CANADIAN TECTONICS GROUP '94

Annual Meeting

October 14th-16th, 1994

Belleville, Ontario

ABSTRACTS

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08.30 Effects Of Phase Continuity On Rheology Of Two-Phase Rocks: A First Model. **Shaocheng Ji and Pinglao Zhao**

08.50 An Analysis Of Hornblende Fabrics. **John Starkey and Ibrahem Qudsi**

09.10 TBA ! **Pierre-Yves Robin**

09.30 The Laramie Anorthosite, Wyoming: An Example Of Submagmatic Recrystallization And Deformation Of Intermediate Plagioclases. **B Lafrance, B E John and J S Scoates**

09.50 **COFFEE**

10.30 Magnetic Anisotropy And Microstructures In Devonian Syntectonic Granites Of The Meguma Terrane, Nova Scotia: Cryptic Fabrics And A Transpressional Strain Gauge **K. Benn.**

10.50 Core Complexes: Lessons From Little Sheared Margins Of The Shuswap Complex. **Phillip Simony.**

11.10 Detachment Versus Décollement Along The West Flank Of The Monashee (Core?) Complex Of The Southeastern Canadian Cordillera. **Dennis Johnston and Paul Williams.**

11.30 Kinematic Histories Of Some Hangingwall Folds In The Rocky Mountain Front Ranges. **Geoff Rait & John M. Dixon**

11.50 Determining The Ages Of Tectonism In Core Gneisses Of Frenchman Cap Dome, Monashee Complex, Canadian Cordillera **James L. Crowley**

12.10 The Use Of Digital Terrain Models For The Visualization Of Structural Geology. **Robert Spark. and Paul Williams**

12.30 **LUNCH**

02.00 Indicators Of Shear Sense On The Kilometre Scale. **W.M. Schwerdtner**

02.20 Tectonometamorphic History Of The Elbow Lake Area, Flin Flon-Snow Lake Granite-Greenstone Belt, Central Manitoba. **Jim Ryan and Paul Williams**

02.40 Structure Of The Squall Lake Area, Flin Flon-Snow Lake Domain-Kisseynew Domain Boundary, Trans-Hudson Orogen, Snow Lake, Manitoba. **Jürgen Kraus and Paul F. Williams**

03.00 Phanerozoic Deformation Of The Precambrian Craton, Manitoba. **C. Elliott**

03.20 **COFFEE**

04.00 A Structural Test For Transpression And Dip Shear At The Interface Between The Western Uchi And The English River Subprovinces. **A. Borowik**

04.20 Evidence Of Reactivated Archean Structures In The Proterozoic Foreland Of The Trans-Hudson Orogen, East Coast Of Hudson Bay, Quebec. **Paul Budkewitsch and Andrew Hynes**

04.40 Geochronology And Deformation History Of The Hanging Wall Structures Of The Annapurna Detachment Fault, Kali Gandaki Valley, Central Nepal: A Proposed Study. **Laurent Godin**

05.00 Alpine Crustal Shear Zones And Pre–Alpine Basement Terranes In The Romanian Carpathians And Apuseni Mountains. **Philippe Erdmer & Dinu Pan**

05.20 Flexure Of Continental Margins And Eclogite Emplacement. Andrew Hynes

05.40 Granulite Mylonitization Within The Minas Fault Zone, Nova Scotia - A Rare Probe Of Deep-Level Terrane Boundary Behaviour. **J C White and Wes Gibbons**

POSTER. PROMONTORY – PROMONTORY COLLISION IN THE CANADIAN APPALACHIANS – LIN, VAN STAAL

POSTERS

Relationships Between Intrusive, Metamorphic And Deformation History In The Winnipeg River Subprovince, NW Ontario **A. R. Cruden, P.-Y. F. Robin, P. Evins, D. L. Ciceri.**

Granites And Deformation In The High Lake Greenstone Belt, NWT. Dehls, **J.F. and Cruden, A.R**

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Lattice Preferred Orientations Of Plagioclase In The Morin Anorthosite **Xiao-ou Zhao, Shaocheng Ji, Jacques Martignole and Changxing Long**

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MAGNETIC ANISOTROPY AND MICROSTRUCTURES IN DEVONIAN SYNTECTONIC GRANITES OF THE MEGUMA TERRANE, NOVA SCOTIA: CRYPTIC FABRICS AND A TRANSPRESSIONAL STRAIN GAUGE

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The anisotropy of magnetic susceptibility (AMS) is used to measure hard-to-see petrofabrics in granites. In conjunction with microstructural study, AMS can provide important constraints on the early structural evolution of plutons. A detailed study was carried out in syntectonic granites from the Meguma Zone, near Canso, Nova Scotia. The AMS in these rocks is dominated by biotite. The granites were emplaced during regional dextral shearing, probably related to movement on the nearby Cobequid-Chedabucto fault system, which marks the terrane boundary between the Meguma Zone and the Avalon Zone to the north. Sampling for AMS analysis was carried out across subtle strain gradients which had been recognized by previous workers, based on field and microstructural studies. All samples were taken from outside of mylonitic shear zones. Granites which have undergone little or no post-full-crystallization strain have no visible fabric in outcrop, while granites whose interstitial quartz is slightly elongate and partially recrystallized show a weak foliation but no measurable lineation. An early, possibly pre-full-crystallization AMS fabric is preserved in the least-deformed granites furthest from the mylonitic zones. The magnetic lineation (KI) is oriented roughly north-south horizontal, and the magnetic foliation (KI-K2 plane) is horizontal. This fabric may be emplacement-related. As the shear zones are approached, this early AMS fabric is progressively overprinted. The change in orientation of the AMS nearer to the shear zones is consistent with dextral shearing. The AMS pattern in the granites provides independent evidence for regional dextral shearing during a period when the granites were still hot (T > 55O°C). These results from natural rocks are compared with results of numerical modelling of AMS fabric evolution during progressive, homogeneous, transpressive strain, in order to constrain the finite strain and strain regime (degree of transpression) recorded in the granites.

A STRUCTURAL TEST FOR TRANSPRESSION AND DIP SHEAR AT THE INTERFACE BETWEEN THE WESTERN UCHI AND THE ENGLISH RIVER SUBPROVINCES

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The Sydney Lake Fault Zone lies at the interface of the Uchi and English River subprovinces. It extends eastward from Lake Winnipeg for 250 km, and eventually joins the Lake St. Joseph fault to the east (Stott & Corfu 1988). SLFZ is 1-2 km wide and composed mostly of diatexites, sedimentary metatexites, and reworked mafic to intermediate volcanics (Stone 1981). Kinematic indicators attest to a dextral sense of displacement (Stone 1981).

Structural mapping by Stone (1981) shows inclined lineations in parts of the Sydney Lake Fault Zone which are incompatible with strike shear. There is also a southerly increase of metamorphic grade across the subprovince boundary from medium grade, low pressure assemblages in the Uchi subprovince to high grade migmatitic rocks in the English River subprovince (Thurston & Breaks 1978). A reexamination of the zone is proposed with two objectives in mind, (1) to determine the early dip-shear history of the boundary, and (2) to compare the strain pattern of the SLFZ with that of a new transpression model (Robin & Cruden 1994). This model assumes ductile transpression with welded zone boundaries, thus producing heterogeneous extrusion that may account for the inclined lineations found in the SLFZ.

References:

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Thurston, P. C., & Breaks, F. W. 1978. Metamorphic and Tectonic Evolution of the Uchi-English River Subprovince; in Metamorphism in the Canadian Shield, Geological Survey of Canada, Paper 78-10,p. 49-62.

EVIDENCE OF REACTIVATED ARCHEAN STRUCTURES IN THE PROTEROZOIC FORELAND OF THE TRANS-HUDSON OROGEN, EAST COAST OF HUDSON BAY, QUEBEC.

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The Nastapoka Arc is a 600 km-long arcuate embayment along the east coast of Hudson Bay and has many features in common with intracratonic basins, such as a large diameter and shallow inward dips of accumulated deposits. Proterozoic arenites, carbonates and flood basalts on-lap over Archean basement gneisses of the Superior Province which are considered part of the autochthonous foreland of the Trans-Hudson Orogen. Excellent coastal exposures of tilted strata offer an unique opportunity to examine the effects of brittle deformation of the cover sequence associated with crustal warping.

A regional view of these brittle structures can be seen from Landsat-TM images. In our study, we examined images derived from bands 3,4, and 5, and found that many large subvertical brittle structures are recognizable as distinct edge-like linear features. Five main directions of linear features are recognized by digital image processing of the satellite data. Many of the identified linear features have been traced from the Archean basement into the overlying cover. Field data reveal these features to represent the expression of subvertical structures, such as: mafic dykes, normal brittle- faults, extensional strike-slip faults, and, zones of enhanced joint development. In addition to the linear character of the traces of dykes, their strong spectral contrast to felsic gneisses in bands 4 and 5 enabled us, in the case of thick dykes, to distinquish them from the traces of faults and joint zones. The most prominent faults strike roughly west, at high angles to the coastline. In the northern part of the Nastapoka Arc, brittle shear-zones exhibit preferred left-lateral displacements, whereas right-lateral displacements are common in the southern part. Integrating field and remotely sensed data, we interpret the orientations of these trans-tensional structures observed in the Proterozoic rocks to be inherited from the underlying gneisses. Their kinematics suggest reactivated during the deformation of the Trans-Hudson Orogen.

DETERMINING THE AGES OF TECTONISM IN CORE GNEISSESOF FRENCHMAN CAP DOME, MONASHEE COMPLEX,CANADIAN CORDILLERA

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The Monashee complex in the hinterland (Omineca belt) of the southern Canadian Cordillera contains the oldest rocks (Early Proterozoic plutons are intrusive into metasedimentary rocks) and deepest structural level exposed in the Cordillera. The complex is a tectonic window beneath the Monashee decollement, a crustal-scale, high-grade thrust fault that is interpreted as correlating with the sole thrust of the Rocky Mountain Foreland belt and transporting the Selkirk allochthon >80 km eastward. Although previous isotopic studies in Frenchman Cap dome, a culmination in the northern Monashee complex, suggested that the most recent significant metamorphism is Early Proterozoic age in the core gneisses and the Cordilleran metamorphism is early Tertiary age in the uppermost level of the unconformably overlying cover gneisses, there remains uncertainty in the ages of (1) intrusion of core plutons, (2) the Early Proterozoic and superposed Cordilleran tectonic events in the core, (3) tectonism throughout the cover, and (4) motion on the Monashee decollement. The objective of my thesis is to refine these ages because they have significant bearing on tectonic reconstruction of the Omineca belt. For example, knowledge of the ages of core plutons allows for comparison with magmatic belts in the Canadian Shield. Also, a better estimate of the timing of Cordilleran tectonism allows for evaluation of tectonic models of the southern Omineca belt.

This talk focuses on how I am attempting to determine the ages of Early Proterozoic (herein referred as "old") and Cordilleran tectonic events in core gneisses of Frenchman Cap dome. U-Pb zircon data are used to date igneous rocks that have multiple relationships to deformation events, and U-Pb monazite, titanite, and rutile data estimate the cooling history. Relationships of a granite that was previously dated as indicating Early Proterozoic intrusion or metamorphism were crucial during initial fieldwork for distinguishing the "old" events from the variably developed Cordilleran overprint; granite intrusion postdated a migmatitic and gneissic fabric that resulted from "old" events and intrusion predated Cordilleran deformation. These relationships only occur in zones where Cordilleran transposition was not complete. Such "windows" into "old" fabrics are common in the well-exposed area in which fieldwork was concentrated. Early Proterozoic U-Pb zircon dates that I obtained from this granite and from an undeformed pegmatite dyke sampled at the deepest structural level that I mapped provide minimum ages on the "old" tectonism. The undeformed pegmatite, along with weak Cordilleran fabric in the nearby Early Proterozoic granite exposures, require that this relatively deep structural level was only mildly affected by the Cordilleran overprint. A maximum age for the "old" tectonism is provided by augen gneiss that contains "old" fabrics. Some monazites in pelitic schist from deep levels of the core yield "old" upper intercept U-Pb dates which I propose approximate the age of the "old" tectonism; deformation and metamorphism were likely coeval because the gneissic fabric is migmatitic. The presence of "old" monazite in these schists indicate that Cordilleran metamorphism was not hot or prolonged enough at this level to reset the "old" U-Pb system. The other monazites in core schist yield concordant early Tertiary U-Pb dates, which I propose approximate the time of peak Cordilleran temperature. Further evidence supporting an early Tertiary age for the Cordilleran tectonism comes from U-Pb zircon data from deformed and undeformed pegmatites.

The most intriguing finding to me thus far is the dramatic deformation partitioning that apparently occurred in the dome during Cordilleran tectonism, as structurally deep core gneisses were mostly unaffected by the severe Cordilleran tectonism, including shearing along the Monashee decollement, that occurred in cover gneisses at just a few km higher in structural level. Continuing U-Pb work will further elucidate this finding.

RELATIONSHIPS BETWEEN INTRUSIVE, METAMORPHIC AND DEFORMATION HISTORY IN THE WINNIPEG RIVER SUBPROVINCE, NW ONTARIO

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The high-grade, metaplutonic Winnipeg River Subprovince (WPR) consists of 3.3 - 2.82 Ga tonalite-, amphibolite- and paragneisses which are intruded by voluminous 2.71 - 2.66 Ga granitic to granitoid plutons. The WPR is in fault contact to the north with the 2.98 - 2.66 Ga, high-grade, metasedimentary English River Subprovince. The WPR is bound to the south by 2.78 - 2.72 Ga metasupracrustals and 2.73 - 2.66 Ga granitoids of the western Wabigoon Subprovince (WBG). Current tectonic models (Davis & Smith 1991; Beakhouse 1991) favour the hypothesis that the WBG collided with and was thrust over the WPR at ca. 2.71 Ga, resulting in the formation of initially horizontal gneissosity, high-grade metamorphic assemblages and anatectic melts. We present preliminary results of field work which test this model.

Metasedimentary and metavolcanic rocks of the WBG show a rapid increase in metamorphic grade and strain intensity over 5 km approaching the southern boundary of the WRP. Strains are of general flattening type as indicated by a lack of mineral lineations, deformed clasts, chocolate-tablet boudinage, and the geometry of shortened and extended pegmatite vein arrays. No shear-sense indicators were found on either side of the boundary and foliations dip steeply to the north. The boundary itself is occupied by a ca 200 m wide pegmatite sheet which, together with many similar but smaller dykes, is synkinematic with the observed flattening event. No evidence for south-over-north thrusting is preserved.

Apparent stratigraphic inversions, interpreted for the cores and mantles of the Twilight and Mystery Domes form the basis for suggesting that a sub-horizontal thrusting or recumbent folding event occurred during emplacement of the WBG over the WPR. The geometry of these "domes" is unusual in that they are asymmetric and show sub-vertical dips on their northern side. Migmatitic paragneisses in the core of the Mystery dome show evidence for an episode of partial melting which was coeval with strong flattening probably caused by the doming event. Again, evidence for shearing is absent.

Deformation within and at the southern boundary of the WPR appears to be largely due to coaxial flattening. Peak metamorphic conditions are of high T - low P type, occurred in the presence of granitic melt phases and were broadly synchronous with deformation. Future work will quantify and clarify these relationships.

GRANITES AND DEFORMATION IN THE HIGH LAKE GREENSTONE BELT, NWT

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The High Lake Greenstone Belt (HLGB) is located within the Archean Slave structural province. Granitoid rocks in and around the HLGB have been studied to determine the relationship between the deformation in the belt and the emplacement of the granitoids. In addition to field measurements of fabrics, approximately 350 oriented samples were collected to determine magnetic fabric using anisotropy of magnetic susceptibility (AMS). The oldest pluton dated in the HLGB is 2605 Ma, while the youngest dated is 2580 Ma. Most of the plutons are biotite and/or hornblende granites, with some subsidiary granodiorites and two-mica granites. Regional gravity data, as well as a gravity profile across the belt, suggest that the batholith on the eastern side is relatively thin. Aeromagnetic data and very large differences in bulk magnetic susceptibilities also suggest marked compositional differences between the granites on either side of the belt.

The 2588 Ma two-mica leucogranitic Ulu Lake pluton is discordant to the structures in its wall rock. It shows very little mesoscopic evidence of solid state deformation except in a few areas and K-feldspar megacrysts define a well-developed shape preferred orientation. The intensity of this fabric appears to decrease towards the edge of the pluton, where the grain size decreases. AMS fabrics in the pluton reflect the preferred orientation of biotite and are in good agreement with magmatic fabrics measured in the field. However, microstructural work has revealed a variably developed solid-state deformation overprint at most locations in the pluton.

AMS fabrics in the center of the pluton are generally prolate to oblate and subvertical, while those near the margins are strongly oblate and more shallowly inclined. The north end of the pluton is characterized by prolate, subhorizontal fabrics. While the AMS foliations in the pluton are locally discordant to the foliations in the wall rock, the general pattern of foliations is similar to that of the main foliation in the belt, implying that the emplacement and deformation were synchronous. However, the discordant nature of the pluton contacts indicates that the emplacement was not the cause of the deformation. Preliminary work on two other plutons suggests that this pattern is repeated throughout the belt, with plutons being emplaced and deformed passively during late regional deformation. John Dehls

PHANEROZOIC DEFORMATION OF THE PRECAMBRIAN CRATON, MANITOBA

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An outlier of strongly deformed Ordovician dolomites in Early Proterozoic gneisses of Northern Manitoba is difficult to interpret in view of current ideas of Phanerozoic evolution in the central craton. Five possibilities exist: 1) The rocks are in their depositional geometry and location; 2) the rocks are in place but have been deformed by karst solution; 3) the rocks were emplaced and deformed by glacial bulldozing; 4) the outlier is an impact structure; 5) the outlier was tectonically emplaced. Despite the commonly held view that this part of the craton has been tectonically static since Precambrian times, the last possibility provides the best explanation for the observed structures. The margins of the outlier are not parallel to bedding and the outlier is up to 120m lower than the projected base of Phanerozoic deposits in Manitoba indicating that the dolomites are not in situ. The exposure is pervasively folded and the presence of a spaced cleavage in vertical bedding is a strong argument against syn-depositional deformation and glacio-tectonics. Uniformly parallel glacial striae indicate that deformation pre-dated the last glaciation. Carbonate solution cannot explain all of the features observed, and karstic weathering on this scale is not reported elsewhere in the western Canadian craton. An impact origin for the outlier is not supported by a circular physiographic feature or signs of shock metamorphism. In short, the geometry of the outlier and its relationship with a regional geophysical lineament suggest an association with strike-slip faulting. This conclusion is significant: post-Ordovician tectonism would be a new thing for this part of the world.

ALPINE CRUSTAL SHEAR ZONES AND PRE–ALPINE BASEMENT TERRANES IN THE ROMANIAN CARPATHIANS AND APUSENI MOUNTAINS

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In the traditional interpretation of metamorphic basement rocks in the Carpathian orogen, three superposed geosynclinal cycles of mid–Proterozoic, Late Proterozoic to Cambrian, and mid– to Late Paleozoic age resulted from the Dalradian, Cadomian– Caledonian, and Variscan orogenies, respectively. Contacts between products of each cycle were inferred to be stratigraphic or metamorphic discontinuities.

Following a reexamination of metamorphic sequences, we consider that some textures previously interpreted as metasedimentary and metavolcanic are pseudodepositional and are in fact polyphase blastomylonitic fabrics. For many epidote– amphibolite and greenschist grade sequences, we consider that the sense of metamorphic reactions is retrograde and that rocks were involved during Alpine tectonism in wide retrograde shear zones that cut continental fragments on both sides of the Tethys suture. In addition, we consider that tectonic syntheses that highlight thrust faulting almost to the exclusion of other processes require revision to accommodate strike–slip displacements.

The Carpathian orocline formed by complex suturing of small continental fragments to the East European (and Moesian) plate. Remnants of continental fragments belong to three pre–Alpine lithotectonic assemblages: a "greenstone–granite" association and two gneissic assemblages. During Alpine collision, crustal fragments were repeatedly fragmented and welded to accommodate heterogeneous strain along the irregular East European plate boundary. Shallow structural levels of Alpine tectonic discontinuities in which the locus of most intense strain migrated over time are now exposed as wide retrograde greenschist grade belts. Repeated, mainly transpressive deformation resulted in early ductile fabrics being overprinted by local brittle shear strain. Igneous intrusion accompanied different phases of tectonic activity. The age of shearing initiation is probably Late Paleozoic, and the configuration of the zones and their Alpine internal structures are consistent with the geometry of the Carpathian arc.

GEOCHRONOLOGY AND DEFORMATION HISTORY OF THE HANGING WALL STRUCTURES OF THE ANNAPURNA DETACHMENT FAULT, KALI GANDAKI VALLEY, CENTRAL NEPAL: A PROPOSED STUDY.

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Located in central Nepal, the Kali Gandaki River transects from south to north three tectonostratigraphic units: 1) the Lesser Himalayan sedimentary sequence composed of Precambrian to Mesozoic low-grade metasediments lying in a nappe sequence, 2) the Greater Himalayan metamorphic sequence composed of highly sheared Precambrian gneisses, and 3) the Tibetan sedimentary sequence comprised of a nearly continuous 11 km thick sedimentary sequence from Early Paleozoic to Early Tertiary representing the continental margin of the Tethys ocean.

Two main tectonic boundaries have been identified in this valley by previous workers; 1) the Main Central Thrust (MCT) which is a Miocene in age, crustal-scale ductile-brittle shear zone that juxtaposes the Greater Himalayan metamorphic sequence southward over the Lesser Himalayan sedimentary sequence, and 2) the Annapurna Detachment Fault which is defined as a ductile-brittle normal fault juxtaposing the Tibetan sedimentary sequence in the hanging wall with the Greater Himalayan metamorphic sequence in the footwall. The Annapurna detachment fault has been correlated with the South Tibetan Detachment System and appears to be coeval with displacement on the MCT. Thus, the inferred relationships between the MCT and the Annapurna detachement fault implies a southward moving, extruding Greater Himalayan metamorphic sequence wedge bounded below by a thrust fault and above by a normal fault .

The existence and the position of the Annapurna detachment fault in the Kali Gandaki valley is still very highly debated. The first objective of this project is to study carefully the boundary between the Greater Himalayan metamorphic sequence and the Tibetan sedimentary sequence. The existence of a major tectonic discontinuity between the Greater Himalayan metamorphic sequence and the Tibetan sedimentary sequence will be tested using 40Ar/39Ar cooling ages and determination of thermobarometric conditions on either side of the boundary.

The north-verging folds lying in the hanging wall of the Annapurna detachment fault are thought to be a consequence of gravitational collapse of the orogen, and some workers relate them with the South Tibetan Detachment System. However, the compatibily between the mechanism of gravity collapse of the orogen and the geometry of the observed folds has not been properly tested with respect to upper crust rheology and corresponding mechanical behavior. Thus, the second objective of this study is to adress the tectonic significance and mechanical compatibility of these northeasterly-verging structures with respect to gravity-driven mechanisms.

FRACTURED GARNETS, METAMORPHIC REACTANTS: ARCHEAN PALEOSEISMIC INDICATORS AND TRANSIENT BRITTLE BEHAVIOUR IN THE PLASTIC REGIME

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The Striding-Athabasca mylonite zone, Canadian Shield, cooled from granulite (850-1000°C, 10+ kbars) to greenschist facies during uplift at ca. 2.6 Ga. Garnet crystals set in the mylonitic matrix contain pervasive, closely spaced fractures aligned normal to the finite extension lineation. The mylonitic matrix shows no trace of the fracture arrays. The fractures have acted as the sites of preferred nucleation and growth of retrograde cordierite-biotite-plagioclase and hornblende-plagioclase assemblages within the garnets (500-700°C, 4-5 kbars). Accordingly, the garnets were fractured at crustal depths where their mylonitic matrix was nominally capable of viscous flow in the plastic regime at geologically reasonable strain rates. However, the preservation of euhedral garnet crystal outlines indicates that the fracture arrays are non-dilational. Therefore, the fracture arrays in the garnets could not have formed during viscous flow in the mylonitic matrix.

A model is presented, in which the fractures formed during transient, geologically instantaneous volumetric strain (dilation), whose symmetry and principal axes were controlled by the elastic anisotropy of the mylonitic matrix. The preservation of such microstructures (fractures and fracture-controlled retrograde reactants) requires that viscous flow was not renewed in the mylonitic matrix around the garnets. We suggest that the microstructure was developed in response to the passage of shock waves radiated from cooling and narrowing, transiently seismic shear zones into their warm, but kinematically inactive, mylonitic wallrocks. These microstructures could therefore serve as indicators of paleoseismic activity in the middle to lower crust.

FLEXURE OF CONTINENTAL MARGINS AND ECLOGITE EMPLACEMENT

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Eclogitic rocks of continental affinity are widely thought to indicate partial subduction of continental material, but their exhumation mechanisms are problematical. Their rapid exhumation may be a direct result of the attempted subduction of continental margins. Such margins are probably rigid, resulting in changes in the flexural profile of the descending slab. We calculated flexural profiles using the 2-D non-linear equation for a thin plate with finite deformations, so that our solutions are applicable at the depths of eclogite formation (up to 100 km). With a fixed dip of the subducting plate at depth, as a region of increased rigidity approaches a progressively increasing downward force must be applied at depth, and the slab subsides at shallower depth. Alternatively, for fixed forces applied at depth to the descending slab the slab tip rises. The extra loads along the slab necessary to maintain constant profile as the flexural transition is subducted are essentially the inverses of the transient normal stresses between the descending slab and the overlying wedge. These stresses are consistently compressional at depth and tensional nearer the surface. They may cause the deeper parts of accretionary wedges to be sucked upward along the descending slab. Eclogitic terrains emplaced by this mechanism should occur low in structural stacks, near continental basement, and should have been emplaced late in the orogenic history, bounded by thrust faults below and normal faults above.

EFFECTS OF PHASE CONTINUITY ON RHEOLOGY OF TWO-PHASE ROCKS: A FIRST MODEL

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Based on continuum mechanics, we have developed a first model for semi-quantitative estimating the effect of phase continuity on flow strength of two phase rocks including partially melted or crystallized rocks. Calculations of the bulk flow strength of composite rocks as functions of the volume fraction, geometrical shape and continuity of the constitutive phases involve in solving numerically two non-linear equations and thus are easy to be performed. The model has been justified by a good agreement between the predicted and measured results on diabase (64% clinopyroxene and 36% plagioclase) in the range of experimental temperatures and strain-rates. It is believed that the present model could provide an approximate estimate for the rheological evolution of magmatic rocks during their life cycle of melting-crystallization-deformation.

ROCK FLOW KINEMATICS AND THE DEVELOPMENT OF STRUCTURES, WITH PARTICULAR REFERENCE TO S/C FABRICS

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Small-scale structures and fabrics such as folds, stretching lineations, S/C fabrics and rotated porphyroclasts develop throughout orogenic histories at all crustal levels. They are direct records of rock flow (Turner & Weiss 1963) and contain important information about the rock deformation history and larger-scale tectonic processes. However, a thorough understanding is still lacking of the links between the paths of rock deformation mechanisms, kinematics and, as the "signatures" of such paths, fabrics and structures, although such an understanding is necessary for proper interpretations of structures and fabrics. This is because current interpretations are based on homogeneous and steady flow and deformation theory or similarly constrained experiments while the rock flow and deformation are demonstrably heterogeneous and non-steady due to the inescapable heterogeneity of rocks (materially, rheologically and geometrically) and the time dependence of imposed geological conditions (Jiang 1994a, b, Jiang & White, *in review*).

Successful structural analysis and regional interpretation requires recognition of the first-order distinction between imposed boundary conditions (e.g. transcurrent, transpression) and the response recorded by rocks characterized by such as sense of non-coaxiality, degree of non-coaxiality. Using the widely-used sense of non-coaxiality indicator or often very loosely "shear-sense indicators", S/C fabrics and rotated porphyroclasts, as examples, we demonstrate how, when geologically realistic non-steadiness is taken into consideration, they can have complicated relations with the host shear zone.

Two foliations are commonly developed in ductile shear zones, S-foliation defined by shape fabrics and related to the accumulation of finite strain, and shear band cleavages (C and C' foliations as termed in the literature). Mechanistically, we note that shear band cleavages have two kinds of origins, kinematical and mechanical. Kinematic origin is solely due to finite strain accumulation and is related to the flow extensional eigenvector which is the end orientation (sink) of all material lines. Mechanical origin is related to the yield surfaces of plastic deformation which are controlled by the orientation of the principal stresses and the existing anisotropy. Subsequent development of shear band cleavages, irrespective of their origin, can be complicated. For example, kinematically-initiated shear bands may serve as sites for strain localization and mechanically initiated shear bands may rotate toward the flow extensional eigenvector. Non-steady flow arisen from either rock heterogeneity or time-dependent boundary movement is often characterized by spinning of the instantaneous stretching axes. Depending on such spinning, sense of non-coaxiality indicators such as S/C fabrics can have various geometric and kinematic relations with respect to the host shear zone boundary.

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DETACHMENT VERSUS DÉCOLLEMENT ALONG THE WEST FLANK OF THE MONASHEE (CORE?) COMPLEX OF THE SOUTHEASTERN CANADIAN CORDILLERA.

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The Monashee Complex is comprised of Early Proterozoic basement "core" gneiss unconformably overlain by Late Proterozoic to early Cambrian platformal "cover" metasediments. The Frenchman Cap and Thor Odin culminations dominate the Monashee Complex to the north and south, respectively. Presently, the Monashee Complex is interpreted as a tectonic window exposed through the Selkirk Allochthon, separated from the allochthonous rocks by the Monashee décollement. The Monashee décollement is a crustal scale shear zone interpreted as correlating with the sole thrust of the Rocky Mountain foreland belt. Along the west flank of the Thor Odin culmination, we see no evidence for a Monashee décollement as presently defined and mapped. Rather we see an approximately 1 km thick, west dipping zone of top-to-the-west meso to megascopic shear bands. The shear bands cut both 52 Ma tourmaline-bearing pegmatite dykes and lampropyre dykes which cut and comingle with the pegmatite dykes. Offset of the dykes along the shear bands are reconciled by movement parallel to a strong east-west mineral lineation. These dykes cut three generations of folds. F_1 cm to km scale isoclinal folds are overprinted by tight symmetrical to northwest verging F_2 folds, producing a transposition foliation. More open F_3 folds are north to northeast verging. A ubiquitous top-to-the-east shear band foliation is associated with the F_3 folds. Boudinage is very common, associated with F_1/F_2, F_3 and the late D_4 shear bands.

Should the Monashee Complex be reconsidered as a core complex? The west dipping zone of shear bands could be a extensional detachment zone that compliments the east dipping Columbia River Fault along the east flank of the Monashee (Core?) Complex.

STRUCTURE OF THE SQUALL LAKE AREA, FLIN FLON-SNOW LAKE DOMAIN-KISSEYNEW DOMAIN BOUNDARY, TRANS-HUDSON OROGEN, SNOW LAKE, MANITOBA

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The Flin Flon-Snow Lake greenstone belt and the Kisseynew belt form two lithotectonic domains in the interior part of the Trans-Hudson orogen, which have been interleaved by complex folding and thrusting in a SW-direction. Both domains contain rock suites of different ages. The Flin Flon-Snow Lake domain and Kisseynew domain consist of volcanic and volcaniclastic rocks of the Amisk Group (1890 Ma) and metasedimentary rocks of the File Lake Formation turbidites and Missi Group arkose (both 1850 Ma), respectively. The study was carried out in the transition zone between the two domains north of Snow Lake, Manitoba, where the boundary is repeated due to polyphase deformation (F_1-F_4). Isoclinal F_1 folds are refolded by the F_2 McLeod Lake synform, which is interpreted as a large scale sheath fold. The McLeod Lake synform has been dismembered along its eastern limb by the McLeod Road thrust in the late stages of F_2 folding. The McLeod Road thrust essentially follows the transposed S_2 cleavage on the eastern limb of the McLeod Lake synform, but locally changes its tectonostratigraphic level along lateral or oblique-lateral ramps. NE-plunging regional F_1-F_2 folds and sheath folds in the McLeod Road thrust zone indicate F_1-F_2 transport to the SW. The Snow Lake and Birch Lake faults, which are broadly parallel to the McLeod Road thrust, are of uncertain relative age but must have formed after F_1 folding. F_1 and F_2 folds, the McLeod Road thrust and the Snow Lake and Birch Lake faults are overprinted by the NNE-trending F_3 Threehouse synform and related minor folds, which are coaxial whith earlier folds. The F_3 Squall Lake antiform on the western limb of the Threehouse synform is a periclinal fold cored by the Squall gneiss dome. The structure is a mantled gneiss dome with a gently to moderately outward-dipping S_2 gneissosity. The F_3 axis plunges shallowly to the N and SW at the northern and southern limits of the dome, respectively. The core is composed of pink gneiss derived from a granitic protolith. The Squall gneiss dome and McLeod Lake synform are overprinted by E-W trending gentle to tight F_4 structures. F_4 is only locally developed in broadly N-S trending strata. It refolds the McLeod Lake synform and the sequence of thrusts and faults. F_1 and F_2, which are separated in time by at least 20 Ma, are interpreted as having formed during SW-directed shearing related to the convergence of the Kisseynew and Flin Flon-Snow Lake domains. F_3 folds are the result of subhorizontal compression or the superposition of a shortening component related to the Superior-Churchill collision along the Thompson Nickel belt during continued SW-shearing. Local F_4 might represent the late stages of the Kisseynew-Flin Flon domain convergence after the termination of the Superior-Churchill collision.

THE LARAMIE ANORTHOSITE, WYOMING: AN EXAMPLE OF SUBMAGMATIC RECRYSTALLIZATION AND DEFORMATION OF INTERMEDIATE PLAGIOCLASES.

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Plagioclase recrystallization microstructures and petrofabrics in the unmetamorphosed, 1.43 Ga Laramie anorthosite complex (LAC), Wyoming, are indicative of deformation at submagmatic temperatures. The LAC consists of a core of porphyroclastic recrystallized massive anorthosite surrounded by a series of layered anorthositic cumulates, which are cut by parallel or slightly discordant zones of recrystallized porphyroclastic anorthosite. Within these zones, both porphyroclastic plagioclase grains (An_{46-53}) and recrystallized plagioclase grains (An_{45-49}) generally have straight extinction, irregular grain boundaries, monomineralic dihedral angles of 120^{o}, and few dislocation substructures. Porphyroclasts are generally elongate and define a relict magmatic foliation. U-stage measurements of [100], poles to (010) and poles to (001) of 231 porphyroclastic and recrystallized plagioclase grains confirm that the rocks retain a magmatic fabric. Poles to (010) define a point maximum perpendicular to the magmatic foliation, [100] and poles to (001) have no preferred orientation within the plane of this foliation.

The microstructures are similar to grain coalescence and grain growth microstructures in a cooling cumulate with the exception that overall grain size reduction rather than grain growth occurred in these recrystallized zones. Grain boundary migration dissected original cumulate grains into several smaller grains, which have identical optical orientation. The large grain size (.5 to 1 mm) of the recrystallized grains suggest that recrystallization of the anorthositic rocks by grain boundary migration took place at submagmatic temperatures. Because grain size reduction is only possible if plastic deformation rather than interfacial surface energy controls grain boundary migration, the recrystallized zones are likely products of deformation at submagmatic temperatures. Deformation temperatures are constrained by cross-cutting, subsolidus (ª1000^{o}C) shear zones characterized by recrystallized olivine and orthopyroxene, supporting this contention.

KINEMATIC HISTORIES OF SOME HANGINGWALL FOLDS IN THE ROCKY MOUNTAIN FRONT RANGES

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Formation of the tight, angular, thrust-carried folds which abound in the Front Ranges and beneath the Foothills of the Rocky Mountains (and in many other foreland thrust belts) is commonly explained by invoking the `fault-propagation fold' kinematic model, in which the anticline forms as a pair of kink bands and grows in amplitude (by kink-hinge migration) but does not tighten as the fault propagates. However, in centrifuge experiments, fold/thrust complexes form as buckles which tighten (limb rotation) before and during thrusting of their forelimbs. Hence, we have attempted to determine the kinematic histories of some Rocky Mountain hangingwall folds by analysing their minor structures.

The Mississippian Carbonates in the close to tight, fault-carried chevron anticline forming Mount Crum (near Tumbler Ridge, B.C.) display a suite of minor structures whose age relations can be determined because most of the fractures (the dominant structural elements) are calcite- filled. Early structures indicating hinge-normal shortening along bedding are cut by structures indicating flexural flow, which in turn are cut by structures indicating hinge-normal extension. We interpret this sequence as resulting from progressive limb rotation in an environment of transport-parallel compression and sub-vertical extension. Two other folds examined in equivalent rocks in Alberta have fabrics dominated by unfilled fractures whose overprinting relations could not be determined. However, fracture sets were otherwise similar in character, distribution and orientations to the ones at Mount Crum, and likely reflect similar folding histories.

TECTONOMETAMORPHIC HISTORY OF THE ELBOW LAKE AREA, FLIN FLON-SNOW LAKE GRANITE-GREENSTONE BELT, CENTRAL MANITOBA

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Elbow Lake is situated in the centre of the polydeformed Paleoproterozoic Flin Flon-Snow Lake granite-greenstone belt, an integral part of the Trans-Hudson Orogen. The Elbow Lake area hosts a variety of *Amisk Group* metavolcanic and related intrusive rocks (1910-1880 Ma), and large granitoid plutons (1871-1845 Ma). The map area is transected by the NNE-trending *Elbow Lake shear zone* (ELSZ) and the NNW-trending *Claw Bay shear zone* (CBSZ), which coalesce in the eastern-central portion of the lake. The regional metamorphic grade increases from sub- to middle greenschist facies on the west side of the ELSZ, to upper greenschist-lower amphibolite on the east side.

A relatively fine-grained unit of the Long Bay conglomerate, exposed on the west side of Elbow Lake, records a complex deformational history within the wall rocks to the ELSZ. The structures developed include: a fabric defined by flattened clasts (S_1), a shear zone fabric (S_4), and three generations of folds (F_2, F_3 and F_5). S_2 forms a pervasive regional foliation on both sides of the shear zone. This fabric is most intense around the margins of and within the older set of granitoid plutons (1872 - 1864 Ma). It can be demonstrated that this fabric is associated with post-emplacement tectonic deformation, as opposed to forcible emplacement or ballooning of the plutons. S_2 on the eastern side of Elbow Lake appears to overprint early hornblende porphyroblasts (M_1) locally. M_1 appears to be a localized metamorphic episode, possibly induced by the voluminous plutonism which occurred between 1870 - 1860 Ma. S_2 is overprinted by randomly oriented hornblende associated with the peak of regional metamorphism (M_2), generally thought to have occurred between 1815 and 1805 Ma.

The ELSZ fabric is a combination of S_3 and S_5 foliations. Dextral movement along the CBSZ (S_4) overprints the early ELSZ foliation (S_3), and is in turn overprinted by a reactivation of the ELSZ in sinistral transpression (S_5), accounting for the large proportion of sinistral kinematic indicators within the zone. S_5 is vertical and has an associated vertical stretching lineation. The ELSZ reaches a maximum width of only 2 km, but a locally intense S_5 fabric persists deep into the wall rocks, forming a 9 km wide zone. S_5 demonstrably developed during retrograde metamorphic conditions, but occurs as a peculiar differentiated crenulation cleavage locally. F_6 folds developed late in the metamorphic history.

The ELSZ appears to have a pre-1869 Ma history, and records at least 70 Ma of deformation during prograde and retrograde regional metamorphic conditions. Late ductile-brittle and brittle structures record continued deformation in the ductile-brittle and brittle regimes, possibly during exhumation of the belt.

METAMORPHIC PETROLOGY AND STRATIGRAPHY OF PARAGNEISSES IN THE VALHALLA COMPLEX, SOUTHERN BRITISH COLUMBIA

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The Valhalla complex is an exhumed metamorphic core complex situated within the Southern Omenica Belt of the Canadian Cordillera. The complex is bounded by two normal faults: the east dipping Slocan Lake fault (SLF) and the east rooting Valkyr shear zone which arches over the complex and merges with the SLF.

This study focuses on a sillimanite grade paragneiss unit which is of an uncertain age and stratigraphic correlation. It has been suggested that this paragneiss is of a North American miogeoclinal origin. It is the basal unit of the Valhalla Complex but it is also exposed in two windows by the Gwillim Creek shear zones.

The paragneiss is a predominantly heterogeneous mixture of metasedimentary rocks including marbles, calc-silicates, quartzites, pelitic schists and psammites. Amphibolites and metamorphosed ultramafic rocks are also present and the entire sequence has been intruded by Eocene Ladybird leucogranites. The aim of this study is to deduce the thermobarometric history of the paragneisses and to attempt to correlate them with appropriate surrounding stratigraphic successions.

INDICATORS OF SHEAR SENSE ON THE KILOMETRE SCALE

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Shear is the property of strained material lines (r') that have rotated with respect to initially perpendicular material surfaces (Cobbold 1983). Examples of such deformed surfaces (E'), at the kilometre scale, abound in deeply eroded orogens, and are a focus of many structural studies. Geological examples of r' are more difficult to identify, but may be found amoung arcuate trajectories of mineral lineations deflected at major structural boundaries (Schwerdtner 1993).

Given the direction of tangential net shear at a given surface E', the shear sense may be expected to be right lateral or left lateral and/or normal or reverse. However, these terms are traditionally applied to structures in which E' retains its original orientation. In general cases of large ductile deformation, E' rotates progressively, and may be tilted by >45 degrees. Terminology needs to be developed in which the shear sense relates to the final attitude of E'.

The sense of net shear depends solely on the orientation of the strain ellipse in a section through the shear direction and normal to E'. Here the shear sense is uniquely determined if one knows the sense of angular departure of the shear direction from the major axis of the sectional strain ellipse (Cote 1993, fig. 3). Practical examples will be given from the Trans-Hudson Orogen, northern Saskatchewan.

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CORE COMPLEXES: LESSONS FROM LITTLE SHEARED MARGINS OF THE SHUSWAP COMPLEX

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"Cordilleran-type" core complexes are characterized by a lower plate of high grade gneisses forming the core, separated from an upper plate of the surrounding low-grade rocks by outward-dipping zones of extensional ductile shearing and faulting. Much work has been done on these shear zones and they are generally considered an integral element of the core complexes. Very useful recent compilations of the Shuswap Complex of southeastern British Columbia show it to be a composite core complex bounded on the east and west sides by outward-dipping ductile to brittle fault zones. Locations where there is little or no shearing and fault displacement are described from both the north and south margins of the Shuswap Complex. There, upper plate geology is continuous with that of the lower plate and the core complex boundary is seen as the upper and outer boundary of leucogranite injection and metamorphism imposed across stratigraphic units and old structures. This suggests that it is in such localities that we see the fundamental nature of the margins and that shearing and faulting, while obviously very important, are superimposed and secondary. Significantly different crustal levels are juxtaposed only where the displacements on the bounding extensional shear and fault zones are large. Where the displacements are small, we observe the (arrested) development of the shear zones and can resolve the original dip problem.

THE USE OF DIGITAL TERRAIN MODELS FOR THE VISUALIZATION OF STRUCTURAL GEOLOGY

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The visualization of three dimensional structure is greatly complicated by topographic relief. Rather than attempting to interpret and visualize structural data on a 2-D map, a **Digitial Terrain Model (DTM)**, within a **Geographic Information System (GIS)** can significantly enhance the visual impact of a complexly deformed terrain. A DTM allows the viewing of landscape surfaces, from any vantage point, combined with geology, satellite imagery, or any other two-dimensional map image draped overtop. Data point interpolation involves the modelling of a surface as a sheet of triangular facets having data points as vertices; thereby, honouring each data point. **The Triangulated Irregular Network (TIN)** is ideally suited for variable topography without data redundancy since the triangular mesh adapts to varying densities of data. All critical topographic features are retained.

The demonstrated data set is that of the Pingston Fold within the Monashee Mountains of southeastern British Columbia. The study of the Pingston Fold is part of ongoing research within the southern portion of the Monashee Complex, situated within the Omineca Belt of the Canadian Cordillera. Thor-Odin represents a major structural culmination within the southern part of the Monashee Complex. The culmination has been previously interpreted as a gravitationally uplifted diapiric mantled gneiss dome and also as a northerly-directed thrust duplex and fold interference structure. The Pingston Fold, mapped as an antiformal syncline, is a major complex structural feature draping the southern half of the Thor-Odin culmination.

The demonstrated structural interpretation of the Pingston Fold utilizes a three-dimensional block diagram that portrays the orientation of structural features in an orthographic projection. Block diagrams are generally the most useful method of illustrating the three-dimensional structural interpretation of a map area. A digital terrain model is the basis for this three-dimensional orthographic block diagram. In order to create a three-dimensional geological model from two-dimensional structural data, the map area must be divided into fold domains. Domains are defined on the basis of the homogeneity of the orientations of folds where reasonably cylindrical (ie. where minor fold axes have consistent orientations). Once structural domains have been outlined on a map, axes can be projected down plunge and the structure joined at domain boundaries. The present surface expression and the three-dimensional geometry of the Pingston Fold can be explained by fold interference and is illustrated using a Digital Terrain Model.

AN ANALYSIS OF HORNBLENDE FABRICS

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Hornblende fabrics have been studied from amphibolites occurring in the Precambrian Arabian Shield at Wadi Liyyah, east of the city of Al-Taif. Grain shape and crystal orientation fabrics have been analyzed. The amphibolites contain an abundance of minor folds. The hornblende occurs as elongated grains which define a well developed lineation, with their long axes sub-parallel to the schistosity and to the fold hinges. Thin, intercalated layers of quartzite, a few millimetres thick, are folded into parallel folds which resemble the buckle folds simulated by computer in layers with a large viscosity contrast with their matrix. Isolated hornblende grains within the quartzite have the same shape orientation as the hornblende in the amphibole matrix. These features are interpreted to indicate that the rocks deformed by pure shear, with the schistosity parallel to the XY plane of the finite strain ellipsoid, and the lineation parallel to the fold axes and parallel to Y.

The grain shape orientation of the fabrics have been studied quantitatively, by computer assisted microscopy. The data confirm the field observation that the long axes of the grains lie sub-parallel to the lineation and the schistosity and the fold axes, Y, and the short axes are sub-normal to the schistosity, Z. The grains with the larger aspect ratios have their axes more nearly parallel to the finite strain axes.

Crystal orientation fabrics show strong preferred orientations, with the c- axis sub-parallel to Y, b-axis sub-parallel to X and [100] sub-parallel to Z. Inverse pole figures indicate that the schistosity tends to be parallel to (100), with some tendency for parallelism with {110}. The lineation tends to be parallel to the c-axis.

In some studies, the preferred orientation of hornblende has been attributed to rigid body rotation of elongated grains, the resulting crystal preferred orientation is an artifact of the correlation between crystallography and grain shape, the c-axis corresponding to the long axis of the grains, the b- axis with the intermediate axis, and [100] with the short axis. These are the same correlations noted here but, where the published analyses orient the c- axes/long axes with the X fabric axis, in these rocks they are parallel to Y.

The development of the observed fabrics by translation glide requires that the dominant slip systems be {100}<b> and {110}<110>. Such slip systems have not been observed in hornblende. They are unlikely because of the large Burgers vectors involved. Further, such systems would produce grains elongated parallel to the b-axis and the strain axis X. Although this could be modified by grain growth to produce the observed shape fabric.

The development of preferred crystal and grain shape orientation in hornblende by growth during deformation is not well understood. The fact that the most rapid growth direction is parallel to the c-axis is clear from the crystal habit of hornblende. However, the possible controls on hornblende nucleation are not known.

SPHERISTAT FOR WINDOWS: A NEW STRUCTURAL ANALYSIS COMPUTER APPLICATION

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SpheriStat for Windows offers a new and very productive way to perform structural analysis, by integrating stereonets, structural maps and rose diagrams in one application. Users can study both the orientation distribution and spatial relationships of their measurements at the same time. Data may be entered directly using our full-screen, spreadsheet-like editor, or imported as ASCII (text) data using a customizable reading procedure. A variety of file formats can be read, including those created by SpheriStat 1.x and GMM/Geological Map Maker.

Using Microsoft Windows' multiple document interface (MDI), SpheriStat allows multiple views of the same data, as well as different data sets on screen at once. Each data set can include a variety of data types (planar and linear), represented in the diagrams by different symbols. The data within a set may be either axial/non-directional (plotted on lower hemisphere only) or polar/vector (upper and/or lower hemisphere). Many options are available to let users customize the plots to suit their particular application or style. Tool buttons give easy access to the different plot types and to the customization dialog boxes, as well as to the commonly used file and print menu options. Users can select and highlight specific data records either by the click-and-drag method within any of the plots or within the editor, or by using the powerful, multi-key, Boolean search facility. Once records are selected, a new data set containing only those records can be created, plotted and analysed.

Spheristat for Windows provides a large selection of analytical tools for examining the data. These tools include: point-density distribution (Gaussian, Schmidt and Kamb methods) with filled/coloured contours and full statistics; removal of single density peaks to examine secondary peaks; spatial averaging, with full station statistics and a variety of different result presentations; principal direction analysis (eigenvector or Fisher statistics); cluster analysis; Gine's uniformity test; circular histograms (bar, peak or Gaussian smoothed) with full statistics; and 2D or 3D data rotation. Each method offers a selection of options, allowing for interactive analysis and testing of different hypotheses. SpheriStat even lets users link their own specialized analytical routines into the program as Windows DLLs, with full access to the currently active data through our own DLL interface. Users choose which menu their new procedures are accessed from. All built-in diagrams and statistical results can be printed with any Windows-installed printer, and, in many cases, exported as metafiles to other Windows applications for combining or enhancing the illustrations.

GRANULITE MYLONITIZATION WITHIN THE MINAS FAULT ZONE, NOVA SCOTIA - A RARE PROBE OF DEEP-LEVEL TERRANE BOUNDARY BEHAVIOUR

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The Minas fault zone is a crustal-scale tectonic boundary separating the Meguma and Avalon terranes of the northern Appalachians. Megabreccia developed at Clarke Head, Nova Scotia, although dominated by shallow level evaporitic and carbonate lithologies, notably contains lower crustal granulite (c. 850^{o}C, 800 MPa) in which mylonite fabrics have been preserved. These rocks are the only extant granulites exposed within the fault zone

Compositional layering within the granulite is defined by varying proportions of pyroxene and feldspar with grain sizes on the order of 50-100μ. Rapid transitions from the mylonitic gneiss to ultramylonite (< 10μ grain size) occur by dramatic dynamic recrystallization. Boundaries of the ultramylonite remain parallel to the gross compositional layering and mineralogy remains substantially constant, consistent with ultramylonitization being a high-strain- rate event during progressive shearing. TEM studies show high dislocation densities and substructures in the host mylonite indicative of high-temperature deformation. The finest-grained material exhibits anhydrous, high-temperature foliae comparable to diffusion-transfer seams observed in fluid-rich, low-temperature deformation. Dislocation densities are abruptly reduced in the finest-grained material consistent with mechanism transfer to stress-induced diffusional mass transfer.

Overprinting of the granulite textures is restricted to veins of extraordinarily Cl-rich amphibole (hastingite) that is locally cataclased. Despite the required large fluid flux, any re-equilibration of the granulite textures can be clearly recognized. A polyphase exhumation history of the granulite is indicated wherein early mylonitization in the deep-crust (369 Ma) is associated with exhumation to a shallow crustal level at which granulite-grade textures remained unperturbed. Cl-rich brine infiltration produced the amphibole veins (335 Ma) with eventual surface exhumation in the megabreccia. The coexistence of deformed material covering the complete range of crustal depths suggests that the current location of the megabreccia has served as a site of repeated intense tectonic release. Additionally, the development of intense localization of deformation and inherent control imposed by the related deformation mechanisms emphasizes the difficulty in establishing bulk lithospheric responses that are commonly used in modelling exercises.

LATTICE PREFERRED ORIENTATIONS OF PLAGIOCLASE IN THE MORIN ANORTHOSITE

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Using a new U-stage method developed recently by Ji, Zhao and Zhao (J. Struct. Geol., vol. 16, No. 11, in press), we have measured lattice preferred orientations (LPOs) of plagioclase (An 45-55) in a set of plastically deformed anorthosite samples from the ductile shear zone that affected the eastern lobe of the Morin Massif Grenville Tectonic Province). The studied samples consists of plagioclase (>90%) and pyroxenes (<10%). The mylonitic foliation is parallel to compositional banding defined by alternating plagioclase and pyroxene layers. The lineation is well defined by elongate polycrystalline ribbons of recrystallized pyroxenes. However, recrystallized grains of plagioclase are equant and show no shape preferred orientation. It is found that intensity and pattern of plagioclase LPO vary significantly with strain. In the relatively undeformed part of the Morin anorthosite, a well-developed foliation is defined by preferential alignment of plagioclase tablet planes parallel to (010). This foliation is considered as resulting from submagmatic flow during the diapiric emplacement of the anorthositic pluton (Martignole and Schrijver, 1970). However, because the plagioclase grains are so coarse (>3 cm) that their orientations cannot be measured using U-stage technique, we had to use an underformed anorthosite sample from the Sept-Iles intrusion (grain size < 5 mm) as analogue for undeformed, laminated anorthosite. In this sample, plagioclase grains developed a strong LPO during magmatic flow and/or submagmatic compaction: (010) plane of plagioclase is aligned parallel to the foliation, and both [100] and [001] directions are aligned in the foliation plane. With increasing plastic strain, pre-existing magmatic LPO of plagioclase in the Morin anorthosite was successively destroyed and weakened by dynamic recrystallization which resulted in a strong reduction in grain size (from >3 cm to <100 µm). The medium-deformed samples display medium strength of LPO: crystallographic planes (010), (02-1), (03-1), (01-1) and (1-21) tend to be aligned parallel or subparallel to the foliation, whereas crystallographic directions [001], [012], [011], [111], [112] and [101] have their high concentrations near the stretching lineation. In the extensively deformed ultramylonites, plagioclase grains were fully recrystallized and their LPOs become very weak. This agrees with our experimental measurements of P-wave velocities up to 600 MPa which show that these anorthositic ultramylonites are seismically quasi-isotropic. It is thus concluded that intensive recrystallization-related plastic deformation does not produce plagioclase LPO, under granulite facies conditions, even in plagioclase-dominated rocks such as anorthosite. Unlike quartz, mica or olivine, plagioclase thus stands as an unusual rock-forming mineral able to undergo large plastic strain without having developed a strong LPO..

STRUCTURE OF THE RED LAKE GREENSTONE BELT, NORTHWESTERN ONTARIO: PRELIMINARY RESULTS OF FIELD WORK

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The structure of the Red Lake greenstone belt is dominated by steeply dipping primary layering, planar shape fabrics and cleavages, as well as small-scale, subvertical shear zones. With the exception of intersection lineations and boudin axes, linear fabrics are generally absent. Regional foliation trajectories are broadly parallel to the contacts of the surrounding granodioritic batholiths, as is the distribution of the amphibolite/greenschist facies metamorphic isograde. The deformation, however, is heterogeneous and concentrated in several linear Au-bearing zones.

Reconnaissance was concentrated on the northeast-trending Flat Lake-Howey Bay and East Bay deformation zones (FLHBDZ and EBDZ) and the northwest-trending Cochenour-Gullrock Lake deformation zone (CGLDZ). Fabrics defined by quartz porphyroblasts in a strongly deformed quartz porphyry within the FLHBDZ are commonly symmetrical and bisect the obtuse angle of outcrop-scale, conjugate brittle-ductile and ductile shear zones. This strongly suggests that the deformation within the FLHBDZ was characterized by progressive pure shear. Similarly, foliation-parallel carbonate-quartz veins along the CGLDZ, observed in the Campbell mine, are commonly boudinaged, whereas foliation-perpendicular carbonate-quartz veins are symmetrically folded. This geometry, together with the fact that foliation-oblique carbonate-quartz veins are generally asymmetrically folded with conjugate shear senses, indicates that the CGLDZ was flattened coaxially. Similar structural features were also observed along the less well exposed EBDZ.

In the absence of compelling evidence for shear-sense indicators along these deformation zones, together with the geometry of structures within the zones, we interpret them to have formed in a progressive pure shear regime. However, the relationships between the deformation zones, and the relationships between the deformation zones and the surrounding batholiths are uncertain and require further detailed mapping and structural studies.

REFINEMENTS TO THE SHEAR-LAG MODEL

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Shear-lag model or fiber loading theory is a powerful method to analyze mechanical interaction between hard and soft phases in the polyphase rocks. It was originally developed by Cox (1952) and then refined by Dow (1961), Kelly and Macmillan (1986), Nardone and Prewo (1986), Lloyd et al. (1982), Zhao and Ji (1992) and Ji and Zhao (1993). Recently we noted that there is a serious error in all the previous derivations of this model: mechanical equilibrium could not be reached. In order to avoid this problem, we refined again shear-lag model based on equilibrium analysis of continuum mechanics. The improved model can be easily used (1) to predict the distribution of tensile stress in the strong inclusions embedded in a continuous weak matrix and to interpret natural boudin structures; (2) to predict mechanical strength of industrial composites and two-phase rocks (Ji and Zhao, 1994); (3) to analyze the distribution of shear stress on the interfaces between rheologically distinct phases; and (4) to calculate the distributions of both tensile and shear stresses in the weak matrix around the strong inclusions and accordingly to interpret the variations of dislocation density and of recrystallized grain size in the polyphase rocks. The analytical results of the improved model agree with those obtained from both experimental investigations and numerical calculations.

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