanic stratigraphy and structural history of the McLeod Road -Birch Lake Thrust (MB) panel suggests that duplication within the MB panel occurred during early thrusting and was followed by the formation of the NorAcme anticline and its axial planar cleavage. The NorAcme anticline was then cut by a second set of thrust faults (e.g. McLeod Road thrust - MRT) that may have formed during the same progressive deformation. The MRT is reactivated as a sinistral shear zone during the formation of a late north-trending cleavage that overprints the thrust and the NorAcme anticline. These structures were last deformed during the formation of the open northeast-trending Threehouse synform. Gold mineralisation at the New Britannia mine is structurally controlled; it spatially occurs in the hanging wall of both the MRT and the Howe Sound Fault and it is consistently found along lithological contacts and secondary fault structures in the hinge area of the NorAcme anticline. The relative timing of these structures is therefore important in determining the emplacement of gold mineralisation. In this talk I will discuss two possible interpretations of the structural evolution and architecture of the panel focussing on the structures hosting gold mineralisation.

# Measuring Planar Features Using CTX Images and Digital Terrain Maps: Searching for Evidence of Faulting in Coprates Chasma, Valles Marineris, Mars

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Valles Marineris is located within the Tharsis province, a volcanic and tectonic bulge that covers ~25% of Mars with elevations ~10 km above datum. It is the largest and longest lived tectonic feature in the solar system. Lithospheric loading led to the deformation of Tharsis and resulted in the development of compressional structures, referred to as Wrinkle ridges, which are aligned concentrically about the Tharsis region. Wrinkle ridges are thought to be a surface expression of blind thrusts or fault-propagation folding. Overprinting the wrinkle ridges are graben sets distributed radially around Tharsis and thought to be a consequence of flexural loading stresses related to lithospheric deformation. Large segments of subsiding crust formed isolated ancestral basins, which were later linked by broadening and elongation through faulting and resulted in the present geometry of Valles Marineris.

The chasmata of Valles Marineris are therefore structurally controlled and trend approximately east west. Valles Marineris extends roughly 4000 km and reaches depths of ~10 km. Wrinkle ridges are perpendicular to Valles Marineris and should be exposed in the eroded walls of Coprates Chasma. The walls of Coprates chasma display spur and gully texture, which is thought to be primarily the result of erosional processes. However a large number of planar features suggest structural control. The ability to measure these planar features allows for identification of possible fault sets. Previous attempts to quantify attitudes of planar feature where limited by the low resolution of available DTMs (50 –150 m/pixel).

This study will serve as a pilot for using new in-house computed CTX (5-15 m/pixel) and HiRISE (1m/pixel) DTMs of the wall rock of Coprates Chasma. The initial purpose is aimed at determining what features can reliably be measured using this high-resolution data. Planar features will be measured using Orion software package, which uses images paired with elevation models to calculate planar attitudes and orientations in 3D.

The primary goal will be to determine to what extent and with what degree of accuracy suspected fault surfaces can be measured. Once planar structural features can unequivocally be identified, the data will be correlated with the known structural history of Valles Marineris. One complicating factor will be that wrinkle ridges are low angle thrust-faults and it may be difficult to differentiate them from purely erosional features.

# Structural Setting of Shear-hosted Gold Mineralization in Geraldton Area, Northwestern Ontario—Preliminary Results

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The Beardmore-Geraldton Belt (BGB) is located along the boundary between the Wabigoon and the Quetico subprovinces of the Archean Superior Province. It consists of three metasedimentary units structurally interleaved with three metavolcanic units. The BGB underwent three major deformation events. D1 thrusting produced isoclinal folds that were refolded by regional east-trending F2 folds during D2 N-directed compression. F2 folds were then refolded by Z-shaped F3 folds and D1 thrusts were reactivated as dextral shear zones during regional D3 dextral transpression. The emplacement of gold mineralization in the belt is thought to be associated with D3 transpression. A new project funded through the Targeted Geoscience Initiative 4 Lode Gold project of the Geological Survey of Canada was initiated this past summer to determine the structural, lithological, and tectonic controls on gold mineralization in the belt. Relationships between structures and gold mineralization were mapped at two large stripped outcrops and will be presented in this talk.

The Portal and Fault strippings occur on the south limb of the F2 Hard Rock anticline in Geraldton. The Portal stripping comprises quartz-feldspar porphyry, pebbly sandstone-conglomerate, green mudstone interlayered with iron formation, mafic to ultramafic dikes and wacke with few iron formation bands. A downward-facing F2 fold is the earliest structure observed on the outcrop. It is overprinted by a S3 cleavage and large F3 fold defined by an isoclinally folded porphyry body. Z-shaped F4 folds, dextral shear bands and dextral asymmetrical strain shadows around clasts overprint the F3 fold. These structures formed during a progressive D3 dextral shear event which began with the formation of the F3 and S3 structures. Boudinaged and folded quartz-ankerite veins commonly appear without significant gold value, but a set of quartz veins with stockwork texture emplaced in the feldspar porphyry yielded high gold value and are folded by F3 folds suggesting that the veins and the gold mineralization were emplaced pre- or early-D3.

The Tombill-Bankfield deformation zone is a 1 km wide zone of high-strain that played a key role in the emplacement of the gold mineralization as it hosts most past-producing gold mines in the BGB. A new stripped outcrop exposed a major break, the Tombill-Bankfield Fault, within the deformation zone. Diorite occurs south of the fault and is separated by the fault from pillowed mafic flows and wacke to the north of the fault. Diorite is deformed by a strong differentiated foliation (S2) in diorite which is folded by Z-shaped F3 folds and overprinted by S3. Dextral shear bands are present in narrow well-developed shear zones between weakly deformed domains. The fault is characterized by fault-filling smoky black quartz veins that were emplaced parallel to S2. The veins were then dextrally sheared and brecciated and sulphide mineralization was emplaced along dextral shear bands. Thus, the emplacement of smoky quartz veins is interpreted as either syn-D2 or early-D3 with remobilization of sulphides later during D3.

In summary, mineralization was emplaced early during D3 or even D2 and was remobilized later during D3, suggesting the presence of several mineralization events in the BGB.

# Effects of Basement Highs on Orogen-Parallel Strain Partitioning: A Case Study of the Faizabad Ridge in Northern India Using Centrifuge Analogue Modelling

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North-east trending Precambrian basement highs within the Ganges Plain south of the Himalayan Frontal thrust continue towards, and thus potentially beneath, the east-west Himalayan orogen. We hypothesize that if these ridges interacted with the orogen early in its evolution, this may have led to orogen-parallel strain partitioning, expressed within the metamorphic core as lateral ductile strain variations, in the foreland fold-thrust belt as lateral ramps and/or sediment thickness variations, or even in the present-day along-strike partitioning of seismicity. These potential interactions will be explored through dynamically scaled centrifuge analogue modelling based on previous studies[1,2,3].

The model prototype is based on existing surficial geological data combined with geophysical subsurface geometry of the Faizabad ridge on north-central India, and on the geology of central Nepal to the north. Models will initially involve a simple 3-layer architecture comprising a rigid lowermost crust and sub-crustal lithospheric mantle (≡ Indian plate), a ductile middle crust, and a laminated upper crust representing the Phanerozoic sedimentary sequence deposited on the northern edge of the Indian plate. The models will be constructed with materials similar to those previously used successfully to replicate Himalayan crust[4]. Rheology testing indicates that all materials used yield constant effective viscosities at low strain rates, allowing for dynamic scaling of all forces and properties necessary for centrifuge modelling.

Preliminary testing suggests that steep reverse faults may localize above basement highs, pinching out and partitioning the ductile mid-crustal layer representing the Himalayan metamorphic core. Future models will be imaged by computed tomodensitometry (''CT scanning'') for a complete 3D view of the system, unravelling the kinematic relationship between basement ridges and the Himalayan structures and enabling a better assessment of the cause of orogen-parallel variations. It is anticipated that this study will be pertinent to the understanding of orogenic cross structures in the evolution of other mountain belts, such as the Canadian Cordillera.

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# Strike-Slip Faults and the Mid-Paleozoic Reconfiguration of the Appalachians in Atlantic Canada

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Dextral NE-SW, roughly orogen-parallel strike-slip faults were active in the Late Devonian and Carboniferous, in both the northern and southern Appalachians. In the southern Appalachians, these faults cut through, and offset, structures related to promontories and reentrants in the Laurentian margin. In the Canadian Appalachians, however, the St. Lawrence promontory was not truncated, but instead formed a right-handed stepover, around which dextral strike-slip faults frame the deepest parts of the Maritimes Basin. This enormous sedimentary basin contains over 12 km of sediment, and accounts for nearly one third of the thickness of the crust beneath parts of the Gulf of St. Lawrence. Two main orientations of strike-slip faults are present: NE-SW orogen-parallel faults with major activity early in basin history, and E-W faults including the Cobequid-Chedabucto Fault Zone of Nova Scotia, which experienced major activity in the mid-Carboniferous.

Restoration of plausible amounts of movement on these strike-slip faults is possible using offset basin margins and extreme contrasts in facies. Using conservative estimates of offset, the Belleisle, Kennebecasis, Caledonia, Rockland Brook, Canso, Cabot, and other faults may be restored to possible mid-Devonian configurations. The resulting geometry places ~1 Ga rocks of the Blair River Complex in NW Cape Breton Island close to rocks of equivalent age in the Indian Head Range of Newfoundland, and rearranges contrasting components of Avalonia into two coherent belts. Widely separated, but similar, components of Ganderia in New England and New Brunswick are also juxtaposed in the reconstruction.

Despite the uncertainties inherent in the restoration, it is clear that offset in the Laurentian margin between the Québec reentrant and the St. Lawrence Promontory played a major role in Appalachian tectonism throughout the Paleozoic, and that late Paleozoic strike-slip faults rearranged the configuration of Appalachian terranes produced by the Acadian orogeny. Restoration of the early Paleozoic assembly of the orogen should take these late Paleozoic movements into account. Misleading results may be obtained by attempting to restore early Paleozoic plate configurations based on present-day cross-sections.