CANADIAN TECTONICS GROUP
23rd ANNUAL MEETING

Parry Sound, October 24-26, 2003

Program with Abstracts

Meeting organized by:

Shoufa Lin
University of Waterloo

Field trip led by:

Nick Culshaw
Dalhousie University

Canadian Tectonics Group 23rd Annual Meeting
24-26 October 2003, Resort Tapatoo, Parry Sound

Program

Friday afternoon and evening, October 24

Arrival and registration
Icebreaker
Poster setup

Saturday morning, October 25

7:00-8:00 Breakfast

8:00 Introduction and welcome

Oral Presentation Session I
Chair: Frank Fueten

8:10 *James C. Bradley*, John W.F. Waldron and Amber D. Henry.
Post-Taconian structures in the Humber Arm Allochthon of Western Newfoundland

8:30 *A.G. Brem*, S. Lin and C.R. van Staal
Deformation styles and isotope geochronology in the Cabot Fault Zone in western Newfoundland

8:50 *Ivan Dimitrov* and Paul Williams
Two distinct deformation events in the Silurian-Devonian section exposed between the Nigadoo river mouth and Limestone Point, northeastern New Brunswick

9:10 Paul Wilson
Alleghanian salt tectonics in the Upper Palaeozoic Moncton subbasin, southeast New Brunswick, Canada

9:30 Carlos Roselli and *John W.F. Waldron*.
Carboniferous transpression along the Avalon-Meguma terrane boundary, Minas Basin, Nova Scotia

9:50-10:30 Coffee and Poster

Oral Presentation Session II
Chair: Phil Simony

10:30 *Stefan Kruse* and Paul Williams
Modification and amplification of folds by non-coaxial flow: examples from the Monashee Metamorphic Core Complex.

10:50 *Paul McNeill* and Paul Williams
The Relationship Between Structural Fabrics, Crustal Anatexis and the Formation of Stromatic Migmatites: Observations From the Mt. Thor–Mt. Odin area of BC.

11:10 *C. R. van Staal*, G. Vujovich and W. Davis,
Evolution of structures in continental subduction zones: an example from the Sierra de Pie de Palo, Cuyania terrane, Argentina

11:30 Schwerdtner, W.M.,
On The Structural Analysis Of Major High-Strain Zones

11:50-1:40 Lunch

Saturday afternoon, October 25

Oral Presentation Session III
Chair: Bruno Lafrance

1:40 *F. Leclerc*, N. Goulet, A. Berclaz. and C. Maurice, C.
Tectonostratigraphic and metamorphic evolution of the Qalluviartuuq-Payne greenstone belt, northeastern Superior Province

2:00 *Normand Goulet*, Sandrine Cadéron, François Leclerc and Patrick Houle
Cr-uvarovite garnet in Archean "ophiolite", Abitibi Greenstone Belt: Implications for diamond and Ni-Co mineralisations in the Cummings Complex, Quebec, Canada

2:20 *Sandrine Cadéron*, Normand Goulet, Daniel Lamothe and Walter Trzcienski
Tectonometamorphic interpretation of the northern Superior Province, Quebec

2:40 *Shoufa Lin*
Kinematics of deformation at a synclinal keel in the northwestern Superior Province, Manitoba: Evidence for synchronous vertical and horizontal tectonics

3:00 *Andrew C. Parmenter*, Shoufa Lin and M. Timothy Corkery
Structural evolution of a greenstone belt in the northwestern Superior Province, Canada: Implications for relationship between vertical and horizontal tectonism

3:20-4:00 Coffee and Poster

Oral Presentation Session IV
Chair: Paul Williams

4:00 *Yvette D. Kuiper*, Shoufa Lin, Christian O. Böhm and M. Timothy Corkery
Preliminary structural geology of the Assean Lake and Aiken River deformation zones, Superior Boundary Zone, northern Manitoba.

4:20 *Paula MacKinnon*, Frank Fueten and Robert M. Stesky,
The Determination of Structural Attitudes of Large Scale Layering in Valles Marineris, Mars, using Mars Orbiter Laser Altimeter Data and Mars Orbiter Camera Imagery

4:40 *Michelle Boast* and John Spray,
Evidence of localised thrust faulting beneath the SIC and disruption of the North Range metamorphic aureole at Sudbury: Implications for ore distribution

Posters

Matthew Downey, Shoufa Lin, Christian Böhm and Melissa Bowerman
Structures and Age Relationships in the Gull Rapids area, northern Manitoba: Preliminary investigations

Yvon Lemieux, Robert I. Thompson and Philippe Erdmer
Stratigraphic and structural relations across the Columbia River Fault Zone and the Kootenay Arc, southeastern British Columbia

Paul McNeill and Paul Williams,
Litho-Cumulonimbus Structure: Description, Mechanism of Formation and Geological Significance

G. Serafini and W.M. Schwerdtner
Structure, Emplacement Style And Ductile Deformation Of The Schooner-Norcan Lakes Granite (Snlg), Grenvillian Composite Arc Belt, Southeastern Ontario

Robert M. Stesky
MyFault: A New Windows Application for Analysing Fault Slip Data

5:00-6:00 Structural Geology and Tectonics Division of GAC meeting

6:00 Dinner

Sunday, October 26

7 :00-8 :00 Breakfast
8 :00 leaving for Field trip led by Nick Culshaw

Abstracts

Evidence of localised thrust faulting beneath the SIC and disruption of the North Range metamorphic aureole at Sudbury: Implications for ore distribution

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The North Range footwall rocks of the 1.85 Ga impact melt sheet (known as the Sudbury igneous complex - SIC), have been mapped and sampled at six transects. This has resulted in the identification of a hornfels facies series that constitutes a metamorphic aureole.

A 1.5 km wide thermal overprint is identified within the Levack Gneiss Complex and Cartier Granitoids of the North Range footwall rocks. This comprises anatexites, preserved in the discontinuous Footwall Breccia unit immediately adjacent to the SIC, a pyroxene hornfels facies, a hornblende hornfels facies, and a zone of quartz and plagioclase recrystallisation that equates to the albite - epidote hornfels facies.

Incomplete sections of the metamorphic aureole have been observed in several transects. In some areas the highest grade facies are missing, in other cases the entire metamorphic aureole appears to be absent from the footwall adjacent to the melt sheet. This implies that the aureole has been locally overthrust by the SIC during a post-impact tectonic event, such as the Penokean orogeny (1.9 – 1.7 Ga). Evidence of faulting is seen in the field, but with no reliable marker horizons in the bedrock, a northward shortening can only be inferred from the known regional geology.

Where shortening of the footwall rocks is observed, thrust faulting occurs along the contact between the Main Mass of the SIC (main body of the melt sheet) and the underlying footwall rocks. The majority of Ni-Cu-PGE ore within the Sudbury Structure is known to be located within the first 100 – 200 m of footwall below the Main Mass of the melt sheet. If the highest grade facies of the metamorphic aureole have been overthrust, it is likely that any ore present in the footwall rocks will have also been overthrust. Understanding the tectonometamorphic history of the metamorphic aureole will therefore lead to insights into North Range ore location.

Post-Taconian structures in the Humber Arm Allochthon of Western Newfoundland

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Emplacement of the Humber Arm Allochthon in the Western Newfoundland Applalachians is generally considered to have been initiated during the Middle Ordovician Taconian Orogeny. However, successive later orogenic events affected the Allochthon up to at least the Devonian Acadian Orogeny, as shown by deformation of Devonian rocks at the western deformational front of the Allochthon.

Detailed mapping, structural sections, and thin-section analysis have shown that several generations of structures post-date those related to the Taconian emplacement of the Allochthon. Overprinting relationships are common between structures in the map area. D1 is mainly characterized as the mélange-forming event and is regionally associated with initial emplacement. Bed-parallel S1 cleavage, with rare occurrences of recumbent isoclinal F1 folds, are also present in coherent stratigraphic sections. In the lowest stratigraphic unit of the Allochthon, S1 takes the form of a well developed pressure-solution cleavage. F1 recumbent folds are refolded by F2, although at many locations this is only evidenced by the existence of folds with a downward facing direction. S2 foliation commonly occurs as axial planar, slaty or crenulation cleavage. S2 fabric development occurs within dissolution bands of S1 pressure solution cleavage and shows a clear cross-cutting relationship. Proximal to shear zones, F2 folds are asymmetric, with a sheared limb that transposes bedding and S1 fabrics into parallelism with S2. Strongly curved hinges are observed on these F2 folds. Elsewhere, F2 folds are more symmetrical and are sometimes folded by F3, or later, upright open folds. S1 and S2 surfaces commonly display strong L2 crenulation lineations and weaker L3 and/or L4 lineations, which also occur on S2 slaty cleavage. Shear zones near thrust contacts show multiple normal and reverse sense kinematic indicators, both brittle and ductile. The late structural features suggest that emplacement of the Allochthon occurred in a more complex series of events than simply the Taconian and Acadian Orogenies. Future efforts will be targeted at the dating of micas developed in foliation planes, in an effort to constrain the timing of deformation more tightly.

Deformation styles and isotope geochronology in the Cabot Fault Zone in western Newfoundland

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The Cabot Fault Zone (CFZ) in western Newfoundland is a long-lived structure that separates the Laurentian margin (Humber Zone) from peri-Laurentian terrains (western Dunnage Zone). Our current interpretation of field data and on-going isotope geochronology suggest the following chain of events for the early Appalachian orogeny in western Newfoundland.

In the Dashwoods Subzone, strongly deformed amphibolite facies tectonites have been observed locally along the trace of the CFZ. Deformation is characterized by a gneissic foliation, and asymmetrical folds. The latter are locally sheath folds. The protolith of the tectonites is interpreted to be meta-sedimentary based on the presence of marble and juvenile conglomerate layers. Locally less foliated granodiorite has intruded as sheets parallel to the gneissic foliation, and most likely intruded during deformation. The timing of deformation is Late Ordovician, based on the presence of a 456 Ma syntectonic pegmatite dyke (U-Pb on Zr). The existence of a Taconic dynamothermal event in the CFZ is corroborated by a 461 Ma metamorphic age (U-Pb on Mon) from a meta-granite within the CFZ. This timing of deformation is contemporaneous with the west-directed emplacement of large allochtons onto the Humber Zone of the Newfoundland and Québec Appalachians.

Along the CFZ, rocks of both the Humber Zone and Dashwoods Subzone have been overprinted by a penetrative greenschist facies deformation. The mylonitic foliations are consistently NNE striking and lineations plunge shallowly (S)SW. Kinematic indicators associated with these mylonites show a predominantly normal-dextral movement, suggesting that the Humber Zone moves up and northward with respect to the western Dunnage Zone. Late Silurian (418 – 417 Ma) $^{40}Ar/^{39}Ar$ Hbl and Mus cooling ages from within the CFZ postdate isotopic ages from within the internal Humber Zone (437 – 424 Ma), suggesting that ductile transtensional deformation has largely ceased by the end of the Silurian period.

Brittle faults and cataclasite zones are localized in the Salinic greenschist mylonite zone of the CFZ. Steeply WNW dipping Carboniferous sandstone and conglomerate beds along the Long Range Fault, large brittle normal faults and small-scale strike-slip fractures indicate that high crustal level, (post-) Carboniferous faulting and creation of the Anguille Basin is extensional rather than strike-slip.

Tectonometamorphic interpretation of the northern Superior Province, Quebec

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The present study clarifies the tectonometamorphic evolution of the La Grande, Opatica, Opinaca and Ashuanipi subprovinces wich constitute the southeastern part of the Archean Superior Province.The Opinaca includes bimodal volcanic sequences and paragneiss units containing detrital zircons older than 2700 Ma. All these subprovinces have been affected by a complex polyphased tectonic history. The first episode of ductile deformation, D1, developed a regional foliation (S1) oriented N-S in the northern sector. The F1 folds are isoclinal, plunging to the NE and overturned to the W-NW. A second D2 deformation phase was restricted to the Ashuanipi subprovince where it manifested as isoclinal F2 folds overturned to the S and plunging to the NE. The regional D3 deformation refolded all previous structures into E-W F3 folds overturned to the south and plunging to the E-NE. A late ductile deformation event (D4) developed large amplitude F4 folds oriented N-S.

The metasedimentary xenoliths of the Ashuanipi diatexites underwent two metamorphic periods characterized by orthopyroxene + garnet + biotite + plagioclase + quartz assemblage that reveal peak P-T conditions of 8.8 (1 kbar - 955 +-50/C for M1 (2700 Ma) and 9.8 (1 kbar - 940 +-50/C for M2 (2680 - 2670 Ma), related to D1 and D2 respectively. In the Opinaca metasediments, an early generation of orthopyroxene pre- to syn-D1 defines the first granulitic event, M1, characterized by orthopyroxene + garnet (cordierite + biotite + plagioclase + quartz assemblage that reveal peak P-T conditions of 8.2 ±1 kbar at 900 ±50 /C and 7.4 ±1 kbar at 960 ±50 /C (with cordierite). A syn-D3 orthopyroxene defines another granulitic episode, M3, characterized by orthopyroxene + garnet +biotite + plagioclase + quartz assemblage dated to 2645 Ma, that reveal peak P-T conditions of 8.3±1 kbar at 890 ±50 /C. These metamorphic events represent a continuous tectonothermal evolution that followed a general clockwise P-T path. The Opinaca subprovince therefore represents an Archean basin interpreted as an aborted intracontinental rift related to a mantle plume. Reverse splay along old normal fault zones led to double-vergence thrusting to the north and south creating a "flower structure" in an oblique compressive tectonic regime. These results show a 65 Ma of granulite facies metamorphism producing partial melting of the Opinaca metasediments culminating by the Ashuanipi diatexites intrusion. This cyclic tectonothermal evolution is related to several orogenic episodes.

Two distinct deformation events in the Silurian-Devonian section exposed between the Nigadoo river mouth and Limestone Point, northeastern New Brunswick

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The rocks of the Silurian - Lower Devonian Chaleurs Group are well exposed along the coast between Nigadoo river and Limestone Point. The Chaleurs Group occupies the time span between the Taconian and Acadian unconformities. Three regressive phases separated by two transgressive phases are recorded in these rocks. The regression during the Ludlovian and Pridolian was also significant and marks the Salinic unconformity recognized throughout the northern Appalachians. The studied area hosts six formations in ascending order: Clemville (shelf turbidities), Weir (marine channel conglomerates), La Vielle (calcareous turbidities); Simpsons Field (sandstone); LaPlante (limestone, shale) and Free Grant (shale, siltstone). All rocks are folded by large, upright, open to tight folds (F2) plunging shallowly to northeast and southwest. These folds are cut by regionally developed cleavage. The cleavage fans from limb to limb. For some of the folds the cleavage is transecting for some it is more or less axial planar. In general, the cleavage strikes consistently more northerly than the axial planes of the folds. In the profile between the Nigadoo river mouth and Pointe Rocher sedimentary structures indicate that the folds are upward facing. At Limestone Point small downward facing folds plunge east or west. Veining, interpreted as coeval with this folding, is common. Some of the calcitic veins have been folded with cleavage parallel to the axial planes. Some of the veins mark faults with more than a meter apparent displacement. Near the lighthouse at Petit Rocher a 6m thick horizon containing folds interpreted as slumps is exposed. The horizon includes dismembered, folded bed segments. The strata below and above face in the same direction. It has a detachment at its base and a depositional contact at the top, which are indications for slumping (Elliot and Williams 1988; Bradley and Hanson 1998). Despite the intensity of the deformation there is no evidence of syn-deformational veining, for example at fold hinges on the convex side of competent beds. No axial-plane cleavage related to these folds is observable. The regional cleavage cuts them at high angle. The exposure is in the southern limb of a large F2 anticline, plunging to southwest. These observations clearly indicates that an early deformation event predated the regional F2 folding. This deformation may have created folds (F1) which at present are difficult to distinguish from the Acadian folds (F2). The present state of knowledge does now allow reliable distinguishing between the soft–sediment and the tectonic structures. The overturned stratification at Limestone Point speaks in favor of a process that is likely to be tectonic and of significant scale. The inversion of the stratigraphy in this area is important, because it has not been taken into account during the stratigraphic subdivision of the rocks.

Structures and Age Relationships in the Gull Rapids area, northern Manitoba: Preliminary investigations

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During the summer of 2003, field research and 1:1000 scale lithological and structural mapping was completed in the Gull Rapids area of northern Manitoba. The goal of this work was to obtain an understanding of the structure and age relationships in this part of the Superior Boundary Zone (SBZ). Based on the mapping, we identified an Archean amphibolite facies supracrustal assemblage consisting of amphibolite (metabasalt) and metagreywacke with interlayered banded oxide-, sulphide- and silicate-facies iron formation. The supracrustal assemblage is in structural contact with granodioritic gneisses of currently unknown origin and age. Extensive leucocratic felsic injections occur in both the supracrustal and granodioritic gneissic rocks, and major east-trending Paleoproterozoic mafic dikes cut all the above lithologies.

Preliminary structural investigations revealed at least four generations of structures, G_1 to G_4, with associated folds, foliations, and lineations. An L-tectonite forms in the westernmost part of the map area: we are unsure as to why there is a change from L-S tectonite, seen in most of the map area, to L-tectonite in one particular area. Augen granodioritic gneiss is predominant in a zone that runs parallel to S_1, flanked by zones of layered granodioritic gneiss. Ductile east-trending shear zones affected the supracrustal and intrusive rocks. The shears cut and deform S_1 fabrics but not any F_2 folds, suggesting that shear zones are late- to post-G_1. Also, shear zones are not present in felsic injection phases, which are interpreted to be syn- to late-G_2, consistent with the interpretation that shear zones developed during late G_1 or after G_1, but likely before G_2. G_2 structures are best represented by meso- and macro-scale folding of S_1 in the supracrustal rocks. Locally, an F_2 axial-planar foliation S_2 is developed subparallel to S_1. Boudinaging occurs frequently, and boudin necks are parallel to the regional lineation. In a few localities, pegmatitic injection fills in along G_2 boudin necks, suggesting the injection is syn-G_2. As well, straight-walled pegmatite veins cut S_1-S_2, indicating they are post-G_2. Samples of these pegmatites have been taken for geochronological analysis. G_3 is an open-style F_3 fold that changes S_1-S_2 strike orientations. Paleoproterozoic mafic dikes cut G_1, G_2, and G_3 structures. One of these dikes has been dated at 2050 to 2070 Ma, thus providing a minimum age of deformation for G_1 through G_3. G_4 deformation is expressed by brittle faulting. These faults are generally oriented 110 to 160°, subparallel to the presumed Superior Boundary Zone, and affect all rock types in the map area, including the Proterozoic mafic dikes, suggesting that G_4 is Hudsonian.

Cr-uvarovite garnet in Archean "ophiolite", Abitibi Greenstone Belt: Implications for diamond and Ni-Co mineralisations in the Cummings Complex, Quebec, Canada

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In the Chibougamau area (Abitibi Greenstone Belt), the Roy Group includes volcanic rocks, the gabroïc to anorthositic Lac Doré Complex (2730 Ma), and the Cummings Complex composed of peridotite, pyroxenite and gabbro sills (2716-2714 Ma). The synvolcanic Chibougamau pluton,formed by tonalite and diorite intrusions, is dated to 2718 ±2 Ma. Cr-garnet has been found into a regional-scale ductile shear zone at the base of the Archean ultramafic Roberge sill lower part of the Cummings Complex. The pyroxenite is highly sheared and contains serpentine, chrysotile, talc and Cr-spinel. The uvarovite-rock is essentially composed of diopside (clinoenstatite) with sub-euhedral emerald-green garnet grains. The diopside has an atypical texture forming acicular crystals with a chemical average composition of 53 wt% Sio2 - 26 wt% CaO - 14 wt% MgO - 7 wt% FeO and traces of Cr2O3. The uvarovite garnet has an average chemical composition of 39 wt% SiO2 - 36wt% CaO - 18 wt% Al2O3 - 3 wt% FeO and contains more than 4 wt% Cr2O3. Some anisotropic uvarovite grains contain more than 2.5 wt% H2O and represent Cr-hydrogrossular garnet typical of the South African Jade found in the Bushveld Complex. Pentlandite - gersdorfitte - millerite - cobaltite -chalcopyrite- sphalerite - niccolite - maucherite are associated with the uvarovite garnet. These sulphides and arsenic phases are zoned and give evidences of the Ni - As - S - Co enrichment of the rock by hydrothermal circulation fluids producing listwaenite related to ultramafic alteration. The ,siliceous and the sulphides-arsenic minerals show the same textural and chemical composition evidences than the minerals found in the Orford Nickel mine localized in the Thetford ophiolite in the ordovician Appalachian Belt (southeastern part of Quebec). New structural observations in the Cummings Complex show that at least part of it is allochtonous with a southward vergent thrusting. This Complex, composed of different layered "sills", over 150 km length and 30 km width, could represent the crustal part of an obducted ophiolite similar to the one found in the Orford Nickel mine known for the Ni - Co mineralisations occuring in listwaenites rocks. Uvarovite is also an indicator mineral in diamond deposits (Venezuela, USSR, South Africa). If the Cummings Complex represents an Archean oceanic crust, it could contain diamond on the base of the model developed in Guyana where diamantiferous komatiites related to mantle plume are found near a subduction zone.

Modification and amplification of folds by non-coaxial flow: examples from the Monashee Metamorphic Core Complex

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The development of drag folds and modification of existing folds by progressive non-coaxial flow is a common process in many high grade terranes. A non-coaxial strain history has specific geometric implications for the development of folds at all scales. In particular the process of transposition can be heterogenous. Heterogenous transposition leads to the development of irregular litho-stratigraphy in some domains and a more regular succession in other domains.

Two end member models are presented for fold modification/amplification: active and passive modification. Passive modification assumes that no rheological contrast exists between folding rock units. Geometric consequences of passive amplification are relatively simple. Active modification, where mechanical anisotropy exists within a deforming package, has less predictable implications for final fold geometry and transposition due to inherent heterogenous and non-steady flow in such a system. Active systems or mixed systems are probably most common in nature.

Geometric consequences discussed are intensity of transposition, fold profile, fold amplitude and orientation of fold axes.

Examples are included from the Monashee Metamorphic Core Complex of British Columbia. The Monashee complex is an amphibolite facies, metamorphic core zone, believed to have undergone a high degree of non-coaxial deformation.

Preliminary structural geology of the Assean Lake and Aiken River deformation zones, Superior Boundary Zone, northern Manitoba

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Preliminary maps and structural data are presented for areas around the Assean Lake and Aiken River deformation zones, along the western side of the Split Lake Block (SLB). The study area is part of the Superior Boundary Zone, which separates the Archean Pikwitonei Granulite Domain (PGD) or Superior Province to the southeast from the Paleoproterozoic Kisseynew Domain or Trans-Hudson Orogen to the northwest. The Split Lake Block is part of the PGD and is bounded by the Assean Lake and Aiken River deformation zones to the north and to the south, respectively.

The Assean Lake deformation zone was initially interpreted as being the Paleoproterozoic contact between the PGD and the Kisseynew Domain. Recent discovery of Mesoarchean (pre-3.0 Ga) crustal material north of the Assean Lake deformation zone, in the Assean Lake Crustal Complex (ALCC), however, indicates that the contact between Archean and Paleoproterozoic rocks lies further to the northwest. The Assean Lake deformation zone may be an older (Archean?) suture zone between the SLB and the ALCC.

Metamorphism reached granulite facies in the SLB and amphibolite facies in the ALCC. Metamorphism in the PGD reached granulite facies, except for the northern part where only amphibolite-facies conditions were recognized. All three domains plus the Assean Lake and Aiken River deformation zones experienced retrograde greenschist-facies conditions.

The Assean Lake deformation zone records at least one generation of tight to isoclinal folding, including south-side-up sheath folding. Shear movement was south-side-up and dextral. The Aiken River deformation zone displays two generations of tight to isoclinal folding, followed by close to open east-trending folding and subsequent open north-trending folding. Shear movement was north-side-up and dextral.

Dextral, south-side-up shear on the Assean Lake deformation zone and dextral, north-side-up movement on the Aiken River deformation zone may have caused uplift of the SLB. Uplift would result in exposure of deeper structural levels, and therefore exposure of rocks with higher metamorphic grades, in the SLB rather than in the ALCC and northern PGD. This is consistent with exposure of rocks that underwent granulite-facies metamorphism in the SLB and of amphibolite-facies rocks in the ALCC and PGD.

Tectonostratigraphic and metamorphic evolution of the Qalluviartuuq-Payne greenstone belt, northeastern Superior Province

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The Archean Qalluviartuuq-Payne volcano-sedimentary belt (<30 km x 150 km), in the northeastern Superior Province, trends NNW-SSE and is surrounded by tonalite-trondjhemite-granodiorite/granite-type and enderbite-opdalite-charnockite-type plutonic rocks. Volcanic rocks packages are composed of ultramafic rocks, anorthosite-gabbro-diorite intrusive bodies, mafic to felsic lavas and volcaniclastic rocks, which grade into oxide-, sulphide-, silicate-facies banded iron formations (< 10 m thick) and paragneiss. Stratigraphic relationships have been established from well-preserved primary structures such as pillow lavas, graded or cross-beddings, flow channels and polygenic conglomerates. The oldest (ca 2,8 Ga) stratigraphic units dominate the northern part of the belt and are syn-kinematically intruded by coeval tonalite-trondhjemite (TT). The southern part of the belt is dominantly intruded by younger (<2,73 Ga) granodiorite-granite (GG) or enderbite-opdalite-charnockite (EOC). Our data suggest a polyphase structural evolution, where the first episode of deformation (D_1), contemporaneous with TT-type magmatism, volcanism and sedimentation, involves N-S compression which led to the creation of E-W to WNW-ESE planar fabrics (S_1 schistosity and F_1 folds) and moderately to strongly plunging linear fabrics (L_1). The second episode of deformation (D_2), contemporaneous with GG-type or EOC-type magmatism, is characterized by a regional S_2 schistosity that affects S_1, F_1 and L_1 fabrics. Regional folds (F_2) have axial planes parallel to S_2 and strike N-S to NNW-SSE. Superposition of D_1 and D_2 deformation episodes produced fold interference patterns between dome-and-basin and crescent types. A third episode of deformation (D_3) appears to be associated with the formation of NNW-SSE to NW-SE-trending oblique shear zones that extend for several kilometers along strike. Volcano-sedimentary units adjacent to TTGG-type intrusions are generally metamorphosed at middle to upper amphibolite facies (3.5-8.1±1 kbars, 555-790± 50°C), whereas those adjacent to high-temperature EOC-type intrusions are metamorphosed at the granulite facies, suggesting a close relationship between metamorphism grade and intrusion type. However, greenschist-facies mineral assemblages are preserved away from intrusions, in thicker volcano-sedimentary package rocks.

Stratigraphic and structural relations across the Columbia River Fault Zone and the Kootenay Arc, southeastern British Columbia

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The Columbia River Fault Zone, southeastern British Columbia, has been interpreted as an Eocene crustal-scale structure with up to 30 kilometres of east-side down displacement. Along much of its length, it is generally defined by a shallow-dipping, thick mylonite zone. It is one of a family of extension faults mapped in the southeastern Cordillera and interpreted to have accommodated crustal extension during the early Tertiary. Recent field investigation in southeastern British Columbia, however, has revealed the occurrence of a Middle to Upper Paleozoic stratigraphic succession forming a semi-continuous belt from west of Vernon to east of Upper Arrow Lake, i.e. from previously interpreted accreted terranes to the outer miogeocline. This belt comprises at its base a distinctive Devonian calcareous quartzite marker unit that can be mapped across Upper Arrow Lake. Field relationships along the Columbia River Fault Zone do not support the presence of a shallow-dipping, large displacement structure, but rather suggest the existence of multiple, moderately- to steeply-dipping brittle fault zones with limited displacement. The Paleozoic stratigraphic succession that can be mapped both in the footwall and hanging wall of the Columbia River Fault Zone, however, appears to be lithologically and depositionally distinct from the succession occuring east of Upper Arrow Lake, that have been included in the Kootenay Arc (i.e., Lardeau and Milford groups). The transition between the two successions could be a basinal hinge, the locus of depositional interfingering, or a fault of syndepositional or post-depositional origin. Its nature remains elusive and is the target of ongoing investigation.

Kinematics of deformation at a synclinal keel in the northwestern Superior Province, Manitoba: Evidence for synchronous vertical and horizontal tectonics

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The northeast-trending Carrot River greenstone belt in the northwestern Superior Province in Manitoba is >50 km long and mostly <2 km wide, and is bounded on both sides by granitoid plutons. In the northeastern half of the belt with which the present study is concerned, the belt consists of ultramafic, mafic and intermediate volcanic rocks (komatiite, tholeiitic basalt, andecite and dacite), subordinate pyroclastic rocks and clastic sedimentary rocks, and ultramafic and mafic intrusive rocks (peridotite and gabbro). Observed younging direction reversal indicates that the greenstone belt represents a narrow synclinal structure, i.e. a synclinal “keel” between two granitoid “domes”.

Deformation in the belt varies from very intense to very weak. In general, supracrutal rocks are much more deformed than intrusive (especially mafic and ultramafic) rocks. Deformation is localized in a northeast-trending zone ~300 to 1000 m wide (the high-strain zone) that runs along the entire northeastern part of the belt. In the high-strain zone, both foliation and lineation are very well developed. The foliation is subparallel to the high-strain zone boundary and is subvertical. The lineation has variable orientations. Folds in the high-strain zone are noncylindrical, and locally sheath folds are observed. An important observation is that the high-strain zone can be divided into two parallel and well-defined subzones with distinct kinematics. In the northwestern subzone, the lineation plunges moderately to steeply to the west, and the folds are southeast-vergent. Well-developed shear sense indicators indicate northwest-over-southeast dip-slip movement with dextral strike-slip component. In contrast, in the southeastern subzone, the lineation plunges moderately to steeply to the east, and the folds are northwest-vergent. Shear sense indicators indicate southeast-over-northwest dip-slip movement, also with dextral strike-slip component. The dip-slip movement components show that greenstone in the synclinal keel moved down relative to the plutonic domes on both sides. Such a kinematics is consistent with a diapiric origin (“vertical tectonics”) for the “dome-and-keel” structure, but not consistent with a buckling mechanism (“horizontal tectonics”) for the formation of the structure. On the other hand, the dextral strike-slip movement can only be explained by horizontal tectonics, especially considering that it is consistent on a regional scale. The data thus shows that vertical and horizontal tectonics were synchronous in this part of the Superior Province. It is possible that there existed a feedback relation between the two.

The Determination of Structural Attitudes of Large Scale Layering in Valles Marineris, Mars, using Mars Orbiter Laser Altimeter Data and Mars Orbiter Camera Imagery

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Valles Marineris is a 4000 km long, 700 km wide and 7 km deep canyon on the flank of the Tharsis Ridge uplift on Mars and exposes strata along its walls. It is interpreted as an extensional feature and has been referred to as a planetary rift. The amount of horizontal extension inferred within the central graben varies systematically, 5-10 km near the ends and 20-30 km within the central graben. Recent work on the fault-population statistics for the Valles Marineris indicates that structure of the region is complex, but consistent with a mixture of faults and grabens of different aspect ratios. While Valles Marineris has been the site of extensive structural and other studies, no direct measurements of the layer attitudes, representing the most basic structural feature, have been made.

We combined Mars Orbiter Laser Altimiter (MOLA) elevation data with Mars Orbiter Camera (MOC) images using our Orion structural analysis software to compute the attitude of the large scale layering. Large scale features of interest are initially identified in MOC wide angle images (250 m/pixel). Following the positive identification of these features as compositional layers within MOC narrow angle images (< 10 m/pixel), the same layer is located within multiple MOC wide angle images. Each MOC wide angle image is then individually registered to the MOLA 1/128° x 1/128° topographic grid file (463 m/pixel) and the orientation of the layer is measured using Orion. Samples are manually selected along the exposed layer trace, giving the horizontal and vertical coordinates of points on the layer. Orion then computes the best-fit plane through these points and provides various fitting statistics to allow the quality of fit to be judged. Sample points can be manually adjusted, within the constraints of the visible image, to give the best determination. Individual layers can be followed for trace length in excess of 100km, with multiple measurements possible along the length.

Initial results are very encouraging. The orientation of a layer measured in multiple images is very consistent, indicating that the measurements are not too sensitive to the manual process of aligning the images to the digital elevation grid. In the eastern part of Valles Marineris layers that are part of the canyon wall dip gently (< 10º) into the canyon. Layering within a block that has faulted off the canyon wall has an outward dip, consistent with rotation produced by listric normal faulting. While this study is still in the early stages it is clear that it has the potential to provide much needed data on the basic structure of Valles Marineris. This data will enable a better understanding of the development of this large Martian feature and therefore of the evolution of the planet Mars as a whole.

The Relationship Between Structural Fabrics, Crustal Anatexis and the Formation of Stromatic Migmatites: Observations From the Mt. Thor–Mt. Odin area of BC

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The formation of a granitic melt through crustal anatexis in high-grade gneiss is a common phenomenon. It has been suggested that macroscopic scale granitic bodies are the product of the coalescence of microscopic and mesoscopic scale melt derived from high-grade gneiss terranes. Few workers, however, have investigated the pathways necessary for the melt to migrate or the relationship of structural fabrics to mobilized melt, which are contiguous. Recent observations in the Monashee Complex of southern, BC, may shed light on this problem.

There are five generations of ductile structures recorded in the area of Mt. Thor–Mt. Odin, in the southern Monashee Complex of BC. The main fabric is a transposition foliation, which is in part a composite of D1 and D2 structures: Isoclinal folds and a well developed differentiated layering. This foliation has a shallowly dipping enveloping surface except where modified by later D3 and D4 structures: open folds and crenulation cleavage. Commonly these structures are overprinted and reactivated by D5 shear on the transposition foliation and the development of a shear band foliation.

Granitic melt is commonly associated with structures. Melt has been observed within the axial planes of D1 and D2 folds and is folded by these folds. Melt is folded by D3 folds, which also have melt in their axial planes. D4 folds fold melt but the relationship to its axial planes is unclear. D5 shear bands contain granitic melt and melt has been observed cross-cutting D2-D3 structures. The overprinting relationships of folding and melt leads to two conclusions: Granitic melt is produced throughout deformation and granitic melt occupies, and in part defines, the main structural fabrics of the gneiss.

Further, if the melt is assumed to be mobile on the scale of the terrane then it appears that the main pathways for the movement of granitic melt is along the structural fabrics such as, axial planar cleavage, transpostion foliation, shear bands, boudin necks and fractures. If granitic melt migrates along structural fabrics and in part defines them, this suggests a fundamental relationship between them.

The epitome of high-grade planer fabrics in anatectic rocks is a stromatic layering or stromatic migmatite. We suggest that stromatic migmatites are commonly produced through the combined, though not necessarily synchronous, effects of crustal melting and deformation. Through progressive deformation and rotation into the shear plane, all anatectic and structural fabrics become parallel. In the case of a leucosome that is still associated with its melanosome, but oblique to the main planar fabric, both become rotated into parallelism. This results in a layering characterized by alternating leucosome and melanosome, though the primary relationship between the two is modified.

Litho-Cumulonimbus Structure: Description, Mechanism of Formation and Geological Significance

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A Litho-Cumulonimbus structure is formed in migmatitic gneiss at the boundary of two lithological layers and is characterized by a granitic melt that has an aspect resembling Cumulonimbus clouds. Mafic and felsic components are well differentiated on a millimeter to centimeter scale within the mafic host, which easily facilitates identification. The structure is at the boundary of two units, occurs periodically, and commonly has a broad base, tapering away from the base of the structure to form a, generally, wedged shaped feature. In other specimens the structure continues across the host layer until both sides of the host layer are bridged by leucosome. In well-developed specimens, this feature produces a new layering that is at a high angle to the original lithological layering.

We consider this structure to be the result of fracturing of a competent layer adjacent to a second, less competent layer, in the presence of a granitic melt. This happens at metamorphic conditions that are consistent with continued anatexis. Locally, shear along the boundary of two units of contrasting competency causes the more competent layer to produce fractures or microfractures into which localized granitic melt flows. Continuing to open the fractures, possibly assisted by the melt, through corrosive action at fracture tips, cause further dilatency and further differentiation of melt and restite. This process may occur to varying degrees at different places along the boundary but continues as long as anatectic reactions produce melt and dilatent sites are propogated. The process is arrested when either of these requirements is not met or changes in the deformation path results in the deformation and destruction of the structures.

Litho-cumulonimbus structure and the process of its formation are important to structural work in migmatitic rocks: It is a structure that indicates crustal anatexis, it postdates the ductile fabrics developed in the host gneiss; a new foliation is formed that is at a high angle to the lithological layering; it indicates the synchronous processes of fracturing and melt migration.

Structural evolution of a greenstone belt in the northwestern Superior Province, Canada: Implications for relationship between vertical and horizontal tectonism

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Classic tectonic models for the Archean invoke vertical body forces to explain the structural evolution of greenstone belts. These models highlight the importance of gravitational instabilities, inherent between dense volcanic sequences and underlying lighter sialic material, in driving dominantly vertical displacements. Contemporary models, based on modern plate tectonic concepts commonly replace this vertical tectonic theory in favour of a system dominated by horizontal boundary forces. The fundamental change in reasoning is due largely to the recognition that many Archean Cratons exhibit a geometry dominated by sublinear structural trends and/or a systematic variation between metavolcanic, metasedimentary, and granitoid terranes.

Structures in the Pipestone Lake area of the Cross Lake greenstone belt record evidence of both vertical and horizontal tectonism produced during four generations of ductile deformation (G1-G4). G1 (>ca. 2760 Ma) is enigmatic due to poor preservation. This study is mainly concerned with G2-G4 (<ca. 2704 Ma). G2 initiated upright-folding and the development of a penetrative foliation at the granite-greenstone contacts. G3 activated major shear zones, under amphibolite-grade metamorphic conditions, to produce a greenstone-belt scale, east-southeast-trending, dextral transpressional, high strain zone. G3 also produced subordinate northeast-trending sinistral shear structures. Kinematics suggest pluton-up movement relative to the supracrustal rocks across the map area. G4 re-activated portions of the G3 shear zones along greenschist-grade (retrograde) deformation zones, characterized by abundant chlorite and talc alteration. Kinematics suggest that oblique, pluton-up, dextral transcurrent movement dominated during G4. Similarity between G3 and G4 kinematics indicate that dextral transpression and peak metamorphic conditions during G3 were continuous with retrograde metamorphic conditions during G4.

Fabric and overprinting relationships suggest that vertical and horizontal tectonics were more or less synchronous and that there was a transition from dominantly vertical tectonism to dominantly horizontal tectonism throughout the G2-G4 interval. This study emphasized that vertical and horizontal tectonism have independent driving forces and do not have to act exclusively of each other. There may be a feedback relationship between the two systems.

Carboniferous transpression along the Avalon-Meguma terrane boundary, Minas Basin, Nova Scotia

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Devonian to Permian successions in the Appalachians of Atlantic Canada record intense deformation in zones related to transform faults active during the assembly of Pangea.

On the south shore of the Minas Basin, Nova Scotia, Late Paleozoic deformation affects the Mississippian Horton and Windsor Groups, units dominated by lacustrine clastics and evaporites respectively. Structures exposed in cliffs and on wave-cut platforms include reverse and strike-slip faults, and tight folds with variably developed axial-planar cleavage. Faults and folds are associated in outcrop-scale flower structures exposed in both cliff and wave-cut-platform view. Locally, in the areas around Rainy Cove and Walton, overprinting has led to the development of spectacular large-scale downward-facing folds.

Low angle thrust faults and oblique strike-slip faults played a role in emplacing Horton Bluff Formation strata over younger strata of the Windsor Group, as interpreted in intermittent outcrop, and as documented in recent petroleum industry drilling and seismic reflection profiling. However, thrusting and strike-slip motion were followed by diapirism and solution of Windsor evaporates, which have significantly complicated the structure.

Deformation was associated with transpressional motion along the boundary between the Meguma and Avalon terranes of the Appalachians. The structures in this zone represent an excellent opportunity to study the effects of transpression on an evaporite-bearing sedimentary succession.

Structure, emplacement style and ductile deformation of the Schooner-Norcan Lakes Granite (SNLG), Grenvillian Composite Arc Belt, Southeastern Ontario

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The Mazinaw domain and adjacent structural divisions of the Grenvillian Composite Arc Belt (SE Ontario) are characterized by folded, originally tabular (?) bodies of alaskite-granite-granodiorite (Methuen Suite rocks). We are studying one such body in the northeastern Belmont domain: the 10 km long, dominantly foliated, Schooner-Norcan Lakes Granite (SNLG). The metasedimentary envelope and contact-parallel internal foliation of the SNLG are subhorizontally folded, on the km-scale. This suggests that the SNLG is a miniature edition of the folded, 120 km long, Addington Granite. However, the SNLG contains discrete sheets of unstrained alaskite, replete with sub-spherical megacrysts of quartz. Moreover, the envelope of the SNLG is composed mainly of highly strained marble.

Well-foliated, pink granite constitutes the main phase, and makes up the synformal closure of the southwestern SNLG. At Round Schooner Lake, the main phase contains foliation-parallel, discontinuous screens of melanocratic or mesocratic tonalite-granodiorite, which exhibit closely spaced, dark xenoliths at some localities. The dm-scale xenoliths are highly flattened and/or stretched, and may provide a measure of the total strain. Despite considerable ductile deformation, however, the igneous-sheet structure is well preserved within the main phase.

We focused on mapping the structure of the southwestern portion of the SNLG, which is very well exposed at Round Schooner Lake and near the northern part of Fortune Lake. Here, the mineral lineation plunges gently to the northeast, and appears to be parallel to the synformal axis. Sheets of unstrained alaskite vary in thickness from a few decimetres to tens of metres, but their contact traces are approximately parallel to the foliation trajectories in the wall rocks. Similar unstrained sheets/dikes occur in well-foliated host rocks on Long Schooner Lake, and postdate the km-scale folding of the SNLG and its host rocks. The difference in absolute age between the foliated granite and unstrained alaskite is unknown.

On the Structural Analysis of Major High-Strain Zones

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The kinematic analysis of straight or curvilinear high-strain zones (also known as shear belts or ductile shear zones) looms large in modern structural geology. Between 1970 and 1990, many workers decided to treat high-strain zones as tabular features, and to regard m-scale (*minor*) zones as miniatures of 10-1000 km long (*major*) zones. I disagree with both decisions, and believe that typical major zones differ markedly from minor zones with tabular geometry.

Minor high-strain zones abound in compositionally homogeneous rock masses, e.g., undeformed granitoid or gabbroid plutons with effectively isotropic or slightly anisotropic mineral-shape fabrics. Structural analysts have focused special attention on tabular zones within such plutons, and derived *general rules* for finding the structural significance of all high-strain zones. Major high-stain zones, however, are typically non-tabular and commonly occur within large, compositionally heterogeneous masses of lineated schists or gneisses. Basic assumptions underlying the *general rules*, particularly those governing the use of elongation lineations in field-based kinematic studies, are therefore untenable. This affects also the analysis of important quantities such as tangential shear strains, within and without major high-strain zones.

Over a forty-year period, I have visited numerous major high-strain zones in the southern Canadian Shield. Most such zones mark a long-lived lithologic or lithotectonic boundary (LB), and typically contain two groups of repeatedly deformed rocks. The non-tabular Parry Sound Shear Zone is >100 km long and 5 -10 km wide, and contains an important LB: the deformed boundary between rocks of the Shawanaga and Parry Sound domains. In the Hwy. 69 segment of the Parry Sound Shear zone, an elongation lineation created by a large increment of late-Grenvillian deformation is effectively normal to the direction of LB-parallel, incremental shear strain. Contrary to one of the *general rules*, the lineation direction makes a large angle with the shear-strain vector.

MyFault: A New Windows Application for Analysing Fault Slip Data

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MyFault is an easy-to-use program for analyzing fault and slip geometry and performing stress inversion. You can make fully customizable scatter plots, histograms, rose diagrams, Mohr diagrams and stereonets. Choosing which features or variables to plot, both measured and computed, including the results of the stress analysis, you can examine the interrelationships between features, their statistical properties and orientation distribution. All the plot characteristics can be saved as templates to standardize your presentations. You can even direct MyFault to create plots automatically when you load a new data file, a good time- and effort-saver.

The program reads data from a text file and accepts a variety of formats for fault (strike/dip or dip-direction/dip) and slickenside measurements (trend/plunge, trend-only or rake). You can even mix the formats in the same data file. You can weight the fault measurements using your own defined quality factor. The raw data, as well as the available options and current results and stereonet plot, are always available on the screen for easy access. The display options include the ability to show or hide the fault planes (as poles or great circles), the slip directions, the movement planes, the slip linears, the computed principal stresses and their confidence limits, the horizontal stresses and the maximum resolved stress on the fault planes.

The current version of MyFault has four processing modules for stress inversion: a tensor averaging method similar to Spang's; Reches' method using a failure criterion; and two methods (Michael's and Angelier's) that minimize deviations in slip direction. Other method modules will be provided as they become available. In all cases, the confidence limits on the principal stress directions are computed using the bootstrap method (also called "resampling with replacement"). You can choose the confidence level, which changes the number of resamplings and hence the computation time. The bootstrap method makes no assumption about the nature and distribution of the errors. The uncertainty in stress directions can be shown either as a cloud of resampled directions contained within the confidence limits or as a set of contour lines at the chosen confidence level.

Evolution of structures in continental subduction zones: an example from the Sierra de Pie de Palo, Cuyania terrane, Argentina

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The study of the evolution of structures in the subduction channel of continental collision zones is commonly hindered by the overprint of subsequent collision-related magmatism. Orogens involving the accretion of microcontinents, such as the Alps and the Ocloyic of the Cuyania terrane in Argentina, seem to have escaped much of the overprinting generally associated with such events, and hence may be used as a proxy for the early development of continental collision zones. The Ordovician subduction/collision complex preserved in the Sierra de Pie de Palo is an exceptionally well exposed (~ 100%) example, due to its recent exhumation (2 Ma) in response to rapid uplift, which is still continuing at a rate of c. 3 mm/year, and concomitant erosion associated with establishment of the flat slab beneath this part of South America. In addition, convergence on the scale of the complex was virtually perpendicular to the overall strike of the nearby, little tectonised Cuyanian passive margin, hence complications introduced as a result of the development of oblique structures are also minimized.

Structural analysis indicates that the earliest penetrative structures developed in these rocks comprise very strong bedding-parallel foliations in Palaeozoic passive margin metasediments and a strong domainal schistosity, as well as potentially a stretching lineation (however this structure could also have developed later) in the juvenile suprasubduction zone rocks of the Mesoproterozoic Pie de Palo complex that were thrust above them. Metamorphic minerals require that thrusting must have been initiated at high pressure (~ 10-12 kb) and confirm a subduction zone setting. This foliation is not axial planar to the earliest formed recumbent folds and is consistently folded by them. The earliest recumbent isoclines (F_1) are penetrative throughout the rock sequence on all scales and hence unlikely to have formed as drag folds. These folds are co-linear with a well-developed stretching lineation, but no F_1 sheath structures have been identified. This is significant considering that outcrop is virtually 100% with significant vertical relief. F_1 structures and early thrusts have been refolded by large F_2 recumbent to strongly westerly overturned inclined F_2 fold nappes, which are associated with a second generation of thrust-related shear zones. Meso-scale F_2 folds are generally curvilinear, whereas macro-scale sheath folds have been mapped.

We interpret the foliation to have formed mainly in response to shear associated with early low-temperature subduction of the Cuyanian margin. Possibly the rocks were too cold and stiff to develop drag folds during this stage of the shearing. F_1 and F_2 are typically buckle folds, with numerous parasitic folds on the limbs of the nappes. We interpret these folds to have developed originally as upright structures, probably as a result of increased traction forces and the resulting rotation of the local shortening direction into near parallelism with the subduction zone. Continuous subduction-related shear subsequently modified F_1 and F_2 folds into intrafolial, recumbent structures.

Alleghanian salt tectonics in the Upper Palaeozoic Moncton subbasin, southeast New Brunswick, Canada

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The Penobsquis salt structure is situated in the western Moncton subbasin, a substructure of the Upper Palaeozoic Maritimes basin. The structure is composed of Viséan Windsor Group evaporites and is currently being mined for rock salt and potash by PCS (New Brunswick). The presence of evaporite deposits in the Moncton Subbasin has profoundly affected the deformation characteristics of the subbasin: however, the timing and mechanisms of emplacement of the Penobsquis salt structure are incompletely understood despite the economic importance of the evaporite deposits. This study uses new information acquired from mineral exploration boreholes and seismic reflection profiles to constrain the timing, structural geology and deformation mechanisms of the Penobsquis salt structure.

Structure contour maps of the top surface of the evaporite deposits prepared from borehole and seismic data show that the salt structure is an elongate, linear northeast-trending feature that may be divided into two segments. The southwestern segment is a relatively gentle asymmetric salt anticline trending approximately 055º. In the northeast, the salt structure forms a large southeast-verging overturned fold, is associated with a major reverse fault in the salt cover, and trends approximately 070º. This overturned fold is thought to have resulted from the salt overburden moving southeastwards over the salt, creating drag folding. It is speculated that boundary constraints may have prevented this in the southwestern segment of the salt structure, as the salt basin narrows towards the southwest.

The association of the salt structure with major reverse faults in the overlying rocks, the presence of strongly asymmetric southeast-verging folds in the northeast part of the structure, and the probable absence of other initiating mechanisms leads to the conclusion that the Penobsquis salt structure formed during a period of regional contraction. Salt-linked reverse faults cut the Cumberland Group, showing that salt tectonics occurred after Cumberland deposition (i.e. post-Westphalian A). Constraints on the upper age limit of salt movement are lacking, but regional considerations suggest that salt movement occurred during the late Carboniferous or Early Permian, and was related to Alleghanian orogenesis.