

LITHOPROBE

Slave-*NOR*thern Cordillera Lithospheric Evolution (*SNORCLE*)

and

CORDILLERAN TECTONICS WORKSHOP

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LITHOPROBE SLAVE/NORTHERN CORDILLERA LITHOSPHERE EVOLUTION WORKSHOP

and

CORDILLERAN TECTONICS WORKSHOP

University of Calgary, March 7-9, 1997

FRIDAY, March 7, 1997

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Chairmen: F.A. Cook and P. Erdmer

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ABSTRACTS of ORAL PRESENTATIONS

Preface

This volume includes the abstracts and short articles submitted for the 1997 LITHOPROBE Slave - Northern Cordillera Lithospheric Evolution (SNORCLE) transect meeting and Cordilleran Tectonics Workshop. These meetings were held concurrently at the University of Calgary on March 7-9. Accordingly, this volume includes several contributions related to both the southern and northern Cordillera. We thank Phil Simony, Leslie Reid and Elissa Lynn for assistance in organizing the meeting.

TECTONICALLY-INFLUENCED SEDIMENTATION ALONG THE BENIAH LAKE FAULT, SLAVE PROVINCE, NORTHWEST TERRITORIES

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The clastic sedimentary Keskarrah and Beaulieu Rapids Formations (2.6Ga) of the Slave Structural Province display features that are consistent with direct tectonic influence on sedimentation. The two sedimentary successions, 250km apart, are preserved along the N-trending Beniah Lake fault, a structure that played a significant role during the latter stages of Slave Province evolution. This structure of crustal magnitude transects the Slave Province and can be traced for at least 400km along strike.

The Beaulieu Rapids Formation (lat. 63°05' to 63°00' /long. 112°25' to 112°23') is bounded by the Beniah Lake fault on the east and overlies unconformably the mafic volcanic rocks of the Beaulieu River volcanic belt along its western margin. Basin subsidence and tectonic influence were greatest adjacent to the fault as represented by the stratigraphy and sedimentology of the four principal lithofacies. These include: (1a) a basal conglomerate lithofacies (1b) a siltstone-sandstone lithofacies, (1c) an upper conglomerate lithofacies, and (1d) a quartz-rich sandstone lithofacies. The 450m-thick basal conglomerate, subdivided into a massive conglomerate unit and a sandstone-interbedded conglomerate unit, is interpreted as debris-flow deposits on proximal regions of alluvial fans and traction-current deposits on medial regions, respectively. The 305m-thick siltstone-sandstone consists of a sandstone-dominated unit and a siltstone-dominated unit that together represent the deposits of an anastomosing sandy braidplain with numerous small lakes. The 120m-thick upper conglomerate contains sedimentary structures that are typical of longitudinal gravel bars and confined in-channel gravels in a braided stream environment. The 750m-thick quartz-rich sandstone contains structures consistent with megaripple progradation along coarse sandy braided-stream channels. The overall depositional setting includes a series of alluvial fans adjacent to a mafic-dominated hinterland which grade downstream into braided streams and small lakes. Two fining-upward sequences, represented by (i) the basal conglomerate and siltstone-sandstone lithofacies as well as (ii) the upper conglomerate and quartz-rich sandstone lithofacies are suggestive of tectonically-controlled sedimentation due to fault-scarp retreat, or fault deterioration and subsequent rejuvenation.

The Keskarrah Formation (lat. 65°08' to 65°21' /long. 112°45' to 113°10'), located adjacent to the Beniah Lake fault, overlies unconformably the mafic volcanic rocks of the 2.69-2.70Ga Peltier Formation, the turbiditic rocks of the Contwoyto Formation and a granitic basement, represented by the 3.15Ga Augustus granite. Three lithofacies constitute the sedimentary sequence: (2a) a conglomerate lithofacies, (2b) a sandstone lithofacies, and (2c) a siltstone-sandstone lithofacies. The 1.6km-thick conglomerate is prevalent adjacent to the unconformity and along fault splays. Both massive to well-stratified conglomerate, commonly in amalgamated beds, and massive conglomerates with angular clasts were documented. The former represents longitudinal gravel bars on streamflow-dominated alluvial fans and proximal braided streams whereas the latter is suggestive of talus scree deposits along steep slopes. The 300m-thick sandstone contains sedimentary structures that typify transitional settings between fluvial and shallow marine environments. The 40m-thick siltstone-sandstone contains structures consistent with deposition along a shallow-water, wave-influenced shoreface. Collectively, the lithofacies represent a coastal setting with alluvial fans (deltas) prograding into a shallow-water environment.

Both the Beaulieu Rapids and Keskarrah Formations are characterized by basin-margin conglomerates and coarse-grained sandstones, and siltstones and fine-grained sandstones toward the basin centre. Rapid lateral and vertical facies changes throughout both sequences and the presence of unconformities and bounding faults further support sedimentation influenced by tectonism. Based on detailed facies mapping, lithofacies distribution and interpreted depositional settings, it is suggested that the crustal-scale Beniah Lake fault controlled the initiation and formation of these late-stage orogenic basins. Successor or strike-slip basins in modern settings are similar.

CRUSTAL-SCALE STRUCTURES AND THEIR INFLUENCE ON BASIN FORMATION, EVOLUTION AND DISPERSAL PATTERNS: EXAMPLES FROM THE ABITIBI BELT AND SLAVE PROVINCE

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Identifying crustal-scale structures is a prime objective of LITHOPROBE but in complex Archean supracrustal sequences this can be problematic. The sedimentary sequences in greenstone belts are the result of large-scale tectonic processes and recognizing different basin-forming events may shed light on how supracrustal sequences evolved through time. Major layer-parallel faults, traceable for 50-500km, occur in both the 2730-2675Ma Abitibi greenstone belt (AGB) and 4.0-2.6Ga Slave Structural Province (SSP). The E-trending Destor-Porcupine-Manneville (DPMFZ) and Cadillac-Larder Lake fault zones (CLLFZ) in the AGB, and the N-trending Beniah Lake fault in the SSP are such crustal-scale structures. The Hay-Duck fault in the SSP is another possible candidate.

Both major faults in the AGB display a complex structural history. The N-S shortening event associated with thrusting (2697-2690Ma) and terrane docking, changed subsequently into dextral transcurrent movement (2689-2680Ma). Distinct basin-forming events are intimately associated with these fault zones in the AGB. Remnant, linear, flysch-type sedimentary basins, preserved along the DPMFZ and CLLFZ, are part of the arc-arc collision phase. The flysch deposits are characterized by Bouma-cycle turbidite sandstone/mudstone beds, iron-formation, and minor conglomerates. The change from N-S shortening to lateral transcurrent motion is characterized by the formation of late-stage orogenic basins of the strike-slip (successor) type. Amalgamated conglomerates, trough crossbedded sandstones and minor mudstone characterize these molasse-type deposits. The transition from a flysch- to molasse-type basin is commensurate with fundamental change in depositional environment from deep-water turbidite to shallow-water and subaerial coarse clastic deposits.

A strikingly similar situation has been recorded along the Beniah and Hay-Duck faults of the SSP. The close spatial association between 2680-2660Ma flysch- and 2.6Ma molasse-types is particularly evident along these faults. As in the case of the (remnant) AGB sedimentary basins, molasse and flysch basins are juxtaposed and similar to the AGB, an unconformity occurs between these two distinct depositional systems. The unconformity between the turbiditic Contwoyto and molasse-type Keskarrah Formation at Point Lake in the SSP demonstrates the sequential evolution of renewed basin formation within a pre-existing basin. It is suggested that a change in tectonic regime from shortening (thrusting in the SSP?) to transcurrent motion is reflected by the drastic change in depositional and sedimentation style: flysch versus molasse basin development. The clastic Jackson Lake Formation overlies the volcanic rocks of the Yellowknife Group unconformably and is bounded by the Hay-Duck fault. The importance of the N-trending faults in the evolution of the SSP remains to be resolved but their influence on basin formation, their control on sedimentary patterns, and their correlation with distinct types of sedimentary basins is evident and certainly is critical for the understanding of the SSP. The presence of long strike-slip faults in Archean orogenic belts infers the interaction between rigid plates and possibly subduction-related processes. The Beniah Lake and Hay-Duck faults may be temporally related and represent two of these important faults.

MULTIPLE EPISODES OF KIMBERLITE MAGMATISM IN THE SLAVE PROVINCE, NORTH AMERICA

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Introduction and General Background

Kimberlite magmas and other related deep-seated intrusions are generated at great depths (>300 km) within the Earth's mantle. Their explosive nature and rapid ascent make them ideal hosts for the transport of a plethora of mantle and crustal xenoliths. Therefore, kimberlites are of immense geological importance, not only for their economic value as a primary source for diamonds, but for the information they potentially carry regarding magma processes and conditions that occur within the deepest regions of the mantle not directly accessible to scientists. In addition, information about the three dimensional nature of the continental lithosphere beneath stable cratons can be obtained through the study of their entrained crustal and mantle xenoliths. In the earliest part of this decade, North America experienced the most extensive staking rush ever known, and in an amazingly short period of time (ca. five years) more than 100 kimberlite pipes have been discovered in the Slave Province covering an area of more than 50 million acres. About thirty percent of the discovered kimberlites are diamondiferous and in 1998 BHP Minerals plans to start large-scale commercial production of diamonds in North America. Despite all the recent kimberlite discoveries in the Slave Province, knowledge of the timing of this kimberlite magmatism is lacking. Other kimberlite provinces in North America are dominated, for the most part, by a single discrete age of magmatism or emplacement over a relative short (20-30 m.y.) time span (Heaman and Kjarsgaard, in prep.) whereas most diamondiferous kimberlite fields worldwide consist of multiple episodes of kimberlite magmatism that often occur over a prolonged period of time (>400 m.y.). The recognition of more than eleven distinct periods of Phanerozoic kimberlite magmatism in South Africa alone (e.g. Kramers and Smith, 1983; Smith et al., 1985) clearly indicates the potential temporal complexity that may exist in poorly studied ancient cratons such as the Slave Province. At present there are virtually no published radiometric ages for Slave Province kimberlites, although a BHP press released indicated an Eocene Rb-Sr phlogopite age (52 Ma) for one of their pipes (Northern Miner, 1993) and reference to preliminary Rb-Sr phlogopite results for the Jericho pipe (172 Ma), the details of which are presented here, was reported by Cookenboo et al. (1996). This Tertiary kimberlite magmatism in the Slave Province is distinctly younger than kimberlite magmatism in other parts of North America (e.g. Heaman, 1989; Hegner et al., 1995) but is similar to the age of some Missouri Breaks alnöite diatremes in the Montana Alkaline Province (e.g. Marvin et al., 1980).

This study has two primary objectives; 1) to obtain precise radiometric ages for a large number of Slave Province kimberlites so that their spatial and temporal distribution can be compared to other well studied kimberlite fields in North America, South Africa and Yakutia and 2) to investigate the protolith and metamorphic ages of crust sampled

directly by the kimberlite during its ascent to the surface through direct dating of entrained crustal xenoliths and/or xenocrystic zircon (e.g. Parrish and Reichenbach, 1991). The latter objective holds the potential to delineate the three dimensional extent of Slave Province crustal domains and possibly provide clues to the extent of the earliest (pre-3.95 Ga) known crust on Earth which is presently exposed in the Acasta region (Bowring et al., 1989). In addition, lower crustal xenoliths could retain information regarding the timing of metamorphism within the Slave craton which has importance in unraveling the tectonic history of this Archean nuclei. A number of eclogite xenoliths entrained in the Jericho pipe are currently under investigation and preliminary results from this research will also be presented at the workshop.

Results

At present, Slave Province kimberlite samples from the Cross, Ursa, Nicholas Bay, Drybones Bay, Lac de Gras C13, and Jericho pipes have been processed through standard crushing and mineral separation techniques to search for minerals suitable for Rb-Sr (phlogopite) or U-Pb (perovskite, mantle/crustal zircon) geochronology. In addition, abundant mantle zircon has been identified in the caustic fusion residues from three drill holes at Drybones Bay and zircon plus phlogopite have been isolated from several eclogite xenoliths from the Jericho pipe. In general the kimberlite samples investigated so far have proven somewhat difficult for absolute geochronology. Groundmass phlogopite in most samples has been partially to completely altered to chlorite with a corresponding dramatic decrease in Rb/Sr ratio and only one sample in this study (pipe C13) has yielded a small amount of perovskite.

Preliminary age determinations have been obtained for three of the pipes listed above and all are older than the Eocene age reported for the BHP pipe. The Lac de Gras pipe C13 contained a small amount of perovskite and the average $^{206}\text{Pb}/^{238}\text{U}$ age of 74 ± 3 Ma for two perovskite fractions is interpreted to be the best estimate for the emplacement age of this pipe and is the first indication of Cretaceous kimberlite activity in the Slave Province.

Phlogopite macrocrysts from the Jericho pipe generally show pervasive chlorite alteration and, although most are not well suited for Rb-Sr geochronology (i.e. low $^{87}\text{Rb}/^{86}\text{Sr}$ ratios < 50), several analyses indicate a Jurassic age. However one phlogopite megacryst isolated from the Jericho kimberlite is well preserved, highly radiogenic ($^{87}\text{Rb}/^{86}\text{Sr} > 250$) and defines a precise model age of 172 ± 2 Ma which is interpreted to be the best estimate for the emplacement age of the Jericho pipe.

Numerous individual mantle zircon crystals isolated from caustic fusion residues have been analysed from kimberlite intersected in three different drill holes at Drybones Bay. The zircon crystals have very low U (3.0-9.0 ppm) and Th (0.8-3.6 ppm) contents, typical of mantle zircon (e.g. Davis et al., 1976), and generally show some degree of discordance. Seven individual grains from hole 95-7 define a discordia line with an upper intercept age of circa 480 Ma. The zircon grains recovered from hole 95-8 show less discordance and have $^{206}\text{Pb}/^{238}\text{U}$ ages that cluster between 437-447 Ma consistent with a Siluro-Ordovician emplacement age but slightly younger than the kimberlite encountered in hole 95-7. A separate piece of core from this hole was processed through standard crushing and mineral separation techniques and a significantly older model Rb-Sr

phlogopite age of circa 1035 Ma ($^{87}\text{Rb}/^{86}\text{Sr} = 180$) was obtained. One single zircon crystal from hole 95-9 yields a significantly younger Permian age of about 270 Ma. Taken together the data from the Drybones Bay samples indicate multiple episodes of kimberlite magmatism occurred over more than a 200 m.y. period at one location.

Summary and Future Work

The Rb-Sr and U-Pb geochronology results obtained so far indicate that, based on only a few age determinations, there are several episodes of Phanerozoic kimberlite magmatism in the Slave Province ranging in age from Ordovician to Tertiary. It still remains to be ascertained which kimberlite events are volumetrically significant but it is apparent that some kimberlite events in the Slave Province (e.g. 480 and 50 Ma) are not presently known elsewhere in central or eastern North America. Additional kimberlite samples are currently being processed with the aim that the age profile for Slave Province kimberlites can be directly compared to other kimberlite provinces worldwide (e.g. South Africa and Yakutia). Once there is a sufficient global database for precise emplacement ages it should be possible to address questions such as why do kimberlite provinces with multiple age fields have greater diamond potential, what is the triggering mechanism to form kimberlite magmas and is there any relationship between kimberlites and mantle plumes.

References

- Bowring, S.A., Williams, I.S., and Compston, W., 1989. 3.96 Ga gneisses from the Slave Province, Northwest Territories, Canada. *Geology* 17, 971-975.
- Cookenboo, H., Orchard, M., and Daoud, D., 1996. Middle Devonian conodonts from limestone xenoliths in the Jericho kimberlite, N.W.T. 1996 Yellowknife Forum.
- Davis, G.L., Krogh, T.E., and Erlank, A.J., 1976. The ages of zircons from kimberlites from South Africa. *Carnegie Inst. Washington Yearbook* 75, 821-824.
- Heaman, L.M., 1989. The nature of the subcontinental mantle from Sr-Nd-Pb isotopic studies on kimberlitic perovskite. *Earth Planet. Sci. Lett.* 92, 323-334.
- Hegner, E., Roddick, J.C., Fortier, S.M., and Hulbert, L., 1995. Nd, Sr, Pb, Ar and O isotope systematics of Sturgeon Lake kimberlite, Saskatchewan, Canada: Constraints on emplacement age, alteration, and source composition. *Contrib. Mineral. Petrol.* 120, 212-222.
- Kramers, J.D. and Smith, C.B., 1983. A feasibility study of U-Pb and Pb-Pb dating of kimberlites using groundmass mineral fractions and whole rock samples. *Isotope Geosci.* 1, 23-38.
- Marvin, R.F., Hearn, B.C. Jr., Mehnert, H.H., Naeser, C.W., Zartman, R.E., and Lindsay, D.A., 1980. Late Cretaceous-Paleocene-Eocene igneous activity in north central Montana. *Isotopes* 29, 5-25.
- Northern Miner, 1993. BHP-Dia Met age date kimberlites. *Northern Miner* 79, no. 2, 1-2.
- Parrish, R.R. and Reichenbach, I., 1991. Age of xenocrystic zircon from diatremes of western Canada. *Can. J. Earth Sci.* 28, 1232-1238.
- Smith, C.B., Allsopp, H.L., Kramers, J.D., Hutchinson, G., and Roddick, J.C., 1985. Emplacement ages of Jurassic-Cretaceous South African kimberlites by the Rb-Sr

method on phlogopite and whole-rock samples. Trans. Geol. Soc. S. Afr. 88, 249-266.

Geochemical and isotopic study of western Slave Province crust

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A detailed geochemical and isotopic study of igneous and sedimentary rocks from the western Slave Province is being undertaken in order to constrain the role of pre-2.7 Ga basement during the formation of the Yellowknife Supergroup rocks (YKSG) and late-Archean (~2.60Ga) syn-post deformation granitoids. Samples were collected from Hanikahimajuk Lake area (425 km north of Yellowknife), Ghost/MacNaughton Lake area (150 km north of Yellowknife) and the Yellowknife area for this purpose. In addition, sedimentary rocks from various different parts of the western Slave Province were collected to observe the correlation between Nd model age and existing U-Pb detrital zircon ages. For all of the samples collected, major/trace elements and Nd isotopic ratios were measured. For some of the samples from Hanikahimajuk Lake area, U-Pb zircon ages were also determined. A summary of the results obtained so far are as follows.

Hanikahimajuk Lake area

- U-Pb zircon ages of basement tonalite, syn-volcanic diorite and highly fractionated felsic granite are determined to be 3379 Ma, 2679 Ma and 2677 Ma, respectively. Felsic volcanic from Izok Lake Volcanic Belt (50 km S of Hanikahimajuk Lake) yielded an age of 2681 Ma.
- $\epsilon\text{Nd}(3.38)$ values of basement tonalites range from -0.3 to 2, which implies a role of pre-3.4Ga crust in their genesis. ϵNd values of these samples at 2.68 Ga range from -4.1 to -10.5.
- 2.68Ga Volcanic rocks have $\epsilon\text{Nd}(2.68)$ values ranging from -1.2 to 2.5. There is a general decrease in $\epsilon\text{Nd}(2.68)$ from mafic to felsic volcanics, indicating a greater involvement of pre-2.7Ga crust in the genesis of more felsic rocks. However, apparent $\epsilon\text{Nd}(2.68)$ - Sm/Nd mixing line between mafic volcanics and basement tonalite indicates that even some of the mafic rocks has interacted with the basement (i.e. the volcanic belt was, at least in part, constructed on the basement).
- One metasedimentary rock has $\epsilon\text{Nd}(2.66)$ value as low as -5.3. This may indicate that at least part of the older basement was exposed during the deposition of YKSG sediments.
- REE patterns and Nd isotopic characteristics of syn-volcanic diorites suggest that they are plutonic equivalent of volcanic YKSG rocks.

Ghost/MacNaughton Lake area.

- Nd isotopic signature of syn-post deformation granitoids are more juvenile ($\epsilon\text{Nd}(2.60)=0.6$ to 1.3) compared to that of Hanikahimajuk Lake area ($\epsilon\text{Nd}(2.60)=-2.2$ to 0.8), indicating that there is an isotopic variation not just in the E-W direction but also in the N-S direction in the western Slave (Davis and Hegner 1992; CMP, 111, 493; Thorpe et al. 1992; GSC Open-File Rep. 2484, 179). This is further supported by Pb isotopic signature of leached feldspars from these granitoids.

Yellowknife area.

- Nd isotopic signature of volcanic rocks can be explained by mixing of depleted mantle source material and evolved sialic crust found in other areas of the western Slave Province.
- For the YKSG sediments (=Burwash Fm. turbidites), different units of Bouma sequence were analyzed separately for geochemistry and Nd isotopes. There is a clear difference in $\epsilon\text{Nd}(2.66)$ values among units of Bouma sequence. This difference is probably due to "unmixing" of detritus with different isotopic composition during transportation and deposition (McLennan et al.: Nature, 337, 547).

- For the YKSG sediments, $\epsilon\text{Nd}(2.66)$ values of upper shale units (Te) are usually lower than that of the lower sand units (Ta). This can be explained by “unmixing” of crustally contaminated volcanic source material and juvenile quartzo-feldspathic material.

Regional YKSG sedimentary rocks.

- For the regional YKSG metasedimentary rocks, there is a clear correlation between the TDM (depleted mantle model age) and the U-Pb age of the “oldest” zircon in each sample. This correlation can perhaps be used as a first order tool to search for the signature of the ancient crust in the Slave Province. The particular relationships between TDM and the detrital zircon population indicate that crustal recycling, rather than addition of juvenile material, dominated the pre 2.7Ga crustal evolution of the western Slave Province.

In addition to these, geochemical, isotopic and geochronological study of central Slave Province (Winter Lake area) is in progress.

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METAMORPHISM AND ITS RELATIONSHIP TO TECTONIC SETTING ALONG THE SNORCLE TRANSECT, YELLOWKNIFE DOMAIN, SLAVE PROVINCE, N. W. T. BETHUNE, K.M., and CARMICHAEL, D.M., Dept. Geological Sciences, Queen's University, Kingston, Ontario, K7L 3N6

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The Slave Province is a classic area for low-pressure metamorphism but its tectonic setting remains controversial. Whereas some have proposed that the high geothermal gradient associated with this metamorphism can only have been generated by crustal thinning in a continental rift setting, others have invoked an origin by subduction and/or accretionary processes. This study aims at placing constraints on modeling of tectonic and magmatic processes through a study of metamorphism in the vicinity of the SNORCLE Lithoprobe Transect, concentrating on the supracrustal rocks of Yellowknife Domain. The area preserves a wide range of metamorphic grade. Following deposition at ca. 2660 Ma, turbidites of the Burwash Formation and underlying rocks underwent polyphase deformation. An early low-grade metamorphism accompanied D1 (M1; slaty cleavage). This was superseded by low- to medium-grade metamorphism (M2) related to second-phase folding (F2, S2) and intrusion of syn- to late-tectonic granites. Metaluminous tonalitic to granodioritic plutons of the Defeat suite have been imprecisely dated at ca. 2.62–2.61 Ga. Several later peraluminous granites have U-Pb ages of ca. 2.59–2.58 Ga, but near the transect, the peraluminous Prosperous granite has not yet been precisely dated. The thermal control exerted by granites during M2 is demonstrated by the zonal arrangement of isograds around them. Consistent with their inferred relative ages and the idea that successive intrusions contributed to the thermal budget as metamorphism progressed, the contact aureole around Defeat pluton (M2a) is much narrower than that around the Prosperous granite (M2b). No fundamental differences in mineral assemblages have been identified between the respective aureoles; however, porphyroblasts in the Defeat aureole are more-or-less pervasively retrograded to muscovite and/or chlorite, particularly within the zone of overlap. Knotted schists in both settings contain assemblages and sub-assemblages diagnostic of Bathozone 2, implying moderate depth of emplacement (2.5–3.7 kbar, 8–13 km paleodepth) and moderate to high temperature (500–600°C). The mineral-assemblage data indicate not more than ~4 km of exhumation during the Defeat-Prosperous interval; quantitative thermobarometry should impose a more stringent upper limit. If the age-interval between the two suites is similar to that documented for I- and S-type granites elsewhere in the Slave Province (i.e. ~10–20 m.y.), the rate of syntectonic exhumation of the mid-crustal part of Yellowknife Domain was at least one order of magnitude lower than average rates of uplift and erosion (e.g. 1–5 mm/yr.) in typical Tertiary- to Recent collisional zones. This relatively low rate in turn raises the question of the timing and mechanism of deposition, and subsequent low-grade metamorphism, of late 'Timiskaming-type' conglomerates, known to contain granitic clasts as young as 2.6 Ga. This study is in progress; further work will be directed at: (1) documentation of mineral assemblages and textural relations relevant to deciphering the P–T–t path followed by rocks; (2) mineral-chemical studies aimed at obtaining quantitative estimates of paleodepth and temperature; (3) $^{40}/^{39}\text{Ar}$ dating of Hbl, Bt and Ms in metamorphic and igneous rocks, undertaken in conjunction with U-Pb geochronology, aimed at elucidating the post-metamorphic cooling history.

Late Archean Turbidites and their Tectonic Setting in the Southern Slave Province

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Introduction

The Slave province is unusual among the Archean cratons in containing a large proportion of supracrustal material, and a particularly large amounts of sedimentary rock. By far the largest component of this sedimentary material is assigned to the Burwash Formation and age-equivalent turbidite packages, conventionally included in the Yellowknife Supergroup. These sediments cover approximately 10⁵ km² within the Yellowknife-Hearne Lake area where they outcrop along about half the length of the Slave portion of the SNORCLE transect; they cover about four times this area in the Slave province as a whole. The minimum thickness of the succession estimated by Henderson (1985) is 5 km; Bleeker and Beaumont-Smith (1995) suggested that the total packages may be as thick as 10 km. The sediments are superbly exposed along the shores of numerous lakes. Inland, though exposures tend to be lichen-covered, exceptional opportunities exist for lateral correlation using air photos, which enable identification of large-scale features of the depositional system. In addition, a number of recognizable ash units can be traced laterally, and dated, providing good stratigraphic control.

Geologic setting of the Burwash Formation

Supracrustal rocks in the southwestern Slave province are exposed in the region between basement gneisses and granitoids exposed in the Anton and Sleepy Dragon Complexes (fig 1). These are overlain by locally developed quartzite/BIF assemblages (e.g., Isaachsen 1992, Bleeker et al., 1997) and more widespread, thick volcanic sequences containing both mafic and felsic flows and felsic pyroclastics. Coarse clastic sediments (sandstones, conglomerates, and minor limestones) overlie and are in part interbedded with the volcanic succession. These are in turn overlain by the thick slate-metagreywacke successions of the Burwash Formation, which occupies much of the region between the two basement massifs. Henderson (1975), in the only previous sedimentological study of the Burwash Formation, described turbidites exposed at Yellowknife Bay, and suggested a submarine fan depositional model to explain some features of the distribution of facies.

The volcanic and sedimentary successions between the Anton and Sleepy Dragon complexes are deformed by at least three phases of deformation and have been intruded by late Archean granitoid plutons (Henderson 1985; Bleeker and Beaumont-Smith 1995). Close to the plutons, metamorphism at amphibolite facies has produced cordierite porphyroblasts, obliterating some sedimentary structures; farther from the plutons the rocks are metamorphosed at greenschist facies; they are variably cleaved but retain their sedimentary textures and structures at outcrop scale.

Farther east and north within the Slave province, the successions are less well known; basement massifs seem to be absent from much of the 'Contwoyto Terrane' east of the Sleepy Dragon Complex. Poorly dated sedimentary successions resembling the Burwash Formation are present in the Back River area (Lambert et al. 1990), surrounding igneous centres of arc affinity. There is a possibility that the eastern Slave represents juvenile crust, possibly arc terranes accreted to a western Slave core (Kusky 1990).

Several tectonic models have been proposed for the southwestern Slave province. The volcanics at the base of the supracrustal succession are interpreted as products of rifting; Henderson (1985) suggested that the present basement massif approximately correspond to the original structural horsts. A contrasting model was proposed by Kusky (1990), who suggested an ocean-floor origin for some of the volcanics, and suggested an allochthonous thrust model for the rest of the

supracrustal succession. Subsequent work has not supported this model, confirming instead a depositional relationship between the basement and lowest sedimentary succession (Bleeker et al. in press). However, substantial shearing has affected parts of the sedimentary succession just above its basal contact with the Sleepy Dragon Complex. This led James and Mortensen (1992) to propose that the Complex represents a core complex, exposed by extension during or after deposition of the Burwash Formation.

Bleeker (Bleeker & Beaumont-Smith 1995, Bleeker 1996) mapped structures in the Yellowknife-Hearne Lake area, showing that the geometry of the Sleepy Dragon Complex corresponds to a 'mushroom' interference pattern between F1 and F2 folds. One consequence of this model is that the present-day margins of the Sleepy Dragon Complex are products of folding and are therefore unlikely to coincide with original (synsedimentary) basin margins. Three main phases of deformation have been identified in the Burwash Formation and underlying volcanics; outcrop scale F1 and F2 folds can be clearly distinguished throughout much of the area.

Certain tuff bands have been found to consist of several distinct and recognizable ash beds. On this basis the same ash band can be recognized at more than one location, enabling lateral correlation within the otherwise monotonous succession. One such ash band has been dated at 2661 ± 2 Ma. (Bleeker and Villeneuve, 1995).

Turbidite depositional systems

The majority of modern turbidite depositional systems are derived from point sources and may be classified as submarine fans. Fan facies models have become the norm for comparisons of ancient turbidite systems with their modern counterparts (e.g. Walker 1978). There are major differences in the data available from modern and ancient fan environments. Modern fans typically provide a good record of bathymetry and surface sediment, but poor information on the subsurface distribution of facies. The surface layers are often atypical because post-glacial sea-level rise has trapped sand on adjacent shelves. Turbidite sands are difficult to core on modern fans, and when recovered the sands are disturbed by the coring process; much more is known about muds than the sands.

In contrast, ancient turbidite sandstones typically display more sedimentary structures than recessive and poorly exposed shales. Vertical sequences are often well exposed, but difficulties of correlation hinder reconstruction of the geometry of the system in plan view. For this reason, asymmetric cycles (fining upward, coarsening upward) have been used as a means to identify components of the depositional system (channels, lobes) but the recognition in modern fans of substantial levee systems, migrating channels, and control by sea-level change (Mutti 1985) creates ambiguities in this interpretation. Lateral tracing of single beds or packets of beds provides a much more reliable basis for interpretation.

In addition to submarine fans, other types of turbidite systems are known: turbidites may be deposited in narrow troughs, in dispersed ramp systems (Heller & Dickinson (1985), or in systems of multiple quasi-parallel channels (Hesse & Rakofski 1992). Nonetheless, many of these systems involve some of the same elements (channels, levees, depositional lobes) as submarine fans, so fan models form an appropriate starting point for interpretation of large ancient systems like the Burwash Formation.

Seismic profiles show that many modern submarine fans are built largely of overlapping channel-levee systems and that the majority of sediments are deposited in levees (fig 2). A possible close analogy between the Amazon fan and the Meguma Group of Nova Scotia has been identified by Piper et al (1995). Within the Meguma Group sandy channel fills and levee sequences can be identified by lateral correlation using geophysical techniques in some well exposed sections (Waldron & Jensen 1985). These sediments are predominantly deposits of high-density turbidity currents, showing successions of sedimentary structures involving thin 'traction carpets', scour and fill structures, and dewatering features similar to those described by Lowe (1982)

Sedimentology of the Burwash Formation

Fieldwork in the summer of 1996 concentrated on a sedimentological investigation of selected outcrops of Burwash Formation around Hearne and Watta Lakes. Careful examination of air photos shows low-angle discordances within the turbidite package (fig 3), recognizable as possible channel-levee complexes comparable in scale and proportions with those on modern fans. Traverses across the feature and several detailed sections confirmed that it is part of the depositional system and not an artifact of deformation or topography.

Approximately 700 m of section were measured in the Burwash Formation, and three possible facies associations were identified:

- Thin bedded, laterally continuous turbidites with Bouma sequences, corresponding to outer fan or inter-channel mid-fan deposits
- Thick bedded sandstones with scour and fill structures, dewatering sheets, and possible traction carpets, corresponding to levee systems. These are volumetrically the most abundant. Locally, laminations are draped over scours producing a structure resembling hummocky cross stratification when viewed in two-dimensional outcrop in areas of steeply raked paleocurrent; these structures when viewed in down-current profile show a directional character similar to dune cross-bedding. They closely resemble scour and fill structures in the Cambrian Goldenville Formation of Nova Scotia (Waldron & Jensen 1985).
- Massive amalgamated sandstones and local granule to pebble conglomerates possibly corresponding to channel fill deposits

The Burwash Formation is thus interpreted as a product of deposition by turbidity currents and other sediment gravity flow mechanisms. Deposition of thick bedded sandstones was by mechanisms characteristic of high density flows, rather than 'classical' turbidity currents, and produced a suite of sedimentary structures similar to those described by Lowe (1982). These structures closely resemble those found in certain Phanerozoic fan systems characterized by thick bedded sandstones, notably the Goldenville Formation of Nova Scotia. Large scale features of the depositional system appear to have included substantial channels with broad (several km) levee systems similar to those in modern submarine fans such as the Amazon Fan. Our future work will involve an examination of the vertical distribution of facies through the Burwash Formation and an investigation the provenance of the sediments using paleocurrents and petrographic data.

References

- Bleeker, W 1996. Thematic structural studies in the Slave province, Northwest Territories: the Sleepy Dragon Complex. GSC Current Res, **1996-C**: 37-48.
- Bleeker, W & C Beaumont-Smith 1995. Thematic structural studies in the Slave province: preliminary results and implications for the Yellowknife Domain, Northwest Territories. GSC Current Res, **1995-C**: 87-96.
- Bleeker, W, & Villeneuve, M 1995. Structural studies along the Slave portion of the SNORCLE Transect. Lithoprobe Report No. 44, p. 8-13.
- Bleeker, W, Villeneuve, M & Bethune, K 1997. Thematic structural studies in the Slave province, Northwest Territories: Contrasting basement/cover relationships on western and southwestern flanks of the Sleepy Dragon Complex. GSC Current Research, 1997-C, 27-37.
- Heller, PL & WR Dickinson 1985. Submarine ramp facies model for delta-fed, sand-rich turbidite systems. Bull AAPG, **69**: 960-976.
- Henderson, JB 1975. Sedimentology of the Archean Yellowknife Supergroup at Yellowknife, District of Mackenzie, GSC Bulletin 246.
- Henderson, JB 1985. Geology of the Yellowknife-Hearne Lake Area, District of MacKenzie: a Segment Across an Archean Basin, GSC Memoir 414.

- Hesse, R., & Rakofsky, A. 1992. Deep-sea channel/submarine-yazoo system of the Labrador Sea: a new deep-water facies model. AAPG Bulletin, **76**: 680-707.
- Isachsen, C.E. 1992. UPb zircon geochronology of the Yellowknife volcanic belt and subjacent rocks, N.W.T., Canada: constraints on the timing, duration, and mechanics of greenstone belt formation; PhD Thesis Washington Univ., St. Louis Missouri, 164p.
- James, DT & JK Mortensen 1992. An Archean metamorphic core complex in the southern Slave Province: basement-cover structural relationships between the Sleepy Dragon Complex and Yellowknife Supergroup. CJES, **29**: 2133-2145.
- Kusky, TM 1990. Evidence for Archean opening and closing in the southern Slave Province. Tectonics, **9**: 1553-1563.
- Lambert, MB, Burbridge, G, Jefferson, CW, Beaumont-Smith, C & Lustwerk, R 1990. Stratigraphy, facies and structure in volcanic and sedimentary rocks of the Archean Back River volcanic complex, N.W.T. GSC Current Research, Paper 90-1C, p. 151-165.
- Lowe, DR 1982. Sediment gravity flows II: Depositional models with specific reference to the deposits of high density turbidity currents. J Sed Pet, **52**: 279-297.
- Mutti, E 1979. Turbidites et cones sous-marines profonds. In P Homewood (Ed) Sedimentation detritique: fluviale, littorale et marine. Institut Geologique University Fribourg pp. 353-419.
- Mutti, E 1985. Turbidite systems and their relations to depositional sequences. In GG Zuffa (Ed) Provenance of arenites. NATO advanced study institute series C 248, pp. 65-93.
- Pickering, KT, RN Hiscott & FJ Hein 1989. Deep Marine Environments: Unwin Hyman.
- Piper, DJW and the Leg 155 Shipboard Scientific Party 1995. ODP Leg 155 on the Amazon deep-sea fan: Amazingly like the Meguma Group. Atlantic Geoscience Society Colloquium and Annual General Meeting, Program and Abstracts, 25
- Waldron, JWF 1992. The Goldenville-Halifax transition, Mahone Bay, Nova Scotia: relative sea-level change in the Meguma source terrane. CJES, **29**: 1091-1105.
- Waldron, JWF & LR Jensen 1985. Sedimentology of the Goldenville Formation, Eastern Shore, Nova Scotia. GSC Paper, **85-15**: -31.
- Walker, RG 1978. Deep-water sandstone facies and ancient submarine fans: models for exploration for stratigraphic traps. AAPG Bull, **62**: 932-966.

Figure 1 Map of southern Slave Province showing proposed location of SNORCLE corridor 1 (dashed). Initial main study area outlined in heavy black. AC = Anton Complex; SDC = Sleepy Dragon Complex. Grey stipple represents Burwash formation and related, mainly turbiditic sediments. Mixed hatching represents Pre-Yellowknife Supergroup metamorphics; black represents volcanics exposed mainly around the margins of the structural basins filled with metasediments. V-symbols show distribution of late granitoid intrusions. Mixed V-symbols and dots are migmatitic gneisses. Scale 1cm = 150 km approx. After Henderson (1985)

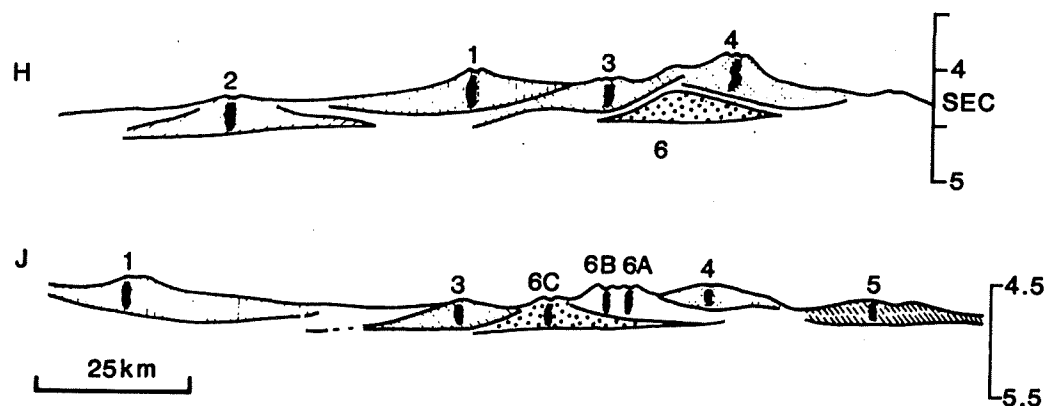
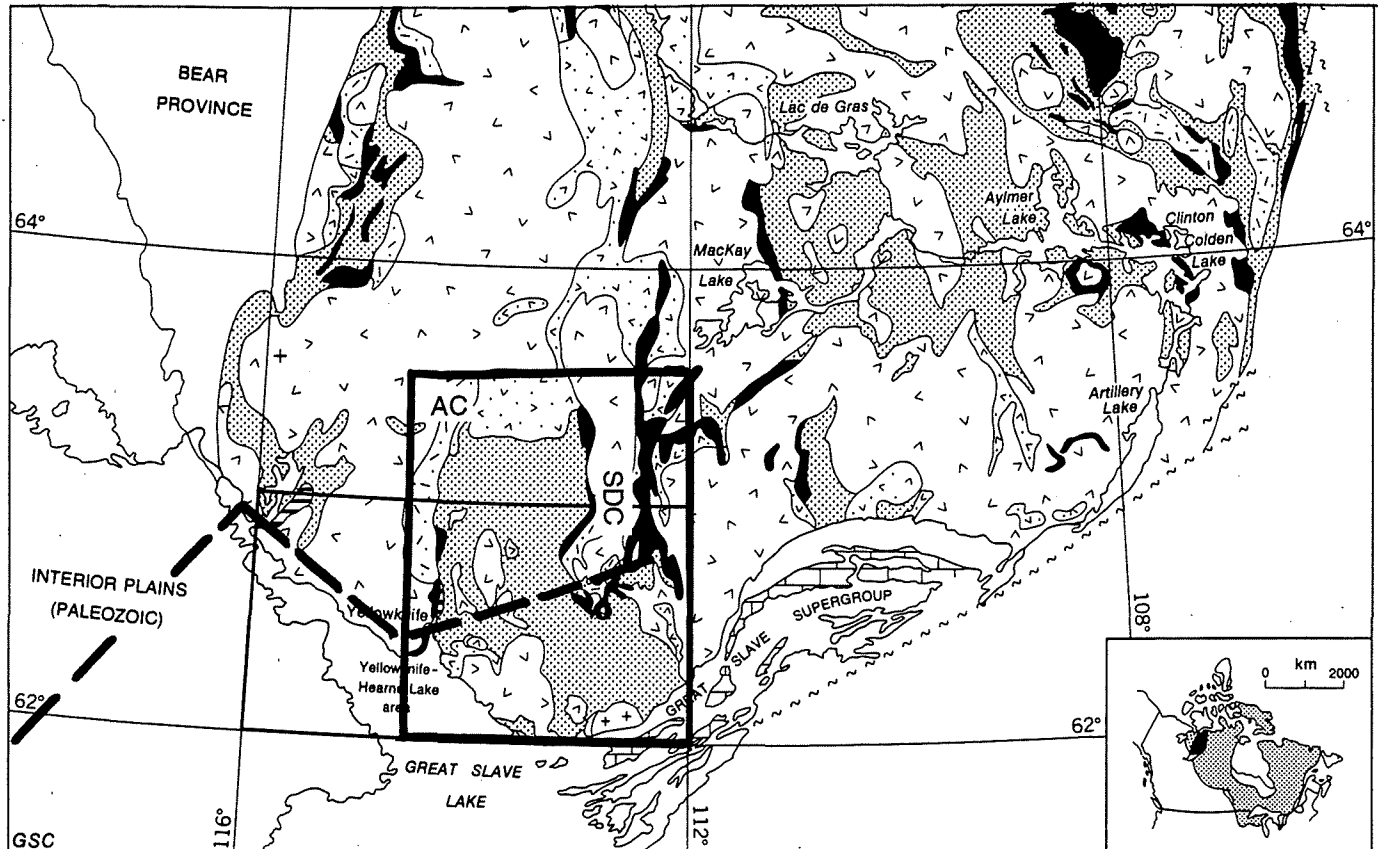


Figure 2 Cross-sections of Amazon fan from seismic profiles showing geometry of sandy channel fill deposits (black) and flanking lenses of levee deposits. Channel 1 is the present day channel; channels 2 through 6 are successively older. Note vertical exaggeration is approximately x20. After Pickering et al (1989)

Figure 3 Interpretation of air photo of west-younging turbidites close to northern closure of Hearne Lake synform, showing lenticular sand bodies. Stippled areas are interpreted as sandstone-dominated probable channel fill. Marked sections were examined in detail in 1996, including discordances to south of major sand body (area of box), interpreted as the transition from channel margin to levee.

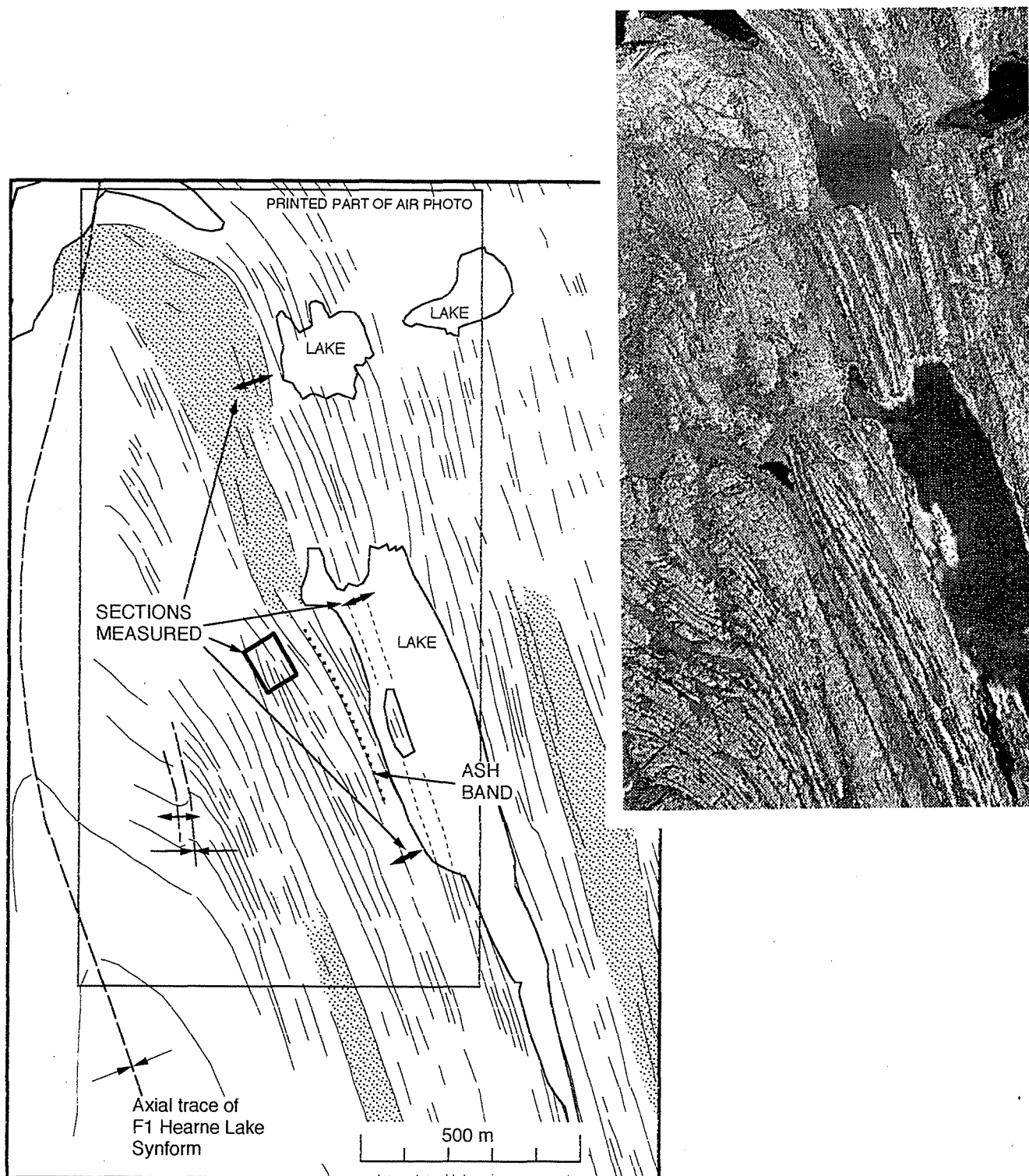
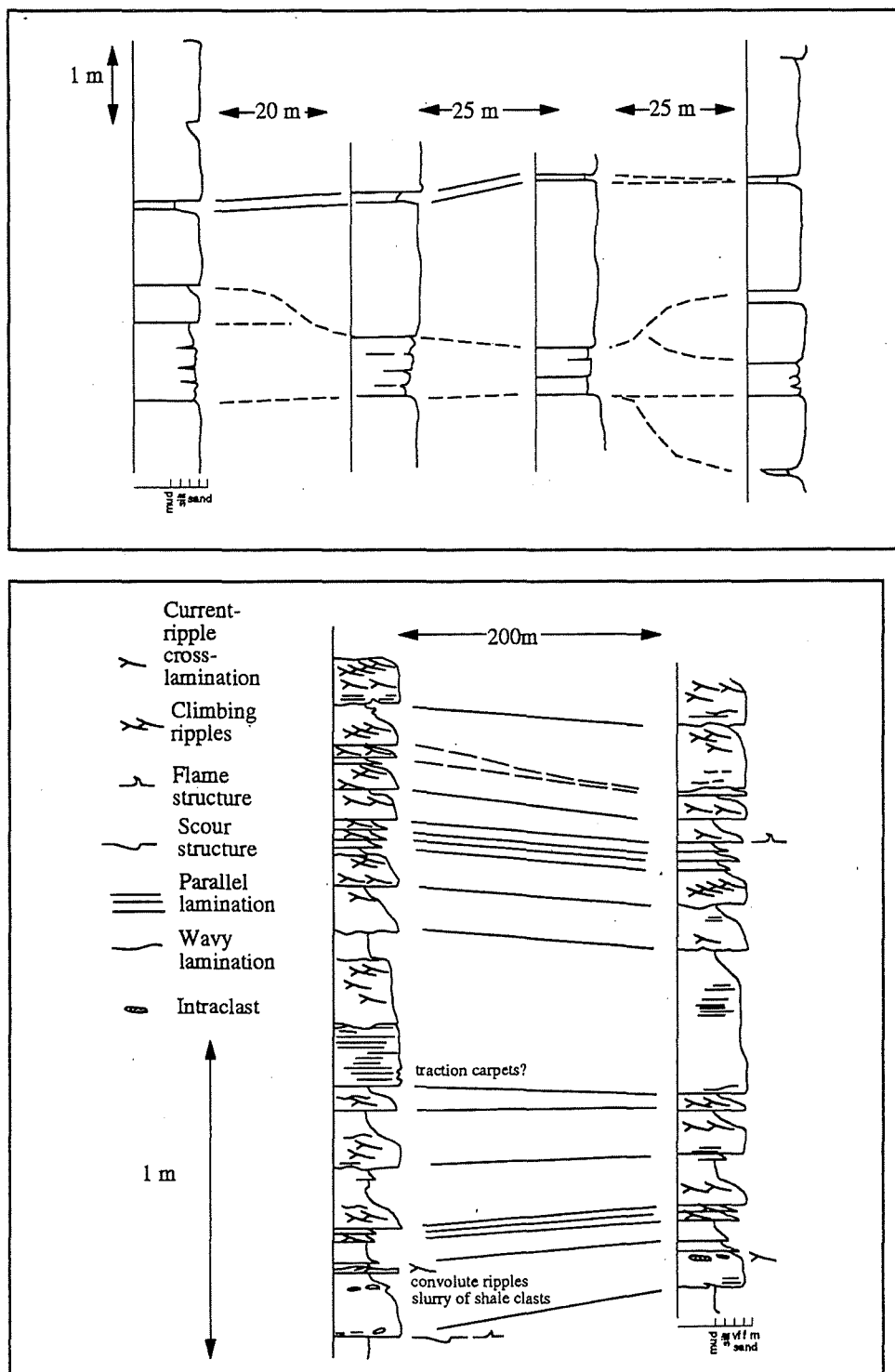


Figure 4 Measured sections selected from about 700 m of logs collected in 1996. Top: sections through lenticular massive sands from northernmost section in figure 3, interpreted as channel-fill. Bottom: equivalent sections separated by 200 m along strike, from islands in Hearne Lake, showing laterally continuous thin beds interpreted as inter-channel or distal levee deposits.



SYSTEMATIC U-PB GEOCHRONOLOGICAL STUDY OF SLAVE PROVINCE "BASEMENT" ROCKS ALONG THE SNORCLE LITHOPROBE TRANSECT: PRELIMINARY RESULTS

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Introduction

The Slave structural province, a relatively small Archean craton in northwestern Laurentia, is characterized by an extensive rock record ranging in age from the >4.0 Ga Acasta gneiss complex (AGC) to <2.6 Ga granitoids. Old, pre-2.73 Ga "basement rocks" have been recognized in the western part of the province (e.g., Baragar, 1966; Henderson et al., 1987; Isachsen, 1992; Thorpe, 1992; Davis and Hegner, 1992). Specifically, such rocks occur in two areas along the SNORCLE Transect: below the Yellowknife greenstone belt, and in the core of a large, north-northeast trending, antiformal basement inlier known as the Sleepy Dragon Complex (SDC). The contacts between these basement complexes and overlying supracrustal packages represent unconformities of different age and in many places high strain zones (Henderson, 1985; Kusky, 1990; Bleeker et al., 1997). Although existing U-Pb and Nd isotopic data confirm the antiquity of these rocks, the database is too limited to allow a detailed understanding of the pre-2.73 Ga history.

Scope of the project

The aim of the present study is to address this problem by systematically mapping and dating a large number of basement rocks along the SNORCLE Transect. We hope to establish or improve a detailed basement chronology of magmatic and metamorphic events for:

- 1) the full extent of the Sleepy Dragon Complex;
- 2) nearby occurrences of known or suspected basement rocks such as in the "Step 'n Duck" area to the east of the SDC (Lambert and Ernst, 1987; Lambert and van Breemen, 1991; Lambert et al., 1992);
- 3) the Anton basement complex below the Yellowknife greenstone belt, and
- 4) if time permits, other poorly documented basement occurrences in the province.

This study is carried out in parallel with detailed geochronological studies of the AGC (Bowring et al., 1989; Bowring and Housh, 1995; Bleeker and Stern, this volume) and a systematic investigation of basement/cover relationships (e.g., Bleeker et al., 1997). With detailed basement chronologies for a number of the complexes, it will be possible to address the question whether basement rocks across the western Slave province represent a single tectonic entity or a collage of discrete blocks that only share a history of later tectonothermal events.

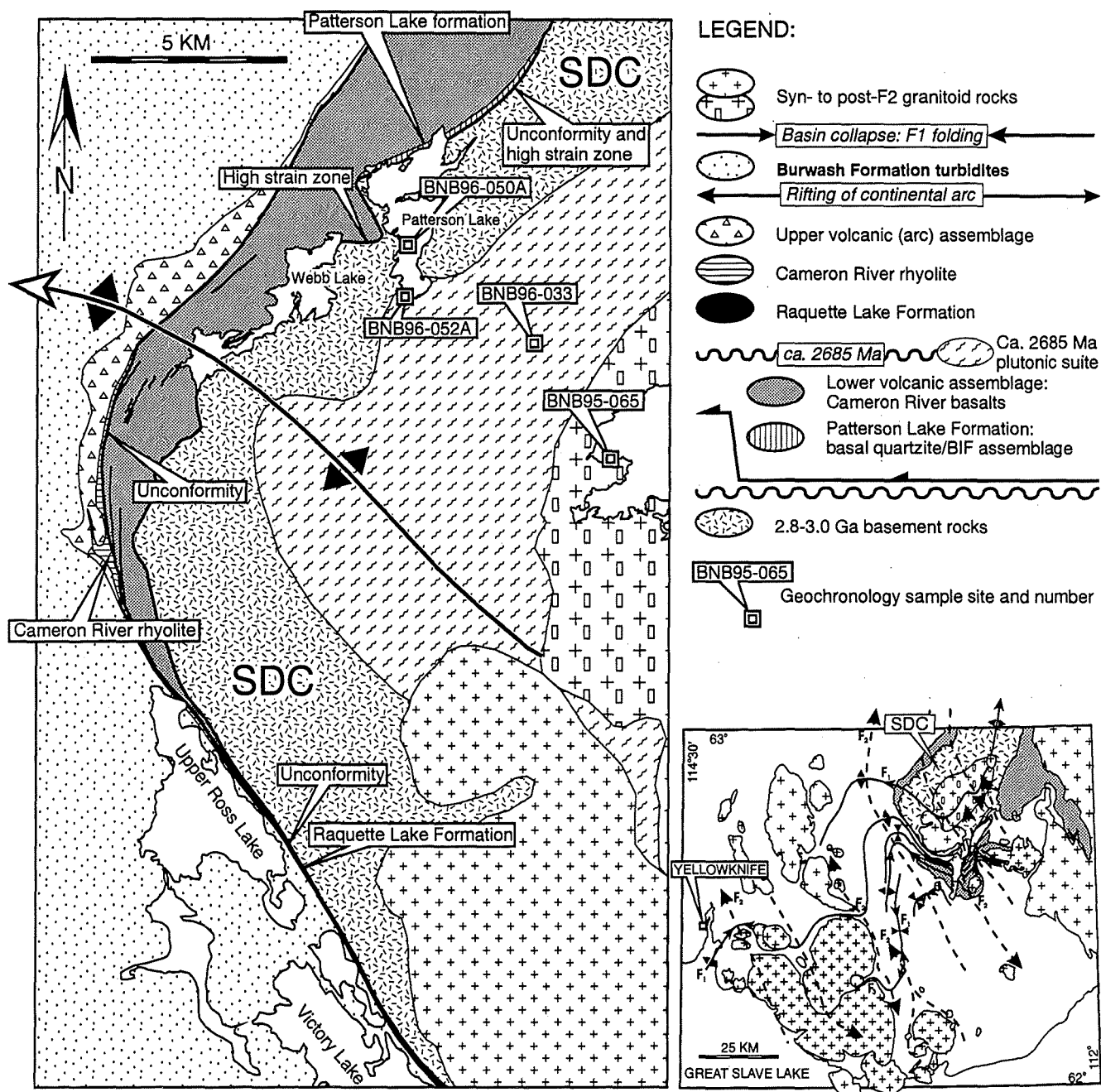


Figure 1: Geological map of the western closure of the Sleepy Dragon Complex (SDC), showing sample localities of the four samples for which results will be presented at the meeting. Preliminary results for sample BNB96-033 (melanocratic hornblende-biotite tonalite) yield an upper intercept discordia age of $2688 \pm 12/-8$ Ma, supporting field evidence for a widespread, ca. 2685 Ma synvolcanic plutonic suite within the SDC (modified after Bleeker, 1996 and Bleeker et al., 1997).

Preliminary samples and results

Preliminary results for four samples from the SDC will be presented at the meeting. The four samples represent both suspected >2.8 Ga basement granitoids and a suspected younger, ca. 2.68 Ga diorite-tonalite-granodiorite plutonic suite thought to be related to an autochthonous, volcanic arc assemblage within supracrustal cover to the complex. The four samples were taken along a transect across the western flank of the SDC (Fig. 1), from near the basement/cover contact to a locality within the late stage Morose Lake granite pluton. A brief description is given below.

Sample BNB96-50A (NTS sheet: 85-I/14 (1:50,000), UTM: 6,971,550mN-395,700mE):

A megacrystic basement granodiorite from Patterson Lake, with a presumed age of ca. 2.8-3.0 Ga (Fig. 2a in Bleeker et al., 1997). K-feldspar megacrysts are well preserved in a matrix of mesocratic biotite granodiorite. This unit is cut by three mafic dyke swarms and becomes progressively more mylonitic towards the basement/cover contact (Bleeker et al., 1997). The sample is from the least deformed member of the basement suite.

Sample BNB96-052A (NTS sheet: 85-I/14 (1:50,000), UTM: 6,970,875mN-395,350mE):

A foliated biotite granodiorite on southeastern Patterson Lake. This rock unit appears to be part of a younger plutonic suite based on the fact that the dyke swarms discussed under the previous sample were not observed in this unit. From field evidence it was proposed that this unit possibly represents a younger, ca. 2680 Ma plutonic suite that is synvolcanic with respect to the arc assemblage at the top of the volcanic stratigraphy in the overlying cover of the Cameron River greenstone belt.

Sample BNB96-033 (NTS sheet: 85-I/15 (1:50,000), UTM: 6,971,000mN-400,300mE):

A foliated melanocratic hornblende-biotite tonalite further in towards the core of Sleepy Dragon Complex. This unit is thought to represent a more tonalitic member of the synvolcanic plutonic suite discussed above. Preliminary U-Pb zircon results show a linear array with an upper intercept age of 2688^{+1}_{-2} Ma that lends support for the preliminary interpretation as a synvolcanic plutonic suite.

Sample BNB95-065 (NTS sheet: 85-I/15 (1:50,000), UTM: 6,966,000mN-400,625mE)

A coarse, foliated, leucocratic hornblende-biotite tonalite in the core of Sleepy Dragon Complex. This unit is intruded by mafic dykes that are themselves deformed. The foliation in the tonalite is cut by undeformed apophyses of the ca. 2.58 Ga (James and Mortensen, 1992) Morose Lake granite. The tonalite thus forms part of an older plutonic suite in the core of the SDC that is locally preserved as enclaves in the Morose Lake granite pluton.

Discussion

Complete results will be discussed at the meeting. Nevertheless, the hypothesis for a widespread synvolcanic diorite-tonalite-granodiorite suite in the SDC is supported by a preliminary age of 2688^{+1}_{-2} Ma for sample BNB96-033. Much of the SDC appears to consist of this suite rather than older basement rocks. This ca. 2685 Ma plutonic suite is likely the plutonic core of an arc complex represented by 2686-2660 Ma calc-alkaline volcanic rocks at the top of the volcanic stratigraphy in the Cameron River, Beaulieu River, and Yellowknife belts.

References

- Baragar, W.R.A., 1966. Geochemistry of the Yellowknife volcanic rocks; *Canadian Journal of Earth Sciences*, v. 3, p. 9-30.
- Bleeker, W., Villeneuve, M., and Bethune, K., 1997. Thematic structural studies in the Slave Province, Northwest Territories: contrasting basement/cover relationships on the western and southwestern flanks of the Sleepy Dragon Complex; *in* Current Research 1996-C, Geological Survey of Canada, p. 27-37.
- Bowring, S.A., Williams, I.S., and Compston, W., 1989. 3.96 GA gneisses from the Slave province, Northwest Territories, Canada; *Geology*, v. 17, p. 971-975.
- Bowring, S.A., and Housh, T., 1995. The Earth's early evolution; *Science*, v. 269, p. 1535-1539.
- Davis, W.J., and Hegner, E., 1992. Neodymium isotopic evidence for the tectonic assembly of Late Archean crust in the Slave province, northwest Canada; *Contributions to Mineralogy and Petrology*, v. 111, p. 493-504.
- Henderson, J.B., 1985. Geology of the Yellowknife-Hearne Lake area, District of MacKenzie: a segment across an Archean basin; Geological Survey of Canada, Memoir 414, 135 p., 1:250,000 map.
- Henderson, J.B., van Breemen, O., and Loveridge, W.D., 1987. Some U-Pb zircon ages from Archean basement, supracrustal and intrusive rocks, Yellowknife-Hearne Lake area, District of MacKenzie; *in* Radiogenic Age and Isotopic Studies: Report 1, Geological Survey of Canada, Paper 87-2, p. 111-121.
- Isachsen, C.E., 1992. U-Pb zircon geochronology of the Yellowknife volcanic belt and subjacent rocks, N.W.T., Canada: constraints on the timing, duration, and mechanics of greenstone belt formation; unpublished Ph.D. thesis, Washington University, St. Louis, Missouri, 164 p.
- James, D.T., and Mortensen, J.K., 1992. An Archean metamorphic core complex in the southern Slave Province: basement-cover structural relationships between the Sleepy Dragon Complex and the Yellowknife Supergroup; *Canadian Journal of Earth Sciences*, v. 29, p. 2133-2145.
- Kusky, T.M., 1990. Evidence for Archean ocean opening and closing in the southern Slave province; *Tectonics*, v. 9, no.6, p. 1533-1563.
- Lambert, M.B., and van Breemen, O., 1991. U-Pb zircon ages from the Sleepy Dragon Complex and new occurrence of basement rocks within the Meander Lake Plutonic Suite, Slave Province, N.W.T.; *in* Radiogenic and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 79-84.
- Lambert, M.B., and Ernst, R.E., 1987. Archean mafic dyke swarm, Beaulieu River volcanic belt, Slave Province, N.W.T.; *in* Current Research, Part A, Geological Survey of Canada, Paper 87-1A, p. 673-679.
- Lambert, M.B., Ernst, R.E., and Dudás, F.Ö., 1992. Archean mafic dyke swarms near the Cameron River and Beaulieu River volcanic belts and their implications for tectonic modelling of the Slave Province, Northwest Territories; *Canadian Journal of Earth Sciences*, v. 29, p. 2226-2248.
- Thorpe, R.I., Cumming, G.L., and Mortensen, J.K., 1992. A significant Pb-isotope boundary in the Slave province and its probable relation to ancient basement in the western Slave province; *in* Project Summaries, Canada-Northwest Territories Mineral Development Subsidiary Agreement 1987-1991, edited by Richardson, D.G., and Irving, M., Geological Survey of Canada, Open File 2484, p. 179-184.

THE ACASTA GNEISSES: AN IMPERFECT SAMPLE OF EARTH'S OLDEST CRUST

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Introduction

The Acasta gneiss complex (AGC), on the western edge of the Slave structural province, contains the oldest known rocks on Earth (Bowring et al., 1989; Bowring and Housh, 1995). A systematic geological and geochronological study of these complex polymetamorphic gneisses has been initiated at the Geological Survey of Canada relying heavily on new, in-house SHRIMP II ion microprobe analytical capabilities.

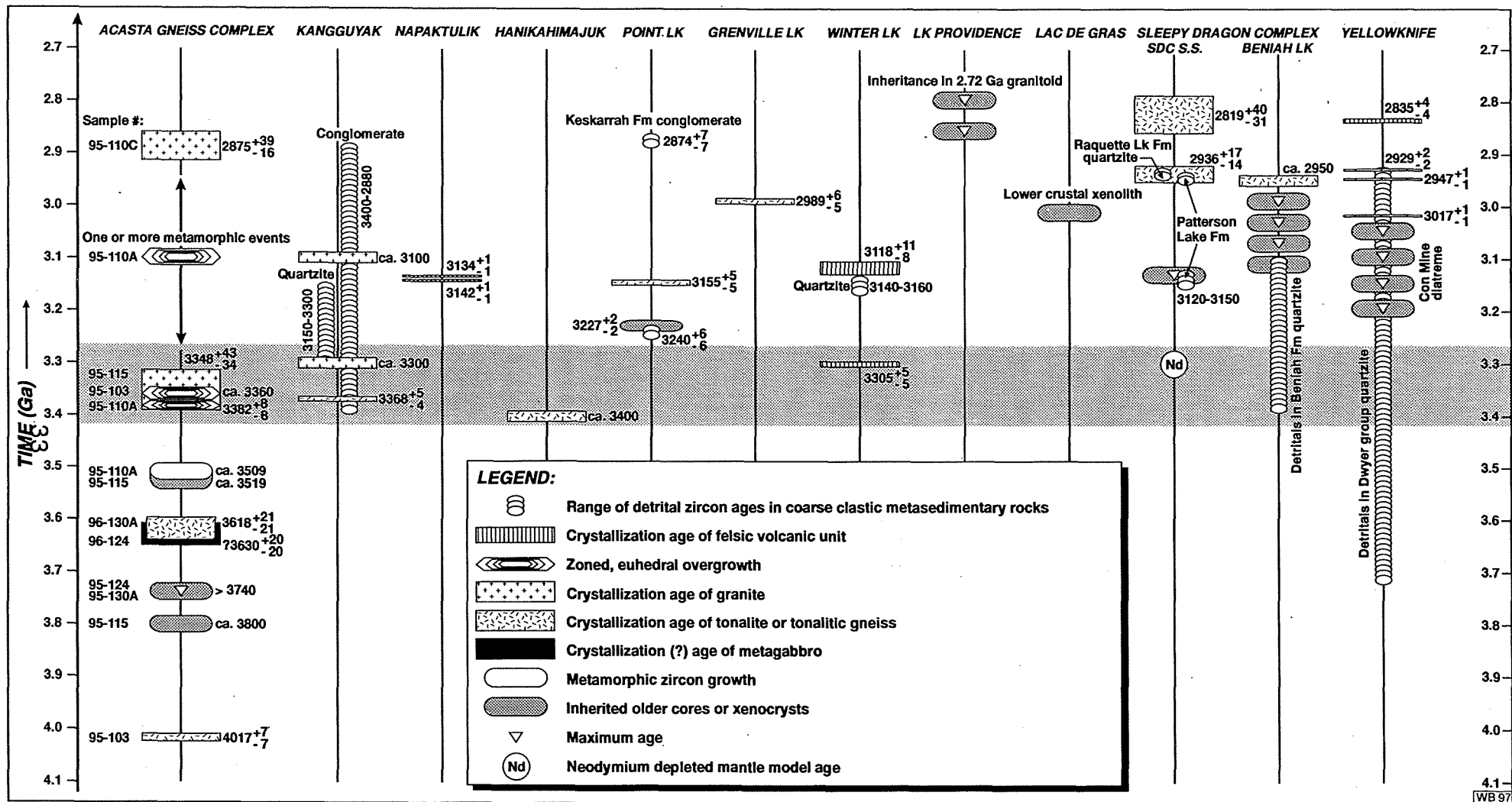
Preliminary Results

Early results have pushed back the age of the "oldest rock": 4017 ± 7 Ma for a grey tonalitic gneiss. This same rock shows evidence for an important high-grade metamorphic and anatectic event at ca. 3360 Ma, resulting in leucosome development, Pb loss from the original zircons, and new zircon overgrowth. A similar age has been established on a large granitic sheet that intrudes nearby gneisses: 3348^{+43}_{-34} Ma. This granitic intrusion is highly foliated and lineated, but not migmatized. Elsewhere, tonalitic dykes cutting metagabbro contain inherited zircons that are older than 3740 Ma, whereas the dykes themselves are interpreted to have crystallized at 3618 ± 21 Ma.

A typical dioritic "banded gneiss" sampled several kilometers further to the west contains i) old metamorphic zircons dated at 3509 ± 19 Ma, which are overgrown by ii) 3382 ± 8 Ma rims related to leucosome development, and iii) even younger rims that provide concordant ages between ca. 3300 and 2900 Ma. The banded gneiss was intruded by granitic sheets that are dated at 2875^{+39}_{-16} Ma. The new SHRIMP-generated U-Pb results are summarized in Figure 1, together with a compilation of all other pre-2700 Ma geochronological data for the Slave structural province.

Figure 1 highlights the fact that, thusfar, a pre-3.5 Ga history has only been documented in the AGC. The high grade, ca. 3.36 Ga event evident from our AGC data set appears to correlate well with similar ages reported from other basement complexes in the northwestern Slave province (e.g., the Kangguyak gneisses). A corresponding history has not yet been convincingly documented in basement rocks from the south-central Slave province, although a Nd model age for Sleepy Dragon Complex gneisses (Dudás et al., 1988) suggest such an early history possibly may be present in this area as well.

Figure 1 (next page): Summary of preliminary SHRIMP U-Pb results on samples from the Acasta gneiss complex (AGC). The AGC data set is compared with a compilation of pre-2.7 Ga data for the entire Slave province. Note that the ca. 3.36 Ga high grade event is the first event in the AGC that appears to be recorded elsewhere in basement complexes of the northwestern Slave province. Sources used for the compilation are listed in the Appendix.



Field evidence suggests that subsequent to intrusion by 2875^{+39}_{-16} Ma granite sheets, the Acasta gneisses were deformed at amphibolite facies metamorphic grade. Later, the AGC experienced intrusion by ca. 2.6 Ga granites, multiple Early Proterozoic dyke swarms, and ca. 1.8 Ga syenites. In addition, the gneisses experienced significant tectonometamorphic events at ca. 2.6 and 1.8 Ga. In the light of this complex evolution, and particularly the severity and "delayed nature" of the ca. 3.60 Ga, 3.36 Ga, 2.88 Ga and younger events, it is possible that the early whole-rock Nd signatures of the gneisses are significantly disturbed, in turn influencing their impact on models for early Earth evolution (*cf.* Bowring et al., 1995). One of the goals of this study is to investigate the behaviour of various isotopic systems in the complex polymetamorphic gneisses and to better constrain the early Nd (and Hf) isotopic record.

References

- Bleeker, W., Villeneuve, M., and Bethune, K., 1997. Thematic structural studies in the Slave Province, Northwest Territories: contrasting basement/cover relationships on the western and southwestern flanks of the Sleepy Dragon Complex; *in* Current Research 1996-C, Geological Survey of Canada, p. 27-37.
- Bowring, S.A., and Housh, T., 1995. The Earth's early evolution; *Science*, v. 269, p. 1535-1539.
- Bowring, S.A., Williams, I.S., and Compston, W., 1989. 3.96 GA gneisses from the Slave province, Northwest Territories, Canada; *Geology*, v. 17, p. 971-975.
- Dudás, F.Ö., Sullivan, R.W., Henderson, J.B., and van Breemen, O., 1988. Nd isotopic reconnaissance of Archean granitoids from the southern Slave province; *Geological Association of Canada, Program with Abstracts*, v. 13, p. A34.
- Frith, R.A., Loveridge, W.D., and van Breemen, O., 1986. U-Pb ages on zircon from basement granitoids of the western Slave structural province, northwestern Canadian Shield; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 113-119.
- Gebert, J., 1994. Final summary of mapping in the Hanikahimajuk Lake area, a portion of the Point Lake volcanic belt, west-central Slave province (86 I/1,2; 86 H/14,15); *in* Exploration Overview 1994, Northwest Territories, NWT Geological Mapping Division, DIAND, p. 35-36.
- Henderson, J.B., van Breemen, O., and Loveridge, W.D., 1987. Some U-Pb zircon ages from Archean basement, supracrustal and intrusive rocks, Yellowknife-Hearne Lake area, District of MacKenzie; *in* Radiogenic Age and Isotopic Studies: Report 1, Geological Survey of Canada, Paper 87-2, p. 111-121.
- Henderson, J.B., Loveridge, W.D., and Sullivan, R.W., 1982. A U-Pb study of zircon from granitic basement beneath the Yellowknife Supergroup, Point Lake, District of MacKenzie; *in* Current Research, Part C, Geological Survey of Canada, Paper 82-1C, p. 173-178.
- Isachsen, C.E., 1992. U-Pb zircon geochronology of the Yellowknife volcanic belt and subjacent rocks, N.W.T., Canada: constraints on the timing, duration, and mechanics of greenstone belt formation; unpublished Ph.D. thesis, Washington University, St. Louis, Missouri, 164 p.
- Isachsen, C.E., and Bowring, S.A., in press. The Dwyer group and Anton complex: basement to the Yellowknife greenstone belt revealed and implicated in greenstone belt formation; *Canadian Journal of Earth Sciences*.
- Isachsen, C.E., and Bowring, S.A., 1994. Evolution of the Slave craton; *Geology*, v. 22, p. 917-920.
- James, D.T., and Mortensen, J.K., 1992. An Archean metamorphic core complex in the southern Slave Province: basement-cover structural relationships between the Sleepy Dragon Complex and the Yellowknife Supergroup; *Canadian Journal of Earth Sciences*, v. 29, p. 2133-2145.
- Krogh, T.E., and Gibbins, W., 1978. U-Pb isotopic ages of basement and supracrustal rocks in the Point Lake area of the Slave structural province, Canada; *Geological Association of Canada, Mineralogical Association of Canada, and the Geological Society of America, Abstracts with Programs*, v. 3, p. 438.

Lambert, M.B., and van Breemen, O., 1991. U-Pb zircon ages from the Sleepy Dragon Complex and new occurrence of basement rocks within the Meander Lake Plutonic Suite, Slave Province, N.W.T.; *in* Radiogenic and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p. 79-84.

Nikic, Z., Baadsgaard, H., Folinsbee, R.E., Krupicka, J., Payne Leech, A., and Sasaki, A., 1980. Boulders from the basement, the trace of ancient crust?; Geological Society of America, Special Paper 182, p. 169-175.

Padgham, W.A., 1996. Slave conglomerate dating; NWT Geology Division, DIAND, Report EGS 1996-12, 85 p.

Schärer, U., and Allègre, C.J., 1982. Investigation of the Archean crust by single-grain dating of detrital zircon: a graywacke of the Slave province, Canada; Canadian Journal of Earth Sciences, v. 19, p. 1910-1918.

Villeneuve, M.E., 1993. Preliminary geochronological results from the Winter Lake-Lac de Gras Slave Province NATMAP project, Northwest Territories; *in* Radiogenic Age and Isotopic Studies: Report 7, Geological Survey of Canada, Paper 93-2, p. 29-38.

Villeneuve, M.E., Relf, C., Hrabi, B., and Jackson, V., 1994. Ages of detrital zircons from supracrustal sequences in the Slave province, NWT, Canada: implications for age of basement; Geological Society of America 1994 Annual Meeting, Abstracts with Programs, v. 26, p. A-232.

Yamashita, K., Jensen, J.E., Creaser, R.A., and Gebert, J.S., 1995. Geology, geochemistry and Nd isotopic study of the Hanikahimajuk Lake area (NTS 86 I/2, 86 H/14,15), northern Point Lake belt, Slave structural province, NWT; Geological Association of Canada, Program with Abstracts, v. 20, p. A-112.

Appendix

Acasta gneiss complex: Bleeker and Stern (unpublished data), see also Bowring et al. (1989).
Kangguyak gneisses: Villeneuve et al. (1994), Villeneuve (unpublished data); see also Isachsen and Bowring (1994).

Napaktulik Lake: Villeneuve et al. (1994).

Hanikahimajuk area: Gebert (1994), Yamashita et al. (1995).

Point Lake: Schärer and Allègre (1982), Padgham (1996), Krogh and Gibbins (1978), Henderson et al. (1982), and Henderson (unpublished data).

Grenville Lake area: Frith et al. (1986).

Winter Lake area: Villeneuve et al. (1994).

Lake Providence area: Villeneuve (1993).

Lac de Gras area: W.J. Davis (personal communication, 1997).

Sleepy Dragon Complex: Henderson et al. (1987), Lambert and van Breemen (1991), James and Mortensen (1992), Dudás et al. (1988), Bleeker et al. (1997), and Bleeker and Villeneuve (unpublished data).

Beniah Lake area: Isachsen and Bowring (in press).

Yellowknife belt: Nikic et al. (1980), Isachsen (1992), and Isachsen and Bowring (in press).

THE SLAVE PROVINCE: EVIDENCE FOR CONTRASTING CRUSTAL DOMAINS AND A COMPLEX, MULTISTAGE TECTONIC EVOLUTION

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The Archean Slave structural province, a relatively small but well-exposed craton in northwestern Laurentia, has an extensive rock record ranging from the >4.0 Ga Acasta gneiss complex to <2.6 Ga granitoids. Recent U-Pb geochronology has documented diverse supracrustal packages with discrete ages ranging from ca. 3.3 Ga, and 3.1 Ga, down to ca. 2.58 Ga.

Supracrustals that traditionally were included into the ca. 2.7 Ga, province-wide Yellowknife Supergroup are now recognized to represent a number of lithotectonic assemblages. These assemblages are bounded by unconformities and (or) structural contacts and must have formed in contrasting tectonic environments. The supracrustal record necessitates a complex, multistage evolution that is most easily explained by interaction between juvenile arc terranes and one or more microplates consisting of older sialic crust and their cover sequences. A newly proposed tectonic model (Fig. 1), constrained by isotopic as well as new field observations and involving multiple stages of arc development, can reconcile the long-standing debate between previous models.

Specifically, in the Sleepy Dragon area of the southwestern Slave province, 2687 ± 2 Ma dykes stitch an older and previously deformed basalt sequence to ca. 2.9 Ga, mylonitized basement and its clastic cover sequence. These dykes, in all probability, fed an overlying continental arc sequence of identical age. Subsequent rifting of this continental arc led to basin development culminating in the deposition of 5-10 km of ca. 2661 Ma turbidites (Burwash Formation) and intercalated felsic tuffs. These events followed an older rift-drift phase recorded in the cover of the sialic basement blocks of the southwestern Slave, and a distinct phase of ca. 2710-2690 juvenile arc construction in eastern Slave terranes such as the Back River complex.

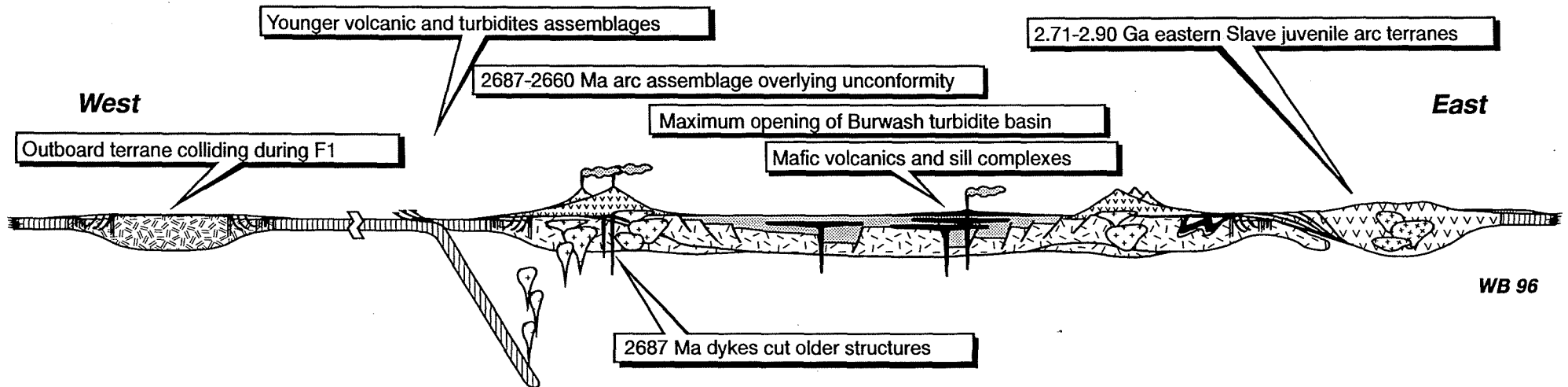
The Burwash Formation turbidite basin was closed and shortened into a northeast-trending regional fold belt (D_1) prior to ca. 2620 Ma, the age of voluminous I-type granitoid plutonism. Large-scale refolding of this fold belt (D_2) followed at ca. 2600 after which deformation became more localized into regional faults zone. The two large-scale deformation events can be interpreted as distinct plate interactions with as yet unidentified colliding terranes.

Figure 1 (next page): Complex, multistage tectonic model for the Slave structural province. The diagram illustrates just one stage of the model (Stage 6: ca. 2660 Ma), during which rifting of a continental successor arc in the west-central Slave province led to opening and deepening of the Burwash depositional basin. The successor arc and Burwash turbidite basin overlap on older juvenile arc and basement terranes and collapsed during D_1 closure prior to 2620 Ma. D_1 closure of the Burwash basin is thought to have resulted from terrane collision along an active western margin. Possibly, old 3.1-4.1 Ga basement such as is exposed in the northwestern Slave province was accreted during this collisional event.

Circa 2660 Ma

Stage 6:
Maximum opening of Burwash basin;
mafic magmatism develops in extended basin

- | | | |
|---|---|---|
|  Mafic dyke swarms |  Mafic volcanic flows and sill complexes |  Pre-2680 turbidites |
|  Old sialic basement of northwest Slave province |  Burwash Formation: >5000 m thick turbidite sequence |  Juvenile arc |
| |  Younger continental arc assemblage |  Synvolcanic arc plutons |
| |  Younger arc plutonic suite |  Oceanic lithosphere |
| |  2.90-2.70 quartzite, BIF, and tholeiite sequences | |
| |  Older supracrustal assemblages | |
| |  Mafic dyke swarms | |
| |  Pre-2.80 Ga sialic basement | |



Use of regional magnetic data in the SNORCLE area: Examples from the Slave Province

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INTRODUCTION

Regional gravity, topography and particularly aeromagnetic data sets for the SNORCLE area are being compiled and enhanced to maximize their utility for tectonic and structural interpretation. Enhancement methods include micro-levelling of flight line corrugations, automated trend reinforcement, and selective removal of directional trends. The enhanced data sets are being analysed, using (semi-) automated interpretation methods, such as analytic signal (Roest et al., 1992) and Euler Deconvolution (Reid et al., 1990). Here, we illustrate the selective removal of radiating magnetic anomalies, related to the Mackenzie dyke swarm. In addition, we report on the preliminary results of a target gravity survey along SNORCLE corridor 1 (Figure 1).

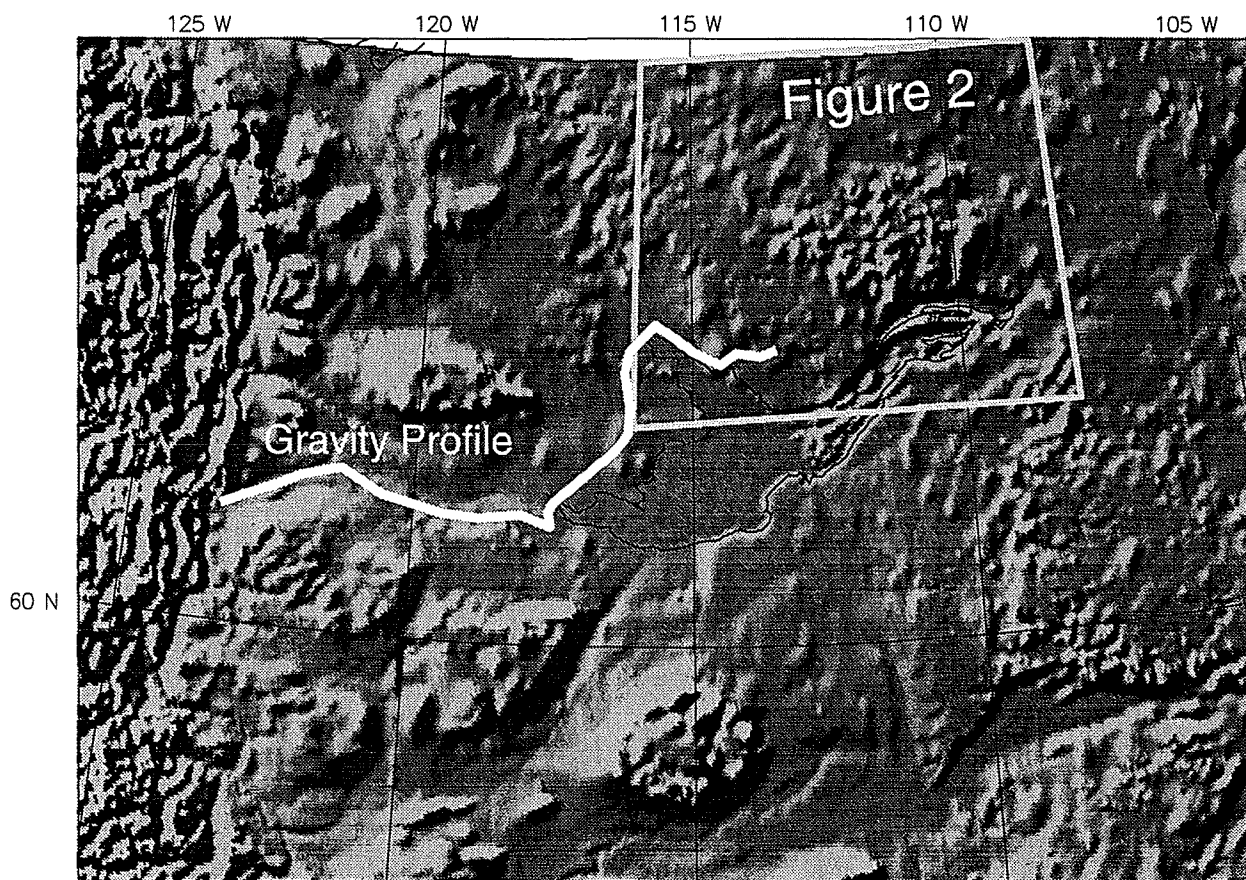


Figure 1: Location map superimposed on shaded topographic relief.

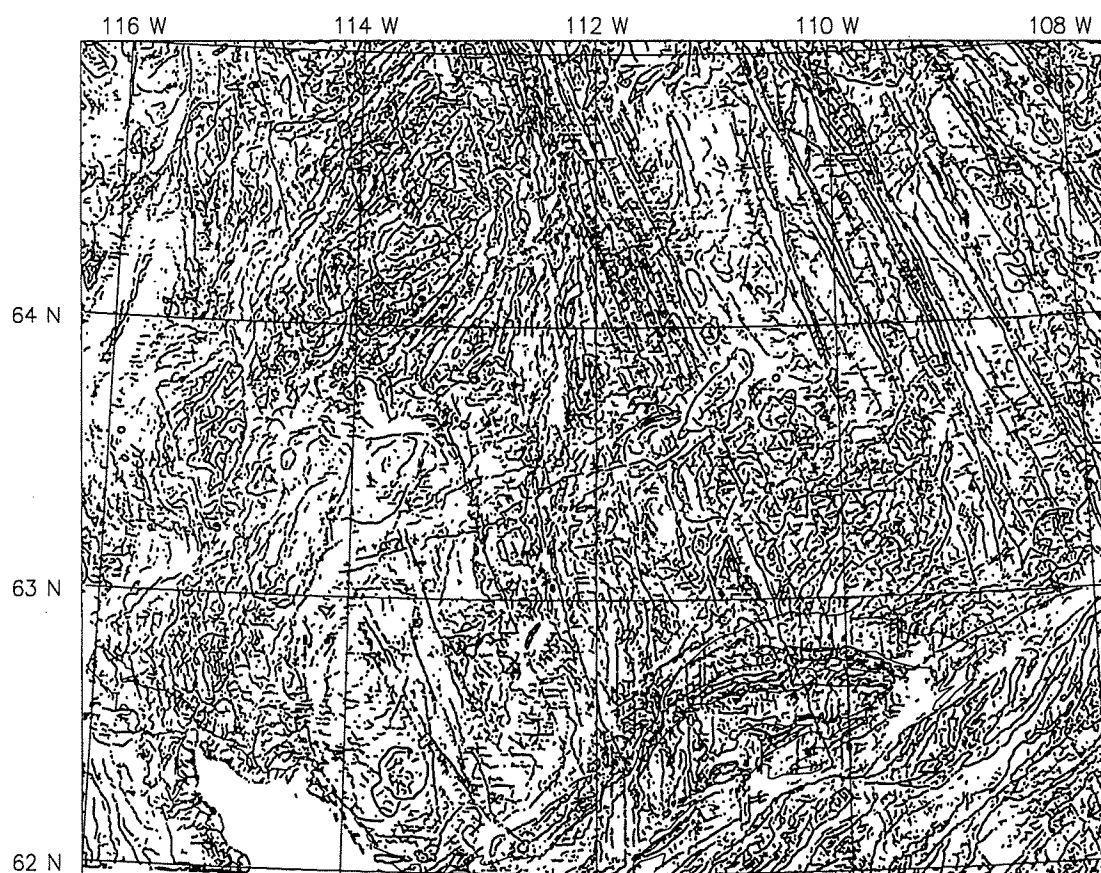


Figure 2a: Pseudo gravity gradient maxima before processing.

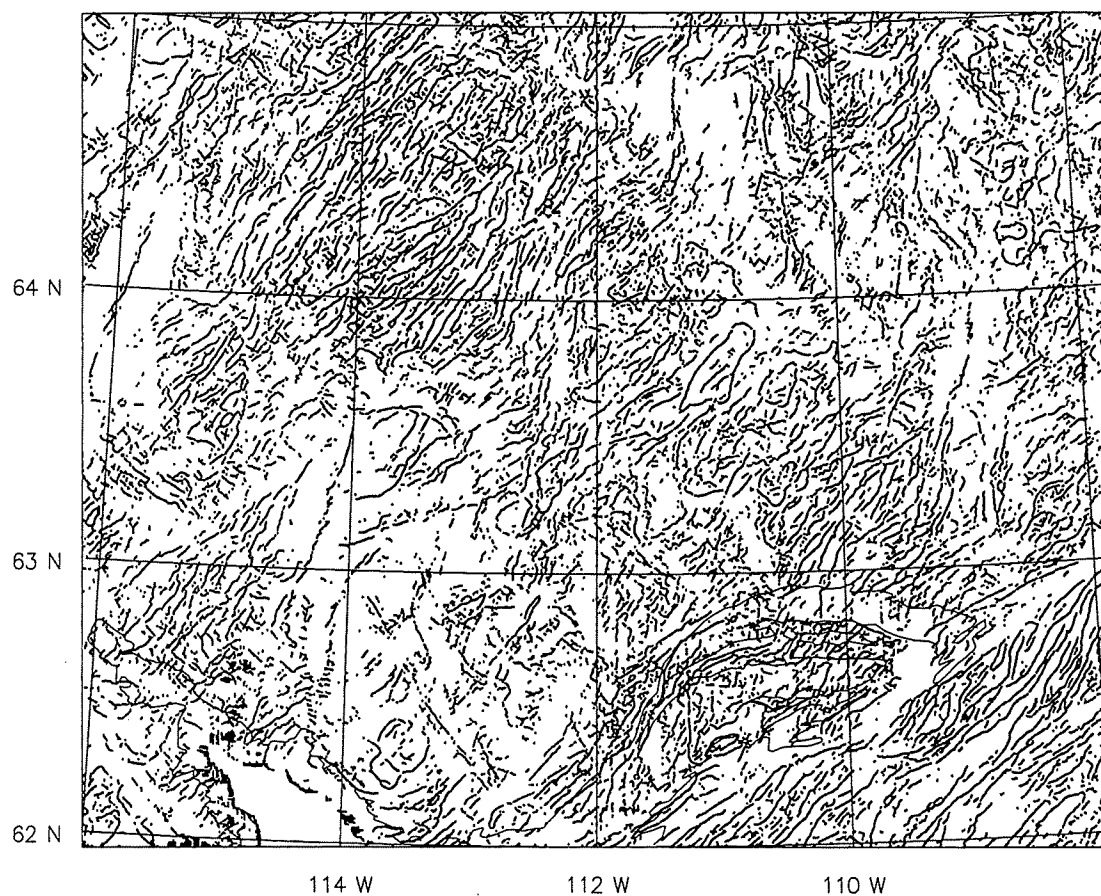


Figure 2b: Pseudo gravity gradient maxima after dyke removal (see text).

AEROMAGNETICS

The Mackenzie dykes constitute the largest known dyke swarm on Earth and likely originated from a mantle plume whose location has been estimated at 70° N, 118° W (e.g. Ernst et al., 1995). Most of the Mackenzie dykes have a quartz-tholeiitic composition and are clearly magnetic, with maximum amplitudes of over 100 nT. The average dyke width is ~30 m, but some reach thicknesses of >100 m (Fahrig, 1987). Both qualitative and quantitative interpretation of the aeromagnetic data are hindered by the presence of the dyke related magnetic anomalies, because they obscure the magnetic signatures due to basement lithology and structure and their effects dominate when automated interpretation methods are applied to gridded data sets.

Figure 2a shows a representation of the trends in the observed magnetic field over a part of the Slave province and illustrates the ubiquitous nature of the Mackenzie dykes. In this example, the pseudo gravity method (Blakely and Simpson, 1986) is used to delineate the positions of magnetic contrasts. In order to remove the effects of the radiating dyke swarm, a simple coordinate transformation is carried out that makes the dyke related anomalies parallel and north-south trending. A normal directional (low-pass) filter is then applied to remove the dyke effects. After restoring the original coordinate system, the 'de-dyked' magnetic anomalies are obtained (Figure 2b). Comparison of Figures 2a and 2b shows a dramatic difference in the dominating structural trends before and after dyke removal. Note that the north-south trends over eastern Great Slave Lake are caused by flight line corrugations that have not been removed as yet. We are currently analysing the processed magnetic data and will report on the preliminary results.

GRAVITY

A target gravity survey was carried out along corridor 1 of the SNORCLE transect, in the fall of 1996. The survey was sponsored by the Regional Geophysics Section, Continental Geoscience Division of the GSC, and carried out by the National Gravity Program, Geomatics Canada. Over 700 gravity measurements were obtained along the seismic line, with an average spacing of 1 km. Preliminary data will be shown, in conjunction with preliminary seismic data and the regional gravity field in the area.

REFERENCES

- Blakely R.J., and Simpson, R.W., 1986, Approximating edges of source bodies from magnetic or gravity anomalies: *Geophysics*, **51**, 1494-1498.
- Ernst, R.E., Buchan, K.L. and Palmer, H.C., 1995, Giant dyke swarms: Characteristics, distribution and geotectonic implications, *in* Baer, G. and Heimann, A. (Editors), *Physics and chemistry of dykes*, Balkema, Rotterdam, pp. 3-21.
- Fahrig, W.F., 1987, The tectonic settings of continental mafic dyke swarms: failed arm and early passive margin, *in*, Halls, H.C. and Fahrig, W.F. (Editors), *Mafic Dyke Swarms: Geol. Assoc. Can. Spec. Pap.* **34**, 331-348.
- Reid A.B., Allsop, J.M., Granser, H., Millett, A.J., and Somerton, I.W., 1990, Magnetic interpretation in three dimensions using Euler deconvolution: *Geophysics*, **55**, 80-91.
- Roest, W.R., Pilkington, M., and Verhoef, J., 1992. Magnetic interpretation using the 3-D analytic signal, *Geophysics*, **57**, 116-125.

Upper mantle structure beneath the Northern Cordillera

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The study area of the SNORCLE Lithoprobe transect comprises the northern Canadian Cordillera and the northwestern Canadian shield. An array of five portable broadband seismographs has been deployed along the trend of the transect, to complement five permanent stations of the Canadian National Seismic Network and seven Alaskan short-period instruments. The objective of the experiment is to examine the physical state of the upper mantle along the transect. P-wave travel-time residuals up to 2 seconds have been measured, and analyzed using a non-linear tomographic technique, thereby recovering velocity structure between 100 and 600 km depth for the western portion of the transect.

Two significant P-wave mantle velocity anomalies have been located. The first, a relatively shallow high-velocity feature located at the western edge of the model, has been interpreted as being the edge of the Pacific slab from the southern Alaska subduction zone. The second is a large, tabular low-velocity anomaly centered at 60°N by 136°W, elongate northwest-southwest, dipping southeast, and reaching a depth of 450-500 km. This low-velocity anomaly is judged to reflect a thermal anomaly of the order of 100°C, with a possible compositional component. Multiple interpretations of the low-velocity feature are considered, the two main hypotheses being a mantle plume or a flow feature related to the proximity of the subducting slab and the opening of the northern Cordilleran slab window. The latter hypothesis is favored, due to the absence of other evidence for a plume in this region. In addition, the upper part of the low-velocity anomaly may reflect the influence of strain heating at lithospheric levels, related to the convergence of the Pacific and North American plates and the uplift of the St. Elias Mountains.

Results from 1996 MT studies along SNORCLE profiles 1 and 1A

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SNORCLE scientific and transect objectives

The first phase of line-item acquisition of EM data along the SNORCLE transect began on August 1st, 1996, with a sixty (60) station magnetotelluric (MT) survey. A contractor (Phoenix Geophysics Ltd.) acquired the high frequency data pertinent to primarily the crust. In addition, longer period measurements were made at each location to image conductivity features in the sub-crustal lithosphere down to the conducting asthenosphere.

Overall and specific "Slave" objectives that can be addressed by these MT studies include:

- What kind of deep crust and mantle underlie the oldest rocks on Earth?
- Did plate tectonics operate in the Early Archean?
- Is the tectonic style of Early Archean protocontinental nuclei unique?
- How have 4 billion year old cratons been modified since the Archean?
- What is the nature of the Anton terrane?

1996 Field Program

During August-October, 1996, sixty magnetotelluric sites were acquired along the whole of the SNORCLE Corridor 1 transect (Fig. 1), including the Fort Providence - Wood Buffalo National Park profile (Profile 1A). There were 13 sites on the exposed Slave craton from Tibbit Lake to Rae, 9 on the Great Bear magmatic arc from Rae to Fort Providence, 24 on the Proterozoic section (Hottah, Fort Simpson and Nahanni terranes) from Fort Simpson to Nahanni Butte, and 15 on the section crossing the Great Slave Lake shear zone (GSLsz) from Fort Simpson to within the boundaries of Wood Buffalo. At all sites was acquisition of high frequency (10 kHz to 0.01 Hz) data by a commercial contractor (Phoenix Geophysics), with three

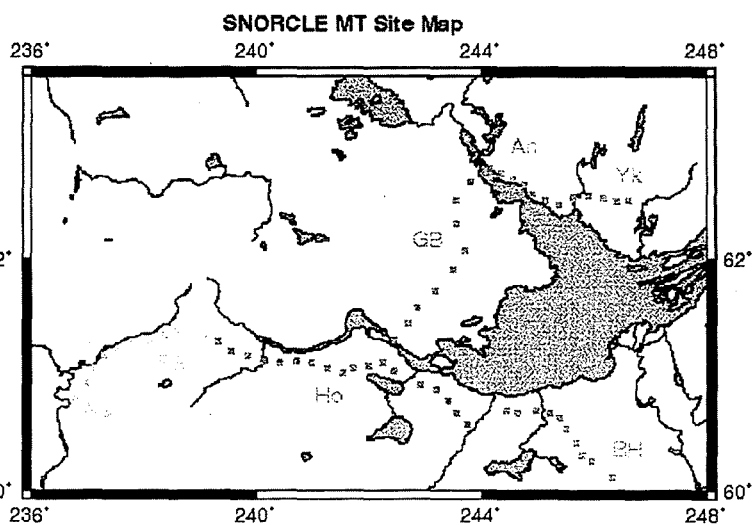


Figure 1: SNORCLE transect corridor 1 on a map of the tectonic elements of the region.

(GSLsz) from Fort Simpson to within the boundaries of Wood Buffalo. At all sites was acquisition of high frequency (10 kHz to 0.01 Hz) data by a commercial contractor (Phoenix Geophysics), with three

nights of recording. Additionally, there was one to four weeks recording of long period (20 - 30,000 s) data, using fifteen GSC LIMS (Long period Magnetotelluric System) units, at each location by the bird-dogger and Nick Grant (a contracted field assistant).

The wideband MT data (using Phoenix's V5 system) were processed in the field using a robust remote-reference code based on the algorithm of *Jones and Jödicke (1984)*. The LIMS data have only undergone preliminary processing, as final processing will involve using data from the Yellowknife geomagnetic observatory and three sites operated as part of the CANOPUS MARIA array (Contwoyto Lake, Fort Simpson and Fort Smith) as remote reference fields to remove noise effects and also reduce non-uniform source field contamination.

Figure 2 illustrates an example of the V5 and LIMS data from a site just to the west of Rae on the Great Bear magmatic arc (Site 101). Even at this level of processing of the LIMS data, the overall data quality from both systems can only be described as superb. Believable V5 data were even acquired in the AMT "dead-band" of 1-3 kHz, albeit with lower quality. The absence of anthropogenic noise and low electric field distortion compound to give highly precise estimates of the magnetotelluric impedance tensor in all elements for almost all sites, which is rarely the case for MT data acquired on highly resistive regions (cratons, batholiths, etc.).

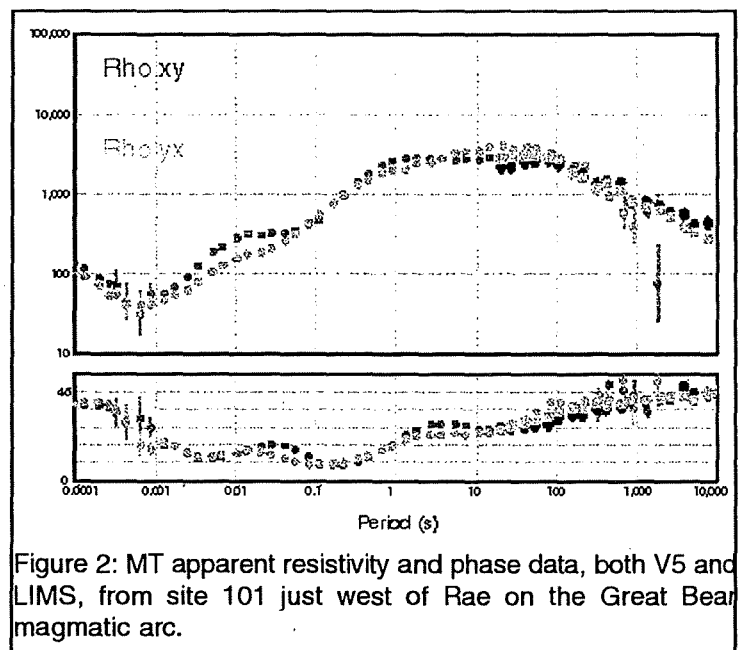
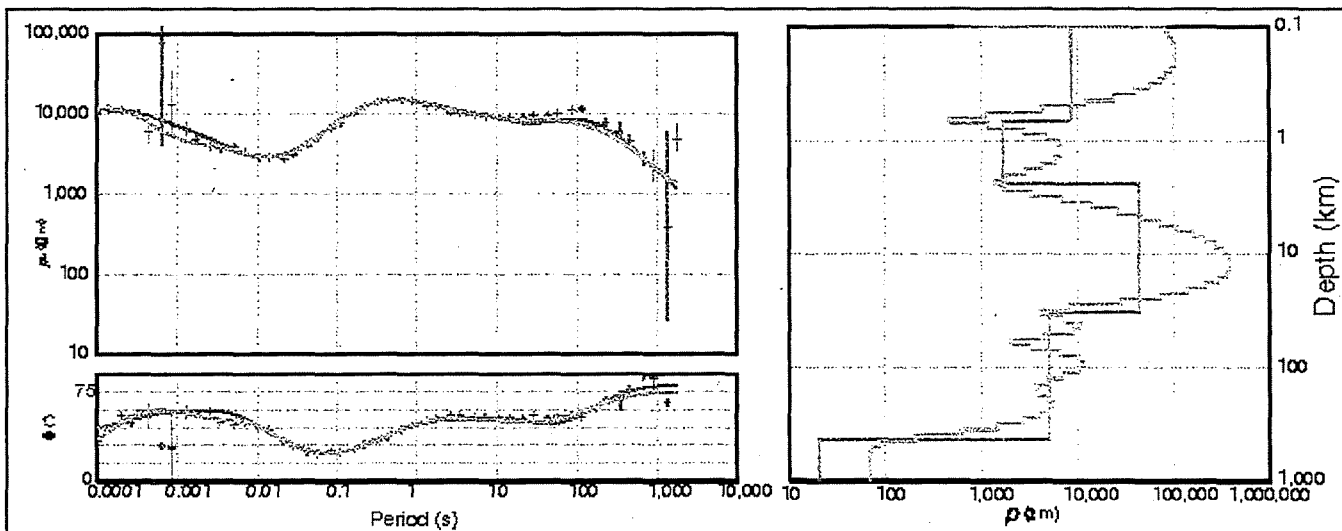


Figure 2: MT apparent resistivity and phase data, both V5 and LIMS, from site 101 just west of Rae on the Great Bear magmatic arc.

Results

Preliminary analyses and interpretation of the MT data have been conducted, and indicate features that are important for the Slave craton specifically, and possibly for the geological history of the early Earth in general.



Site 106 (Anton terrane) 1D models

Figure 3: MT data from a site in the middle of the Anton terrane (site 106) and 1D models, obtained by nonlinear inversion, that fit the data. Two classes of 1D models are shown. The layered earth model assumes discontinuous jumps in resistivity at each layer. There is a discrete jump from the very high resistivity ($>40,000 \Omega.m$) of the crust at 32.5 ± 2 km, to lower resistivity ($\sim 5,000 \Omega.m$) in the mantle. This depth correlates well with the crustal thickness of 32 km reported by early refraction experiments (*Berry and Mair, 1977*), and reasonably well with the thickness of 34-38 km derived from receiver function analysis by *Owens et al. (1987)*. The smoothest possible model shows that this jump is indeed quite sharp.

The Anton terrane shows no conducting lower crust (Figs. 3 and 4). This is in contrast to all other Archean cratons, such as the Superior, Kaapvaal, and Siberian, and younger-aged (Proterozoic and Phanerozoic) crusts. Although the cause of lower crustal conductivity is controversial, with either interconnected saline fluid or interconnected grain-boundary carbon being the two most currently-promoted theories, the absence of either of these beneath a terrane hosting the oldest dated rocks on Earth is a first-order result.

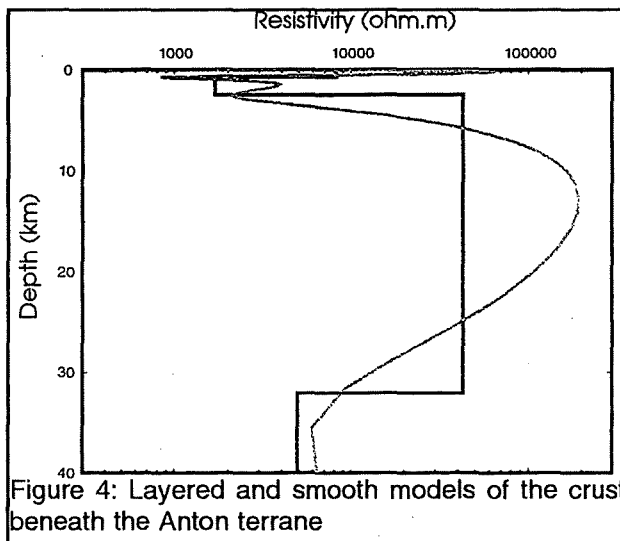


Figure 4: Layered and smooth models of the crust beneath the Anton terrane

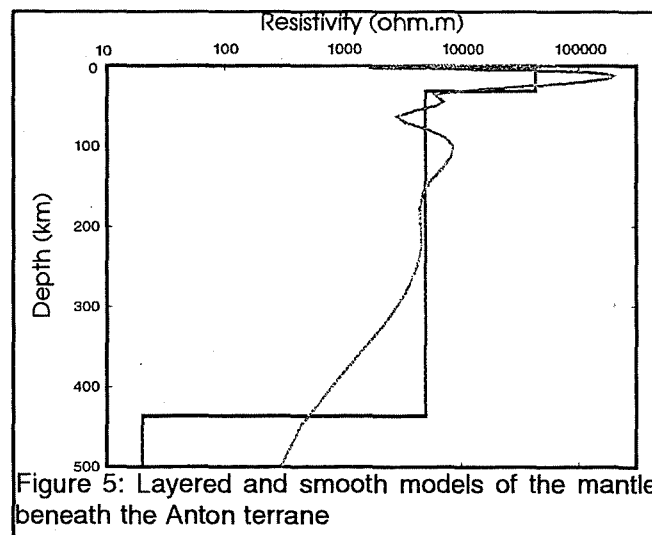


Figure 5: Layered and smooth models of the mantle beneath the Anton terrane

Beneath the Anton terrane there is an order of magnitude increase in conductivity at a depth corresponding to the crust-mantle boundary (Fig. 4). This observation, of the electrical equivalent of the seismic "Moho", is a first, as at other locations the existence of a lower crustal conductor precludes confirmation of a crust-mantle conductivity contrast.

The lithosphere beneath the Anton terrane is laterally homogeneous, thicker and more resistive compared to lithosphere to both the east and west. Models show that it is resistive ($>1,000 \Omega.m$) to at least 250+ km depth (Fig. 5).

The lateral variation in the subcrustal lithosphere can be derived from the lateral variation in the MT parameters. Figure 6 shows the apparent resistivities at a period that is sampling about 50 km into the lithosphere (30 s). The values rise from 100-300 $\Omega.m$ on the Proterozoic terranes to around 10,000 $\Omega.m$ on the Slave craton. This rise occurs mostly on the Fort Providence - Rae section of the Profile (GBMZ). These results imply that the lithosphere thins dramatically westward beneath the Great Bear magmatic zone, from 250+ km to 100+ km.

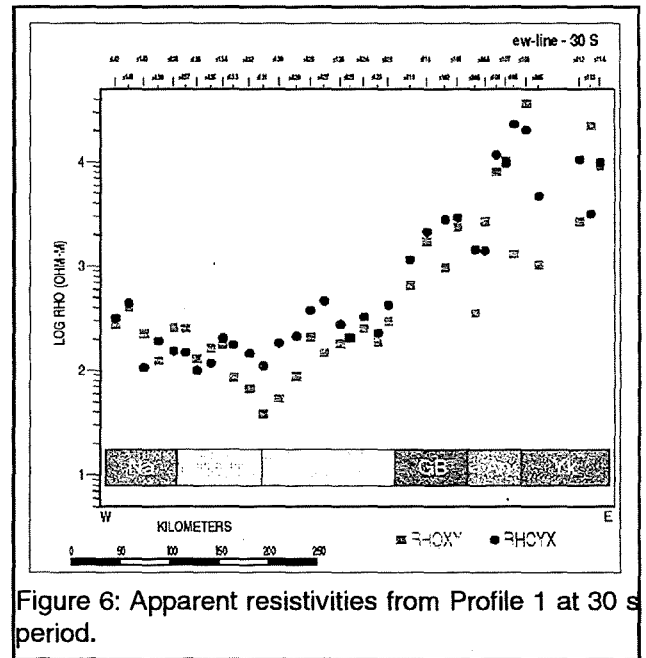


Figure 6: Apparent resistivities from Profile 1 at 30 s period.

By studying the phase difference between orthogonal impedances of the MT tensor, it is possible to determine whether there is any anisotropy in the measurements associated with structures, similar to the SKS technique in seismology. Figure 7 displays the phase differences for all stations at a period which samples around 50 km depth in the subcrustal lithosphere (30 s). Beneath stations around Yellowknife, the lithosphere is electrically anisotropic, with the more conductive direction being around N105E (Fig. 6), compared to the seismic SKS direction for RSNT of N48E. The lithosphere is laterally homogeneous between Fort Providence

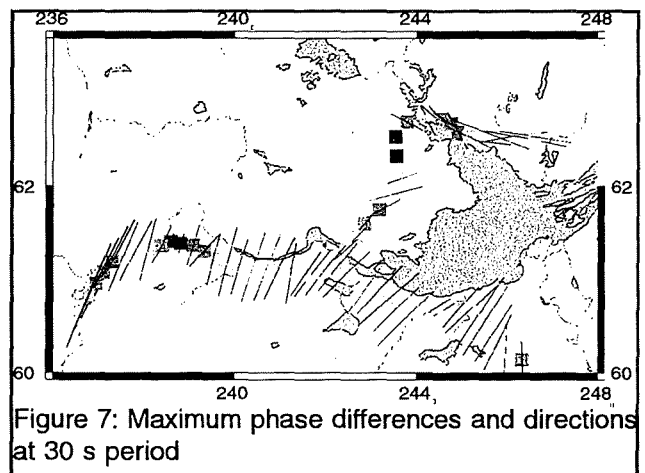


Figure 7: Maximum phase differences and directions at 30 s period

and Rae, but becomes anisotropic west of Fort Providence (Fig. 7).

Sites around the Great Slave Lake shear zone display a strong anisotropy with a most conductive direction of N35E (Fig. 7), i.e., oblique to the direction of the GSLsz of N45E. This obliquity is consistent with the dextral movement sense on the shear zone (hypothesis of *Ji et al.*, 1996), and suggests that the GSLsz penetrates deep into the mantle.

These results already speak directly to various of the defined transect objectives. Those on the Anton terrane give support for the contention of *Padgham and Fyson* (1992) that at least part of the Slave exhibits distinctive features not apparent in the Superior or other Archean cratons.

In addition, very long period MT recording is being made within the Yellowknife seismic array (at seismic station B4). The LIMS system deployed there has been modified to remove the high-pass 30,000 s analogue filters on the telluric channels. It is intended to remain in place for at least two years in order to try to obtain a long record from which very long period MT responses can be derived. The success of the work in Carty Lake on the Superior craton (*Schultz et al.*, 1993), where a conductivity-depth curve was defined to depths in excess of 1,000 km exhibiting discrete conductivity jumps near depths of 425 km and 660 km, motivated this deployment.

Future MT measurements

Vehicle access of the Slave craton is very limited, and Echo Bay's winter road provides a logistical opportunity to extend the geophysical observations from around the southwest corner of the Slave to well into the interior. In particular, the winter road affords the possibility to cross the Sleepy Dragon Complex and the Contwoyto Terrane, and to map electrically the lateral variation of the crust and sub-crustal lithosphere across the Slave craton.

MT along the winter road is an affordable geophysical method for obtaining information on the regional-scale lateral variation of the Slave's lithosphere, and will contribute significantly to the objectives of the transect. The winter road has a total length extent of 600 km, and requires a minimum of 40 MT sites along it to characterize the substructure electrically. The results should provide an improved picture of the assembly of the Slave Province and allow evaluation of models such as that of *Helmstaedt and Schulze* (1989) and *Kusky* (1989) etc.

Questions to be addressed are:

- Is the lack of a lower crustal conductor a Slave characteristic, or just an Anton terrane one?
Or is it associated with the older rocks (>2.8 Ga) thought to underlie much of the west compared

to the east?

- Is there a difference between the mantle lithospheres on either side of the Pb isotope boundary?
- Is the lithosphere in the northern part different from the south as a result of modification caused by the emplacement of the plume that generated the McKenzie dyke swarm (1280 Ma)?
- What is the crustal geometry of the Sleepy Dragon complex?

Measurements along the winter road are planned for February-April, 1998. This work is partially supported by contributions from industry.

Auxiliary "Slave Lakes" Experiment

A proposal will be resubmitted to the National Science Foundation for an experiment in which ocean-bottom instrumentation will be placed in lakes around the southern and central Slave. The instruments belong to Dr. Alan Chave at Woods Hole Oceanographic Institution. If this experiment is funded, we will install the systems in mid-July, 1998, with a recording rate of 1 s. They will be retrieved in mid-September, 1998, and redeployed with a slower recording rate (60 s) for ten months. This should give us a year of data from each of the nine lakes, which will give information on the large scale lateral variability of conductivity to depths in excess of 400 km to compare with the Superior Province (Schultz *et al.*, 1993).

References

- Berry, M.J. and J.A. Mair, 1977. The nature of the Earth's crust, in *Canada AGU Geophys. Mon.* 20, J.G. Heacock, Editor, Washington, D.C., 319-348.
- Helmstaedt, H.H., and D.J. Schulze, 1989. Southern African kimberlites and their mantle sample: implications for Archean tectonics and lithosphere evolution, in J. Ross (ed.), *Kimberlites and related rocks*, vol. 1: Their composition, occurrence, origin, and emplacement, *Geol. Soc. Aust. Spec. Pub.*, 14, 358-368.
- Ji, S., S. Rondenay, M. Mareschal and G. Senechal, 1996. Obliquity between seismic and electrical anisotropies as a potential indicator of movement sense for ductile mantle shear zones. *Geology*, 24, 1033-1036.
- Kusky, T.M., 1989. Accretion of the Archean Slave province. *Geology*, 17, 63-67.
- Owens, T.J., S.R. Taylor and G. Zandt, 1987. Crustal structure at regional seismic test network stations determined from inversion of broadband teleseismic *P* waveforms. *Bull. Seism. Soc. Am.*, 77, 631-662.
- Padgham, W.A. and W.K. Fyson, 1992. The Slave Province: a distinct Archean craton. *Can. J. Earth Sci.*, 29, 2072-2086.
- Schultz, A., R.D. Kurtz, A.D. Chave and A.G. Jones, 1993. Conductivity discontinuities in the upper mantle beneath a stable craton. *Geophys. Res. Lett.*, 20, 2941-2944.

LITHOPROBE SNORCLE-ing BENEATH THE NORTHWESTERN CANADIAN SHIELD: DEEP LITHOSPHERIC REFLECTION PROFILES FROM THE CORDILLERA TO THE ARCHEAN SLAVE PROVINCE

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ABSTRACT

Nearly 725 km of new deep reflection data from the SNORCLE transect in the northwestern Canadian Shield provide images of terranes and their boundaries from the Archean Slave Province on the east to the Cordillera on the west. The crust is highly reflective along the entire profile, even where results from the recent magnetotelluric measurement indicate highly resistive crust in the Anton terrane of the Slave Province. The Moho is generally subhorizontal near 11.0 s except in the Hottah terrane, where it is near 12.0 s, and beneath the Fort Simpson arc, where its position is uncertain.

INTRODUCTION

The first SNORCLE seismic reflection acquisition took place along Corridor 1 from October 14 to November 16, 1996. The profile began near the front of the Mackenzie Mountains about 100 km southwest of Fort Simpson and ended 724.5 km later at Tibbit Lake northeast of Yellowknife. It crosses

the major Proterozoic domains that are situated beneath the thin Phanerozoic sedimentary rocks on the west, and those of the Slave province that are exposed on the east. From west to east, these are (Figure 1): the Fort Simpson structural high, the Hottah terrane, the Great Bear magmatic arc, the Anton terrane, and the Yellowknife basin. Nearly all of these Precambrian domains are oriented north-south, and thus are crossed at high angle to strike by the profile.

Acquisition

Data were recorded by JRS exploration of Calgary using the following parameters:

No. of vibrators	= 4 or 5
No. of sweeps	= 5 or 4
Sweep frequencies	= 10 - 80 Hz (linear)
Sample rate	= 4 ms
Sweep length	= 20 s
Record length	= 32 s (uncorrelated)
No. of channels/record	= 404
Receiver station spacing	= 60 m
No. of geophones	= 9 per station
Vibrator point spacing	= 90 m
Geophone frequency	= 10 Hz
Nominal fold	= 134
Instruments	= Sercel 388 (24 bit)

At every 20th VP (vibrator point), data were correlated to 12 s in the field for quality control monitoring. Once JRS began working 24 hours (after the first week of recording), they averaged more than 25 km/day. The weather was nearly perfect for the whole survey with little snow and little wind. There were few logistical problems; exceptions included ferry travel across the Liard and Mackenzie Rivers, recording through Yellowknife, and occasional 60 Hz power line interference (near Ft. Providence, Rae, and Yellowknife). The 60 Hz noise was severe enough to mask the desired signal in the field; however, the 24 bit dynamic range of the instruments was sufficient to allow us to record without adding an in-field filter. Application of a 60 Hz notch filter during data processing removed this noise.

Data Processing

The entire data set is being processed at the LITHOPROBE Seismic Processing Facility at the University of Calgary. A normal processing sequence includes:

1. Diversity-type stack of uncorrelated records
2. Extended cross-correlation to full 32 s record length
3. Crooked line geometry: 30 m x 1500 m bins
4. 60 Hz notch filter where necessary
5. Trace edits; first break picks
6. Refraction statics computation; two layer model
7. Velocity analysis; local constant velocity stacks
8. Application of first break mutes
9. Automatic gain control; 800 ms window
10. Gapped deconvolution on sediments; spectral balance on shield
11. Statics application
12. Normal moveout correction on CMP gathers
13. Residual statics computation; 2.0-6.0 s window
14. Stack; nominally 134 fold
15. Trace energy balance; 8-16 s window
16. FX deconvolution (sliding window)
13. (Migration; constant velocity phase shift migration)
14. Coherency filter
15. Plot.

RESULTS

General

A number of key observations can be made at this preliminary stage of analysis. First, and most importantly, the data quality is extremely high along almost the entire survey line. The only exception is in the vicinity of Yellowknife where sharp road bends, mining operations, and heavy traffic interfered with the signal quality. The crust is reflective throughout with the base of reflectivity varying from about 11.0 s (about 35-36 km) beneath the Slave Province and Great Bear arc, to 12.0 s (about 39 km) beneath the Hottah terrane, then back to about 10.0-11.0 s (33-36 km) beneath the Fort Simpson structure. Following are brief descriptions and some preliminary interpretations of crustal and upper mantle structures for each of these regions.

The Fort Simpson Terrane

The geometry of the Fort Simpson structure has been outlined previously (Cook et al., 1992; Cook and Van der Velden, 1993), but the SNORCLE data provide the most continuous and definitive view of it to date; it is a west facing monocline with at least 20 km of subsurface relief. The base of the monocline is delineated on the reflection data as a nearly continuous reflection that dips about 20-30° westward from about 1.0 s (where it is truncated by the base of the Paleozoic) to about 8.0 s (about 24 km) near the west end of the profile where it flattens. A subparallel reflection that is truncated at the base of the Paleozoic about 20 km east of the first may be a related en echelon feature.

The west side of the Fort Simpson monocline is overlain by a series of prominent layers that are almost certainly Proterozoic (meta-) sedimentary rocks and/or sills. Drill holes on the Fort Simpson magnetic high near the top of the ramp penetrated from Paleozoic rocks into 1.845 Ga basement (Villeneuve et al., 1991); in the Cordillera to the west, the stratigraphic section includes more than 5.0 km of Proterozoic strata and lower Paleozoic strata that are not present in the wells (e. g., Cook and Van der Velden, 1993).

The east side of the Fort Simpson structure is characterized by a ca. 10 km wide zone of reflections that project to the surface where a prominent gravity high and less prominent magnetic trend (Figure 1) are observed. These anomalies have previously been interpreted as the suture between the Fort Simpson magmatic arc (ca. 1.845 Ga) and the Hottah Terrane (ca. 1.9 Ga) (Hildebrand et al., 1986; Hoffman, 1987). On the SNORCLE profile, these "JH" reflections dip about 30° westward from the base of the Paleozoic sediments at 1.0 s to near 7.0 s, or about 20-21 km depth, where they are underlain by subhorizontal to slightly east dipping reflections to about 11.0 s. Whether the JH reflections flatten into the subhorizontal reflections, and therefore may be associated with crustal-scale detachment, or whether they are truncated by the deeper layers as a result of later intrusion (underplating), is uncertain. However, the observation that Moho reflections dip eastward and correlate with events that project to nearly 80 km indicates the JH reflectors are probably detached.

The Hottah Terrane

The transition from the Fort Simpson terrane to the Hottah terrane is characterized by the west dipping reflections described above, east of which a series of antiformal structures appear to be thrust over a prominent 4.5-5.0 s reflecting surface. This surface rises to near the base of the Paleozoic at the west side of the Great Bear magmatic arc magnetic anomalies and appears to outline a basin geometry. It is overlain by as much as 4.5 s of nearly non-reflective material within which some weak reflections appear to be associated with complex structures. At greater times (depths) lower crustal reflections dip eastward from the Fort Simpson terrane into the mantle beneath the Hottah terrane. These are most likely related to the subduction of Fort Simpson beneath Hottah during formation of the Great Bear arc, and are preserved today as mantle reflectors to perhaps 100 km depth.

Some portions of the data across the Hottah-Great Bear boundary (as delineated by magnetic anomalies) indicate that much of the crustal reflectivity dips eastward from the Hottah into or beneath the Great Bear arc. An interpretation of this geometry that is consistent with results from various mapping studies is that the Hottah and/or Fort Simpson terranes dipped eastward beneath the eastern Hottah and western Slave province during or at the end of accretion of the Hottah terrane to the western Slave Province at about 1.91-1.90 Ga, and perhaps during formation of the Great Bear magmatic arc in the middle Proterozoic (ca 1.90 - 1.84 Ga).

The Great Bear Magmatic Arc

The reflection data cross the Great Bear arc exhibit a large amount of complexity throughout the crust beneath about 1-1.5 s (about 3-4.5 km). Near the surface, immediately beneath thin (400 m or less) Paleozoic sedimentary rocks the reflection data have outlined a synformal basin whose axis is situated about 50 km northeast of Fort Providence. Here, two drill holes (GPD Noel Mills Lake # 41 and GPD Noel Mills Lake P-52) drilled from lower Paleozoic sands into granitic rocks. Due to the fact that only well cuttings are available, it is uncertain whether the cuttings are from *in situ* granite, granite wash, or granite boulders. This is important because if the wells penetrated into *in situ* granite, then the synformal layers observed on the reflection profile

may be largely granitic sheets. In any case, there were granitic rocks nearby, and these are probably associated with the intrusive rocks of the Great Bear arc.

The volcanic, plutonic and sedimentary rocks of the Great Bear arc have a composite stratigraphic thickness of more than 30 km (Hoffman and McGlynn, 1977; Hildebrand et al., 1987). However, the section thickens dramatically toward the northeast, with the thickest (about 10 km) section near the Wopmay fault about 500 km north of the reflection profile. The section thins southward to only a few km thickness, but its thickness beneath the Paleozoic sedimentary east of Fort Providence is unknown. If the reflection synform represents the Great Bear magmatic arc succession at this latitude, it is only about 3-4.5 km thick.

The base of the synform is characterized by diffracted energy, similar in appearance to the reflection signature from oceanic basement beneath oceanic sedimentary rocks. While it is unlikely that the "basement" beneath the Great Bear synform is oceanic crust, the prevalence of diffractions indicates that the surface is rough. Hence, another interpretation of the synform is that it represents that latest stage of Great Bear sedimentation and igneous activity that was deposited onto rocks of an earlier phase.

Slave Province

The profile from the Archean Slave Structural Province has reflections throughout the crust and into the upper mantle (Cook et al., this volume). Reflections are visible that project to the surface, for example at Yellowknife, and then merge into or flatten into the top of a zone of middle and lower crustal reflections. A preliminary interpretation, therefore, has the top of the middle crust as a detachment horizon above which many of the upper crustal rocks were transported. This is most obvious near Yellowknife where a prominent reflection dips eastward from the surface near Yellowknife to about 8-10 km near Tibbit Lake. Reflections above this surface appear to merge with it or are truncated by it. At the eastern limit of the profile, a prominent west-dipping reflection projects to the surface about 20-30 km east of the profile, near the Sleepy Dragon complex, and into the subsurface westward where it flattens into the middle crustal reflectivity zone. In addition, it appears to offset the east-dipping Yellowknife reflection. An easy interpretation is that

the Yellowknife reflection is a shallow dipping detachment along which the metasedimentary and plutonic rocks of the Yellowknife basin were carried westward (e. g., Kusky, 1990; Ham et al., this volume), and the Sleepy Dragon reflection is a west-dipping extensional fault that offset the Yellowknife reflector during late to post-orogenic extension (e. g., James and Mortensen, 1992).

The middle and lower crust are reflective throughout this portion of the Slave Province; there is no apparent difference between the Anton terrane and the Yellowknife basin, even though the results from the coincident magnetotelluric survey are interpreted with highly resistive crust of the Anton terrane and highly conductive crust of the Yellowknife basin (Jones and Ferguson, this volume). Apparently, electrical conductivity and seismic reflectivity have no simple relationship in this area.

CONCLUSIONS

Preliminary analyses of the SNORCLE Corridor 1 reflection survey provide new images of the deep crustal structure associated with the late Archean and Proterozoic assembly of the northwestern Canadian shield and the subsequent middle and late Proterozoic breakup of the western margin of North America. The results thus establish the crustal architecture upon which the Cordillera was constructed during Paleozoic continental separation and terrane accretion; these topics will be addressed in greater detail in Corridors 2 and 3.

ACKNOWLEDGMENTS

This work is supported by the Natural Sciences and Engineering Research Council of Canada and the Geological Survey of Canada. Industry participants in this phase of the SNORCLE reflection program are UNOCAL Canada and PanCanadian Petroleum. Kris Vasudevan and Rolf Maier provided much support during all phases of the work, and Elissa Lynn provided the figure.

REFERENCES

- Cook, F., J. Varsek, and E. Clark, 1991, Proterozoic craton to basin transition in western Canada and its influence on the evolution of the Cordillera, *Can. J. Earth Sciences*, v. 28, p. 1148-1158.
- Cook, F., M. Dredge, and E. Clark, 1992, The Fort Simpson structural trend in northwestern Canada, *Bull Geol. Soc. America*, v. 104, p. 1121-1137.
- Cook, F., and Van der Velden, 1993, Middle Proterozoic crustal transition beneath the western Canada Sedimentary basin, *Geology*, v. 21, p. 785-788.
- Ham, N., K. Benn, G. Pignotta, and W. Bleeker, this volume, Magnetic fabrics in the Sparrow granite pluton: Markers of the Late Archean strain field in the southern Yellowknife domain.
- Hildebrand, R., P. Hoffman, and S. Bowring, 1987, Tectonomagmatic development of the Great Bear magmatic arc, northwestern Canadian Shield, *J. Volcanology and Geothermal Research*, v. 32, p. 99-118.
- Hoffman, P., 1987, Continental transform tectonics: Great Slave Lake shear zone (ca 1.9 Ga), northwest Canada, *Geology*, v. 15, p. 785-788.
- Hoffman, P., and J. McGlynn, 1977, Great Bear batholith: a volcano-plutonic depression, in W. R. A. Baragar, L. C. Coleman, and J. M. Hall, eds., *Volcanic Regimes in Canada*, *Geol. Assoc. Can. Sp. Paper* 16, p. 169-192.
- Kusky, T., 1990, Evidence for Archean ocean opening and closing in the southern Slave Province, *Tectonics*, v. 9, p. 1533-1563.
- James, D., and J. Mortensen, 1992, An Archean metamorphic core complex in the southern Slave Province: basement-cover relations between the Sleepy Dragon complex and the Yellowknife Supergroup, *Can. J. Earth Science*, v. 29, p. 2133-2145.

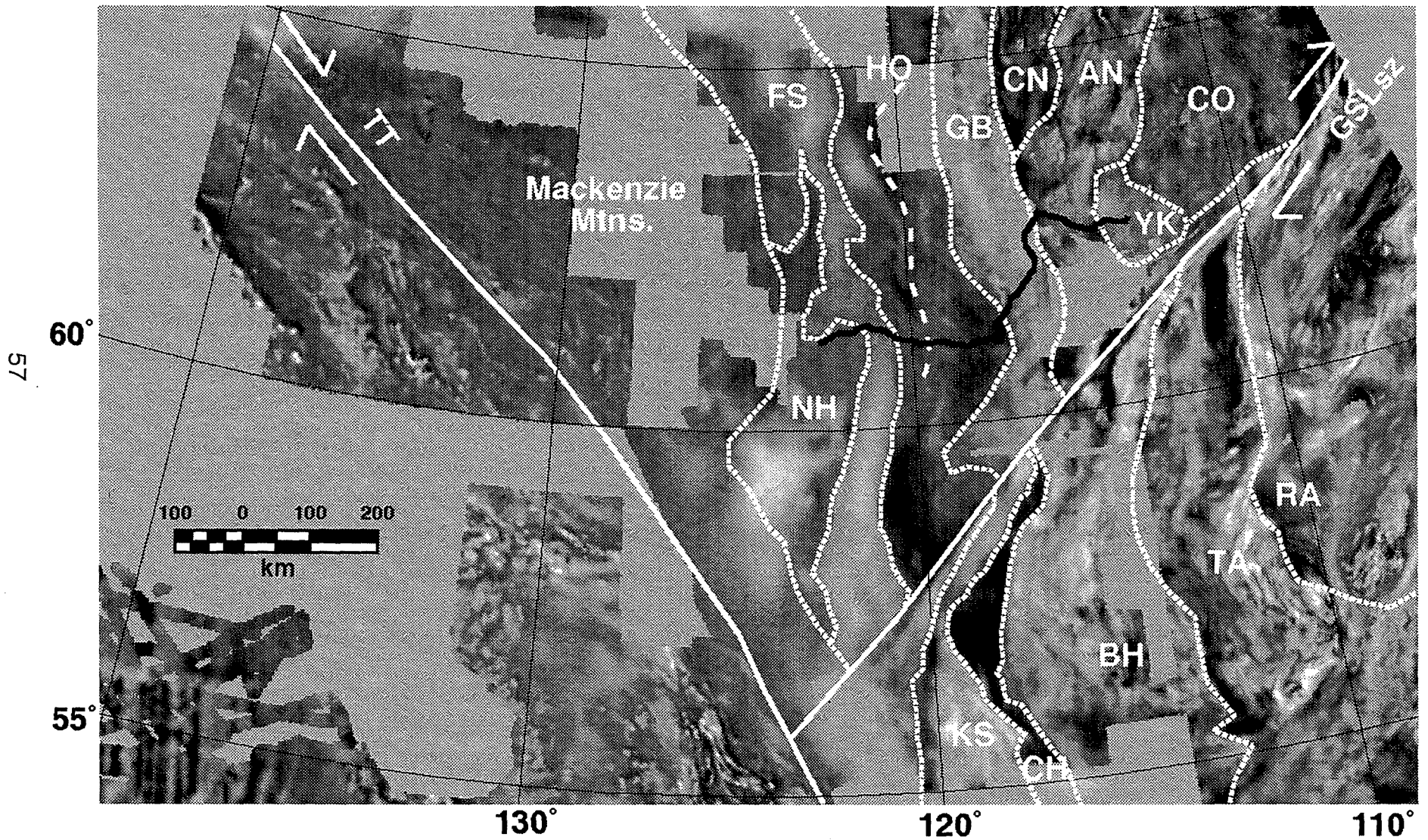
Jones, A., and I. Ferguson, this volume, Results from the 1996 magnetotelluric studies along SNORCLE profiles 1 and 1a.

Villeneuve, M., R. Theriault, and G. Ross, 1991, U-Pb ages and Sm-Nd signature of two subsurface granites from the Fort Simpson magnetic high, northwest Canada, *Can. J. Earth Sciences*, v. 28, p. 1003-1008.

FIGURE CAPTION

Figure 1. Map of the aeromagnetic anomalies in the SNORCLE transect region with the tectonic domain boundaries indicated. The solid black line is the location of the SNORCLE 1996 reflection traverse, and the heavy north-south dashed line near 120° N is interpreted as the suture zone between the Fort Simpson arc and the Hottah terrane (Johnny Hoe suture of Hildebrand et al., 1987; Hoffman, 1987). Abbreviations are: TT = Tintina Trench; NH = Nahanni terrane; FS = Fort Simpson terrane; HO = Hottah terrane; GB = Great Bear magmatic arc; CN = Coronation fold and thrust belt; AN = Anton terrane; YK = Yellowknife basin; CO = Contwoyto terrane; GSLsz = Great Slave Lake shear zone; KS = Ksituan terrane; CH = Chinchaga domain; BH = Buffalo Head terrane; TA = Taltson arc; RA = Rae province.

SNORCLE TERRANES AND MAGNETIC ANOMALIES



UPPER MANTLE REFLECTORS BENEATH THE SNORCLE TRANSECT - IMAGES OF THE BASE OF THE LITHOSPHERE ?

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ABSTRACT

Reflections between 22 and 28 s (about 80 -105 km depth) are visible on the SNORCLE seismic reflection profile across the Archean rocks of the western Slave Province (Yellowknife Basin and Anton terrane), the Great Bear Magmatic arc, and the Hottah terrane. These reflections are some of the deepest (longest travel time) events ever observed on vibroseis data. Some reflection zones are correlatable (though not continuous) over more than 100 km and are therefore likely regionally significant boundaries. On the west, east-dipping reflections are visible from the lower crust of the Fort Simpson terrane to 80-100 km beneath the Hottah terrane and Great Bear arc. These are most easily interpreted as relict surfaces from the mid-Proterozoic (ca 1.9-1.86 Ga) subduction associated with the formation of the Great Bear magmatic arc. Beneath the Great Bear arc, these events appear to flatten near 100 km where they spatially correlate with the position of the base of the electrical lithosphere. East of there, reflections near 80 km beneath the Slave Province may be a fossil lithosphere-asthenosphere boundary.

INTRODUCTION

Seismic reflections from the upper mantle are rare, especially on land and especially on data recorded with the vibroseis method. In most previous studies, upper mantle reflections are seen to dip from the Moho into the mantle (e. g., Flannan reflection of McGeary and Warner, 1986), or are typically limited in lateral extent and are thus difficult to interpret (e. g. Knapp et al., 1996). Here, we describe preliminary results from the SNORCLE 1996 reflection profile where reflections are observed between 22 and 28 s, more than 11-17 s below the Moho.

The 1996 SNORCLE reflection survey was recorded to 32 s with a 20 s sweep and without field correlation, thus allowing us to increase the record length with extended correlation processing at the Lithoprobe Seismic Processing Facility. This type of analysis uses a self-truncating sweep to permit crustal data (to 12 s) to be processed with the full bandwidth (10-80 Hz in this case), and the deeper data (> 12 s) to be processed with increasingly narrow bandwidths. For example, the correlation bandwidth at 20 s is about 10-52 Hz, and at 26 s is about 10-31 Hz. Even the deep (26 s) times include 1.5 octaves, thus allowing reflections without severe ringing effects.

We recognize that there are always several possible interpretations other than primary reflections for events with very long travel times. These include: very long period multiples (e. g., surface to Moho), wave conversions, and side echoes. We have investigated several of these for the SNORCLE data and believe, for a variety of reasons, that they are not applicable to the most important events observed. Although we will continue to consider them further as more information becomes available, our preferred interpretation is that the events described below are primary deep reflections.

RESULTS

Deep Reflections From Beneath the Great Bear Magmatic Arc and the Hottah Terrane

Numerous discontinuous reflections are visible to 28 s (about 105 km) from beneath the Great Bear Magmatic Arc and the Hottah terrane. Most of

these do not correlate over very large distances; however, a zone of reflections, perhaps 10-12 (about 4 s) km thick is traceable from the lower crust of the Fort Simpson terrane to about 22 - 26 s (about 90 - 100 km) beneath the Hottah terrane and Great Bear arc. There it flattens over a distance of about 100 km before dipping eastward again beneath the Slave Province. This zone, if correlatable to the Fort Simpson crust, may be a remnant of the Fort Simpson subduction that produced the Great Bear magmatism between 1.9 and 1.86 Ga.

According to Jones and Ferguson (this volume) the electrical asthenosphere is located at about 100 km beneath the Great Bear arc, and deepens to more than 200 km beneath the Slave. Accordingly, the ca. 100 km reflection zone is tentatively interpreted to be near the base of the lithosphere today.

Deep Reflections From the Slave Province

The profile across the Slave Province exhibits a band of reflections at about 21.5 s (about 79 km) in the western portion of the Anton terrane near Rae that deepens to about 22.5 s (about 83 km) near the centre of the Anton terrane, and then shallows again to near 21.5 s near Yellowknife. Although there is a gap in the reflection near Yellowknife (probably due to cultural noise and road bends), this event appears to correlate with a reflection near 19.5 s (about 70 km depth) east of there. We presently make this correlation with the implication that this boundary shallows from slightly more than 80 km beneath the Anton terrane to about 70 km beneath the Yellowknife basin over a distance of 80 - 100 km.

Initial results from the regional SNORCLE magnetotelluric survey have been interpreted with the base of the electrical lithosphere near 200-250 km beneath the Slave Province (Jones and Ferguson, this volume). On the other hand, heat flow data from near Yellowknife have relatively high surface flux (about 61 mW/m²; Lewis and Wang, 1993), a result that could be interpreted to represent a relatively shallow (near 100 km) asthenosphere. In any case, we believe it is unlikely that the 70-80 km boundary represents the base of the lithosphere today.

At first glance, a thick (> 200 km) modern lithosphere (from the electrical data) is consistent with the presence of diamonds at the surface in kimberlites.

If the diamonds in this area are Archean, as many around the world are, then it is necessary that the lithosphere exceeded about 150 km thickness for diamond formation. However, late Archean and early to middle Proterozoic plutonism and volcanism in and near the Yellowknife basin are indicative of regional heating events, and probably thinned lithosphere (perhaps 80 km or so; Nisbett, 1984), at that time (late Archean). We speculate that thick (>150 km) Archean lithosphere necessary for diamond formation was thinned by heating in the late Archean to early Proterozoic, and has since thickened to ca. 200 - 250 km today. If this is true, the boundary at 70-80 km may be a fossil lithosphere-asthenosphere boundary from late Archean or early Proterozoic.

CONCLUSIONS

Reflections are observed that dip eastward from the lower crust of the Fort Simpson terrane to ca 80 - 100 km depth beneath the Hottah terrane and Great Bear arc. These are most easily interpreted as an ancient (ca. 1.9 -1.86 Ga) subduction zone responsible for the Great Bear arc magmatism. The boundary near 100 km beneath the Great Bear and Hottah regions may be at or near the modern lithosphere/asthenosphere transition, and, if the reflections observed at 19.5 - 22.5 s (about 70-80 km) from beneath the Slave Province are primary events, they may be associated with a fossil lithosphere/asthenosphere transition, perhaps as old as 2.5 Ga.

ACKNOWLEDGMENTS

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REFERENCES

- Knapp, R. W., and the URSEIS working group, 1996, A lithosphere scale seismic image of the southern Urals from URSEIS '95 explosion source seismic profiling, in Seventh International Symposium on Deep Seismic Profiling of the Continents, ed. by S. Klemperer and W. Mooney, program and abstracts, p. 26.
- Jones, A., and I. Ferguson, Results from the 1996 magnetotelluric studies along SNORCLE profiles 1 and 1a.
- Lewis, T., and K. Wang, 1993, Influence of terrain on bedrock temperatures, *Paleogeography, Paleoclimatology, and Paleoecology*, v. 98, p. 87-100.
- McGeary, S., and M. Warner, 1985, Seismic profiling the continental lithosphere, *Nature*, v. 317, p. 795-797.
- Nisbett, E., 1984, The continental and oceanic crust and lithosphere in the Archean: Isostatic, thermal, and tectonic models, *Can. J. Earth Sciences*, v. 21, p. 1426-441.

SNORE 97 – THE SNORCLE REFRACTION EXPERIMENT

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INTRODUCTION

The SNORCLE Transect addresses structure and evolution of the continental lithosphere in a region of northwestern North America where the rock record spans 90% of Earth's history. Principal objectives include (i) the structure and formation of Early Archean crust and the evolution of cratons, (ii) the Archean to Proterozoic transition and collisional suturing associated with Proterozoic orogens, (iii) processes of ocean opening and the Proterozoic-Paleozoic rifted margin and miogeocline of North America, (iv) growth of continents by terrane accretion, and (v) the deep architecture and Phanerozoic evolution of the Cordilleran orogen. As one component of the scientific program addressing these general objectives, an explosive source seismic refraction/wide-angle reflection (R/WAR) survey, SNORE 97, has been planned along the three primary corridors.

TRANSECT BACKGROUND AND SIGNIFICANCE OF SNORE 97

From east to west, the SNORCLE Transect crosses a series of orogens including the Archean Slave Province, Early Proterozoic Wopmay Orogen, the southern projection of the Middle Proterozoic Racklan Orogen (mostly buried beneath Phanerozoic cover), and the northern Cordillera, which records a complex history of crustal extension (1.5-0.37 Ga) followed by crustal accretion (since 0.37 Ga).

The R/WAR experiment has as its primary purposes determination of the velocity structure of the crustal and sub-crustal lithospheric mantle of the tectonic elements crossed by the profiles and relationship of the results to the coincident seismic reflection, magnetotelluric and other geophysical and geological data to better define the current tectonic structure of these domains and elucidate their past history. Completion of a full set of profiles will enable (i) a near-continuous velocity structural cross-section of the lithosphere from the westernmost Archean Slave craton to the young accreted crust of the Cenozoic western Cordillera; (ii) indication of the lateral variability of crustal structure along strike in the northern Cordillera; (iii) a direct tie with ACCRETE, an NSF-funded seismic reflection and R/WAR experiment, in combination with geological studies, located in the southern Alaska Panhandle; (iv) comparison with the velocity structure of the southern Canadian Cordillera (Clowes et al. 1995), which, in contrast to the northern Cordillera, has experienced extensive Eocene extension; and (v) comparison with a seismic cross-section across a similar region of Alaska (Beaudoin et al. 1994). The combination of studies will enable variations in the continental-scale, three-dimensional structure of the Cordilleran orogen to be investigated.

SNORE 97 – THE EXPERIMENT

The SNORCLE Refraction Experiment is planned for all three corridors of the transect (Figure 1). A schematic illustration of the shot patterns along each line is shown in Figure 2. Line 11 (Corridor 1, line 1) addresses the Archean and Proterozoic components of the transect. It extends WSW about 600 km from east of Yellowknife along existing roads to about Nahanni Butte. Twelve shot points at intervals of 50-60 km are planned; with the availability of 620 portable seismographs, station spacing will average about 1 km. The long length of the profile should enable determination of velocity structure to depths of about 150 km, as demonstrated by results from the THOT refraction experiment (Hajnal et al. 1997).

Line 21 extends from the western Proterozoic tectonic elements, including the enigmatic Nahanni terrane, into the autochthonous/paraautochthonous portion of the northern Canadian Cordillera. Although offset along strike, it provides some overlap with the western end of Line 11 and focusses on the crust associated with the miogeoclinal

element of the Cordillera. Line 21 starts at about Fort Nelson and heads WNW to about Watson Lake. Nine shot points are located along the ~450 km line. Because of the road configuration, the first station on the east will be near SP 2102 (Figure 1); SP 2101 is included to provide longer offset ranges at the westernmost stations. Station spacing will remain at an average of about 1 km because some recording units will be deployed at 2 km spacings along Line 22 from SP 2209 to about SP 2204, to provide broadside recording over the Tintina fault zone (a Late Cretaceous to Oligocene fault more than 1900 km long with dextral strike-slip of at least a few hundred kilometers). Line 22 addresses primarily the accreted terrane component of the northern Cordillera and will specifically investigate Stikinia, the largest accreted terrane identified in the Cordillera and one not investigated in the Southern Cordillera Transect. The line extends principally N-S from near Watson Lake to Stewart. At its northern end, Line 22 ties with the western end of Line 21 and at its southern end, it ties with the reflection/refraction program associated with the ACCRETE project (Hammer et al. 1997). In effect, the tie with ACCRETE will enable compilation of a cross-section extending west from Stikinia across the Paleogene arc, Coast shear zone, the mid-Cretaceous Western thrust belt and into the Insular superterrane. Ten shot points are planned along the 500 km long profile. As for Line 21, station spacing along Line 22 will remain at 1 km with some stations being redeployed at 2 km spacings along Line 21 from SP 2108 to about SP 2104, to enhance the broadside recording across the region of the Tintina fault zone.

Line 31 runs NE-SW for about 300 km from the autochthonous/paraautochthonous portion of ancestral North America across the Tintina fault and into the accreted terrane portion of the Cordillera which is dominated by smaller units of many terranes. The line will provide information on along-strike crustal variations in the northern Cordillera through comparisons with results from Lines 21 and 22, and more generally with the equivalent elements from the study of Beaudoin et al. (1994). Six shots are planned; station spacing will be about 0.5 to 1 km to increase the spatial resolution along this shorter profile. To provide broader coverage on either side of the Tintina fault, seismographs will be deployed at about 2 km intervals for up to 120 km on either side of line 31 for broadside recording along the Robert Campbell highway which runs approximately perpendicular to the main profile. One or two additional small shots to focus energy in the region of the Tintina fault may be added, if sufficient funds exist, but these have not been scheduled in the program or the budget at present.

Current Status of Planning. All lines have been scouted and preliminary shot point locations selected (Figure 1). The tedious and time-consuming job of obtaining all the necessary environmental and other permissions is in progress and will continue throughout the winter and spring. Requests placed with the IRIS/PASSCAL consortium to obtain 220 3-component RefTek instruments and with the Stanford University/USGS SGR group for their 185 SGR vertical-component instruments, in each case with adequate technical personnel, have been approved. With the 185 GSC/LITHOPROBE PRS-1s and 30 PRS-4s, a total of 620 instruments should be available. At the present time, the planned start of SNORE 97 is August 11 and we anticipate the field program will take 3-4 weeks. A field crew of 60-70 persons is required to enable efficient deployment of the instruments. Hence we are looking for volunteers who would like to participate with us in this final LITHOPROBE R/WAR field experiment, SNORE 97.

REFERENCES

- Beaudoin, B.C., G.S. Fuis, W.J. Lutter, W.D. Mooney and T.E. Moore 1994. Crustal velocity structure of the northern Yukon-Tanana upland, central Alaska: results from TACT refraction/wide-angle reflection data. *Geological Society of America Bulletin*, 106: 981-1001.
- Clowes, R.M., C.A. Zelt, J.R. Amor and R.M. Ellis 1995. Lithospheric structure in the southern Canadian Cordillera from a network of seismic refraction lines. *Canadian Journal of Earth Sciences*, 32: 1485-1513.
- Hajnal, Z., B. Nemeth, R. Clowes, R. Ellis, G. Spence, M. Burianyk, I. Asudeh, D. White, and D. Forsyth 1997. Mantle involvement in lithospheric collision: Seismic evidence from the Trans-Hudson Orogen, western Canada. *Geophysical Research Letters*, in press.
- Hammer, P.H.C., R.M. Clowes and R.M. Ellis 1997. ACCRETE crustal velocity structure across the transition between the Coast Plutonic Complex and Stikinia (Extended abstract). SNORCLE Transect 1997 Workshop (this volume).

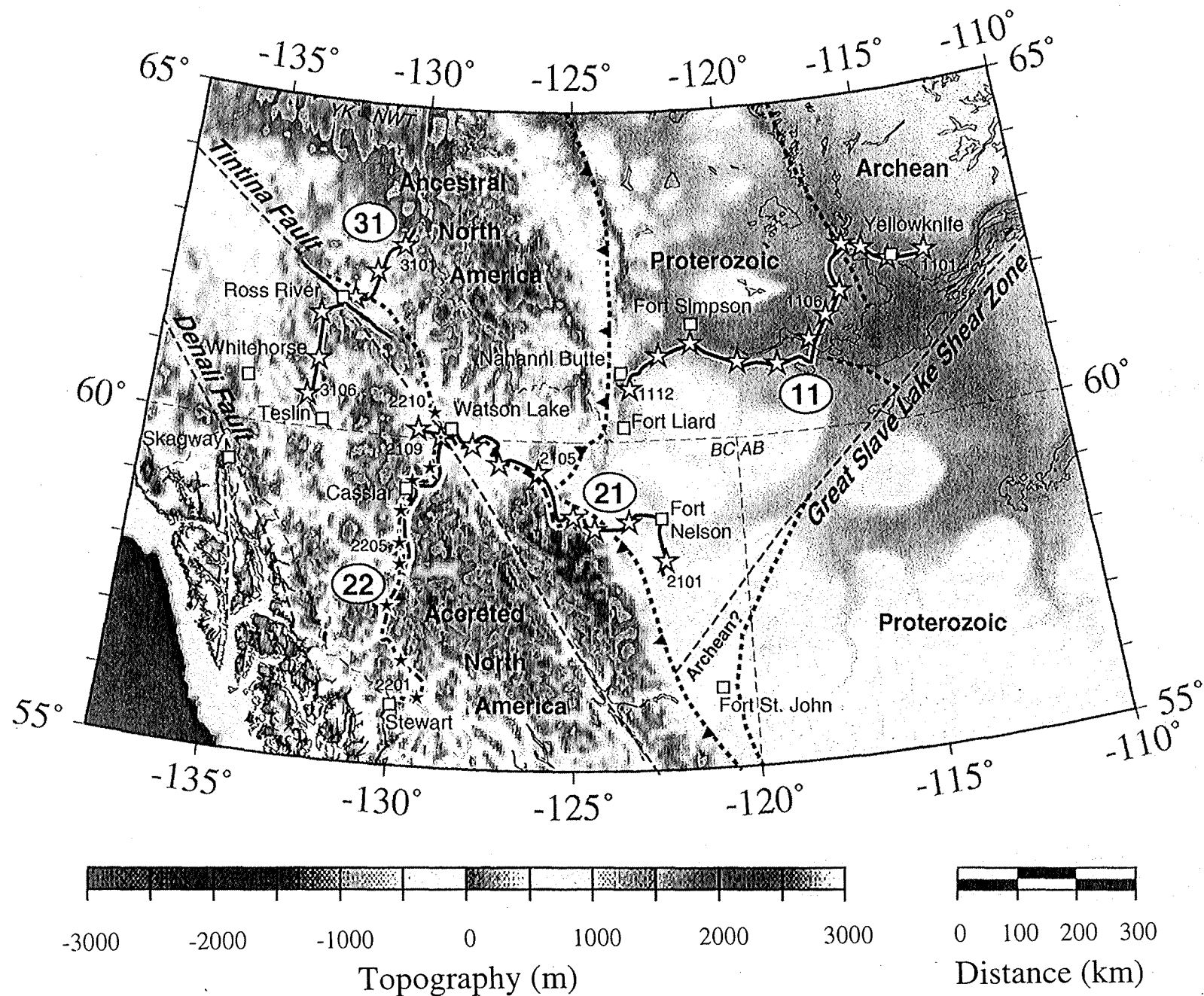
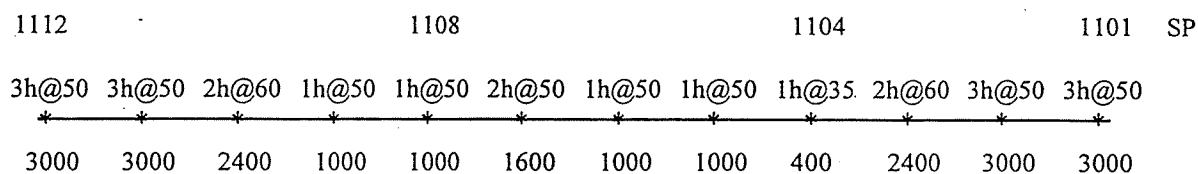
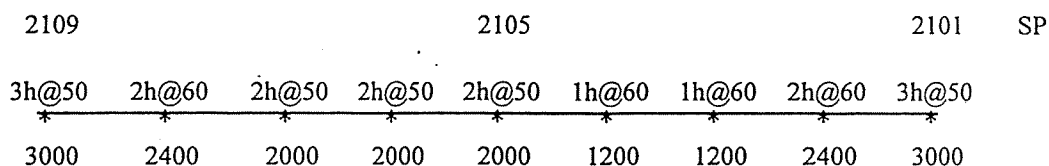


Figure 1: Shot point (stars, some numbered) and line locations (large numbers) for SNORE 97 on a topographic map of the SNORCLE Transect area. Solid and dashed lines are used for Lines 21 and 22, respectively, to show deployments along one when shots will be fired along the other. Major tectonic units are outlined and separated by heavy dotted lines; major fault zones are indicated.

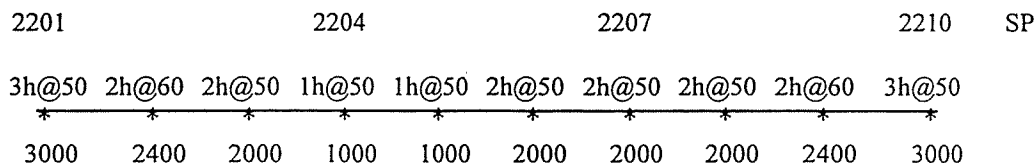
LINE 11: ~600 km; 12 SPs; 23DHs



LINE 21: ~500 km; 9 SPs; 23DHs



LINE 22: ~500 km; 10 SPs; 20 DHs



LINE 31: ~300 km; 6 SPs; 8 DHs

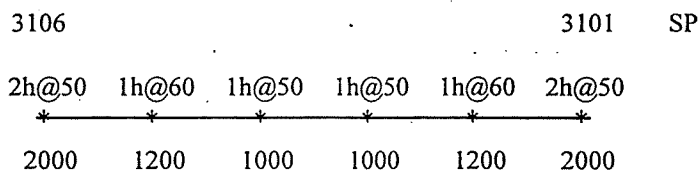


Figure 2. Schematic illustration of shot points (SP) for lines 11, 21, 22 and 31. “3h@50” - 3 drill holes (DH) at 50 m depth each; “3000” - 3000 kg of explosives.

Multiple Paleohydrogeological events in the Northern Canadian Rockies and the MacKenzie Basin

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Abstract: A multidisciplinary approach has been used to analyse crustal fluid movement throughout the history of the northern Canadian Rockies. This has allowed the identification of six distinct fluid events, each of which can be interpreted in terms of sedimentary, diagenetic or tectonic processes. The final, Laramide Orogeny related events have not obscured those events that went before.

Introduction

Field relations, fluid inclusion analyses, stable (O, C and H) and radiogenic (Sr) isotope analyses are being used to study an area of complex crustal fluid history in the northern Canadian Rockies. By synthesis of many types of data we have distinguished and interpreted the origin of six distinct fluid events.

Progress since previous report (Morris *et al.*, 1996a) includes sampling of mineralisation along the Alaska Highway between Stone Mountain and Liard Hot Springs, and along the Tungsten Highway (Fig. 1). Additional samples from the subsurface were obtained courtesy of the ISPG-GSC, Calgary.

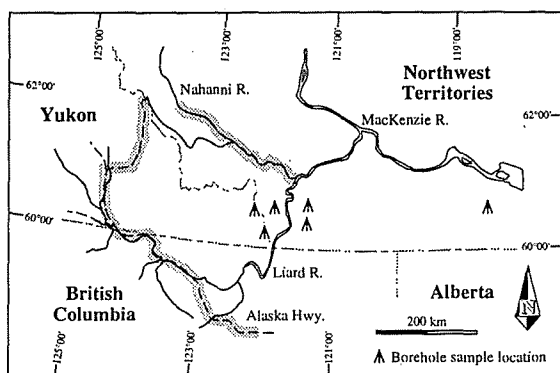


Figure 1. Location map of river, boreholes and Ram Plateau. Shading indicates lines of sampling traverses.

Analyses of oxygen and carbon isotopes are complete, hydrogen, strontium and lead isotopic analyses are in progress. Fluid inclusion salinity and homogenisation temperature determinations are nearly complete. Selected samples were analysed at Montanuniversitat, Austria, for ionic ratios of solutes extracted from fluid inclusions.

Regional Geology

The northern Canadian Rocky Mountains consist of Cambrian shelf carbonates grading through to lower Carboniferous (Mississippian) shallow water carbonates with occasional bands of shale and coarser siliciclastic sedimentary rocks. The entire area was subject to intense shortening and uplift during the Laramide Orogeny (late Jurassic - Tertiary) which resulted in a large number of north-south oriented faults (& Yorath 1992).

Fluid Events

To date, six distinct fluid events have been identified in the northern Canadian Rockies. A summary of events, their petrology, chemistry, and interpreted origin is given in Table 1.

Sedimentary Exhalative Event

Seafloor venting of hydrothermal fluids associated with extensional processes took place during deposition of carbonates in the late Ordovician and early Silurian. This event is characterised by

banded, stratiform, chert-rich high-Mn dolomite, and economically important fine-grained stratiform Pb-Zn sulphide mineralisation. This mineralisation has been identified in two places, Prairie Creek and Howards Pass (Fraser 1996; MacIntyre, 1991). Dolomites have $\delta^{18}\text{O}$ values of $23.0 \pm 0.8\text{‰}$ SMOW and $\delta^{13}\text{C}$ values of $-2.8 \pm 0.4\text{‰}$ PDB (Fraser 1996). Strontium Initial (Sr_i) ratios for dolomite associated with Pb-Zn mineralisation are reported from Prairie Creek at 0.721 - 0.724 (Fraser, 1996), and from Howards Pass as 0.714 - 0.717 (Goodfellow and Jonasson, 1986).

The event, which was responsible for both the Prairie Creek and the Howards Pass deposits, was synchronous with sedimentation, i.e. late Ordovician or Silurian.

Diagenetic Dolomite

Widespread diagenetic dolomitisation produced fine-grained grey matrix dolomite, which outcrops throughout the Cambrian to Mississippian succession in most of the study area. Analyses of $\delta^{18}\text{O}$ ratios show fairly uniform values of $22 \pm 1.4\text{‰}$ SMOW, which are somewhat depleted in ^{18}O compared to typical Ordovician marine carbonates (23‰ to 27‰ SMOW; Veizer 1983). Carbon isotopic values of dolomites ($\delta^{13}\text{C}$ of $-0.5 \pm 0.5\text{‰}$ PDB) lie within the normal range of values (-1‰ to -3‰ PDB) for marine carbonates. Some depletion in oxygen values is observed near to the contact with the sedimentary exhalative mineralisation (Fraser 1996).

Manetoe Facies

Lower and middle Devonian strata host the broadly stratiform, and regionally extensive Manetoe facies (Aulstead 1987; Morrow *et al.* 1990). This body of megacrystalline, white sparry dolomite occurs as both a breccia-fill and a replacement feature of the host rock. The Manetoe facies has been correlated with the Presqu'île hydrothermal dolomites, further east and south in the MacKenzie Basin, and is related to major MVT Pb-Zn mineralisation at Prairie Creek (Manetoe) and Pine Point, NWT (Presqu'île).

$\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of dolomite (14.7‰ to 15.1‰ SMOW and -2.9‰ to -2.2‰ PDB, respectively) are consistently lower than values for the sedimentary exhalative related dolomites, the diagenetic grey dolomite, and the dolomite associated with the later

vug-fill event (Fig. 2). High fluid inclusion δD values (-80‰ to -12‰ SMOW) distinguish the Manetoe Facies from carbonates associated with later fluid movement related to the Laramide Orogeny (Table 1). Fluid inclusion analyses suggest that the Manetoe dolomites were precipitated from a CaCl_2 -rich fluid of approximately 18 - 25 eq. wt% NaCl salinity at a minimum temperature of 185 - 235 °C. Low Na/Br (138-149) and Cl/Br (119 - 240) ratios compared with seawater (564, 655 respectively) combined with the high salinities and δD values suggest that the dolomite-forming fluids were evaporitic brines. The fluid event that produced the Manetoe Facies is therefore interpreted as a west to east subsurface flow of warm evaporitic brines during the late Devonian to early Mississippian.

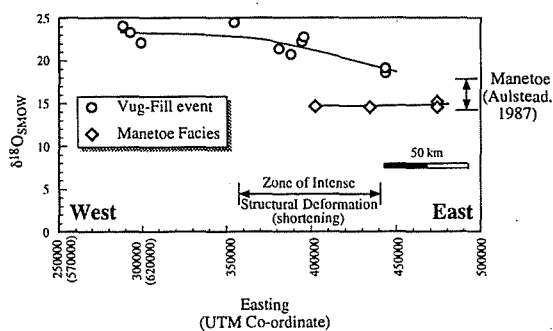


Figure 2. Variation of $\delta^{18}\text{O}$ of dolomite along the Nahanni River section. This clearly distinguishes the vug-fill event from the earlier Manetoe Facies.

Vug Fill Event

Calcite and dolomite vug fillings and veins are present stratigraphically below the Manetoe Facies dolomites. Field relations indicate that the vug fillings and veins post-date the grey dolomites but preceed the Laramide deformation. δD values of fluid inclusions in these minerals (-184‰ to -114‰ SMOW) are lower than values from the Manetoe facies and similar to values from the Laramide veins. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values for dolomites (24.3‰ to 19.2‰ SMOW and 0.2‰ to -0.7‰ PDB respectively; Fig. 2) and calcites (22.1‰ to 9.8‰ SMOW and -0.1‰ to -3.4‰ PDB respectively; Fig. 3) of the vug-fill event show a distinct gradient, with values near to those of the host grey diagenetic dolomite in the west, declining to the east. Fluid inclusion analyses yield a wide range of eutectic temperatures indicating an NaCl-rich solution containing varying quantities of MgCl_2 and CaCl_2 . Salinities of inclusions fluids vary between 13 and 26 eq. wt% NaCl and homogenisation

temperatures indicate minimum temperatures of formation between 190 and 220°C. Both Na/Br (average = 368) and Cl/Br (average = 502) fall largely below ratios obtained from seawater (564: 655), suggesting that the predominant influence on fluid composition is from residual basin brines. High I/Br (average = 0.053) ratios indicate that fluids have picked up I from interaction with marine organic material. The vug-fill event is interpreted as an east to west subsurface flow of surface-derived meteoric water mixing with residual brines, which occurred immediately prior to Laramide compression.

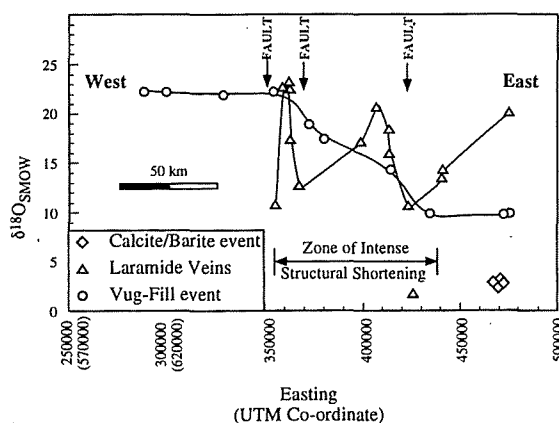


Figure 3. Variation of $\delta^{18}\text{O}$ of calcite along the Nahanni River section. The attenuation in gradient of the vug-fill event is due to subsequent crustal shortening during the Laramide. $\delta^{13}\text{C}$ values for calcite show a similar pattern. The location of major Laramide faults also shown.

Laramide Orogeny

Fluids associated with the Laramide Orogeny produced two types of veining. The first consists of largely calcite veins along thrust faults, while the second is comprised of quartz and calcite veins in high angle brittle structures. Fluid inclusion data from both the fault-related veins and the high angle veins produce a tight range of salinity values (15 ± 1.0 eq. wt% NaCl), and eutectic temperatures of -21°C suggesting a pure NaCl solution. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of calcite vary from 22.6‰ to 10.4‰ SMOW and 1.1‰ to -4.9‰ PDB respectively, with the lower values occurring in fault-hosted veins and in high-angle veins near to the major faults (Fig. 3). This suggests that a similar fluid regime was present throughout the Laramide Orogeny, and that fluid movement in this area was concentrated along the major faults during compression and subsequent uplift. δD values (-184‰ to -113‰ SMOW; Fraser, 1996) are directly comparable with values

from the earlier Vug Fill event. Na/Br (average = 208) and Cl/Br (average = 299) ratios are less than seawater (564: 655) with the lowest ratios corresponding to high δD (-97‰) values. I/Br ratios (0.05) are elevated above seawater ratios (<0.01) suggesting interaction with marine organic material. δD values clearly indicate a strong Mesozoic or Cenozoic meteoric water influence, but $\delta^{18}\text{O}$, $\delta^{13}\text{C}$ and dissolved halides suggest modification of these fluids by residual basin brines.

Calcite / Barite event

The final fluid event identified in the northern Canadian Rocky Mountains resulted in a megacrystalline calcite and barite cave and fracture fill. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values (calcite: 2.8‰ to 4.1‰ SMOW and -1.8‰ to -1.2‰ PDB respectively) combined with salinity values of nearly 0 eq. wt% NaCl suggest that these minerals were deposited from meteoric water. However, a combination of δD values (-157‰ to -136‰ SMOW) and growth bands within the barite that return fluid inclusion salinities and homogenisation temperatures that are within the range recorded for the Laramide veins suggest that the fluids from which both the Laramide veins and the Calcite / Barite veins were deposited, co-existed, but did not mix. This event is therefore interpreted as a surface water influx into cave systems and voids during the Laramide orogeny.

Conclusions

From the data that we have assembled, we can identify six distinct fluid events during the formation and subsequent development of what is now the Northern Canadian Rocky Mountains and the MacKenzie basin (Fig. 4; Table 1).

The first fluid event was syngenetic sedimentary exhalative, hydrothermal fluid flow during the deposition in the Ordovician and Silurian, which resulted in economically important Pb-Zn sulphide mineralisation. This event is associated with rifting and sedimentary basin formation. This was followed by widespread diagenetic dolomitisation that affected the majority of carbonates in the area.

The third fluid event formed the white sparry dolomite of the Manetoe Facies which has been correlated with the Presqu'île hydrothermal dolomites, further southeast in the MacKenzie basin. The Manetoe Facies is associated with

significant Pb-Zn deposits and hosts much of the hydrocarbon reserves of the MacKenzie basin. Contrary to Garven (1985), we interpret this event as a late diagenetic subsurface flow of evaporitic brines during the late Devonian and early Mississippian. The west to east flow of Manetoe Facies forming fluids might have taken place in response to Antler orogenic activity.

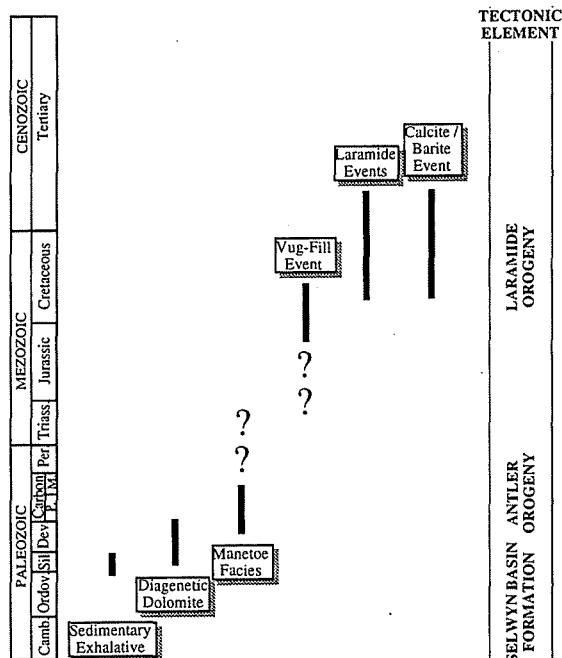


Figure 4. Summary of fluid events in the northern Canadian Rocky Mountains through time. Timing of events is approximate and based upon relative dating. Dashed lines represent areas where the timing of events is uncertain.

No evidence of additional fluid events has been identified until the vug-fill event. This is suggested to be a pre-Laramide (Cretaceous) flow from east to west of meteoric water, mixing with residual brines in the process and possibly correlatable with sub-aerial exposure in the MacKenzie Basin at this time (Aitkin, 1993).

Fluids associated with the Laramide Orogeny produced two physically distinct vein sets. The first is intruded along low-angle thrust faults during compression. These were cut by high-angle brittle veins. The fluid inclusion data indicate that both sets of veins were deposited from chemically evolved meteoric waters, while the isotope data show that the fluid flow was centered on the major faults in the area. The Calcite / Barite fluid event, was contemporaneous with the Laramide fluids, but

physically separate. This is interpreted to have resulted from an influx of meteoric water into voids that were occasionally occupied by Laramide fluids.

It is important to note that, despite the widespread nature of the Laramide deformational event, it has neither obscured nor has it altered the evidence for previous fluid events. This approach has therefore allowed us to interpret a long series of fluid events in an area of complex fluid history.

Publication & Completion of Project

Analytical work will be completed early this year. Preliminary results from this study have already been published in abstract form (Morris *et al.*, 1996b; 1996c; Nesbitt *et al.*, 1996). An extended abstract has been published (Morris *et al.*, 1997) and will be accompanied by an invited paper in a geological Society of London, Special Publication (in preparation). At least one further major paper is envisaged from this work and will be prepared in the first half of this year.

References

- AITKEN, J.D. 1993 Tectonic framework; Subchapter 2D in Sedimentary Cover of the Craton in Canada: STOTT, D.F. and AITKEN, J.D. (eds) *Geological Survey of Canada, Geology of Canada*, 5, 826pp.
- AULSTEAD, K.L. 1987 *Origin and Diagenesis of the Manetoe Facies, southern Yukon and Northwest Territories, Canada*. unpublished M.S. thesis, University of Calgary. 143pp.
- FRASER, S.C. 1996 *Geology and geochemistry of Prairie Creek Zn, Pb, Ag deposits, southern MacKenzie Mountains, N.W.T.* unpublished M.S. thesis, University of Alberta. 146pp.
- GABRIELSE, H. & YORATH, C.J. 1992 *Geology of the Cordilleran Orogen in Canada*. *Geological Survey of Canada, Geology of Canada*, 4, 843pp.
- GARVEN, G. 1985 The role of Regional Fluid Flow in the genesis of the Pine Point Deposit, Western Canada Sedimentary Basin. *Economic Geology*, 80, 307-324.
- GOODFELLOW, W.D. & JONASSON, I.R. 1986 *Geology and geochemistry of the Howards Pass Zn-Pb deposits, Yukon: constraints on metal source, migration and concentration*. in The genesis of stratiform sediment-hosted lead and zinc deposits: conference proceedings, Turner, R.J.W. & Einaudi, M.T. (eds) *Stanford University Publications*, 22-32.
- MACINTYRE, D.G. 1991 SEDEX - Sedimentary - Exhalative Deposits; in *Ore deposits, Tectonics*

- and Metallogeny in the Canadian Cordillera, W.J. MCMILLAN, T. HOY, D.G. MACINTYRE, J.L. NELSON, G.T. NIXON, J.L. HAMMACK, A. PANTELEYEV, G.E. RAY AND I.C.L. WEBSTER; *Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Paper 1991-4*, 276p.
- MORRIS, G.A., NESBITT, B.E., MUEHLENBACHS, K. AND FRASER, S. 1996a Paleo-Hydrogeology of the Nahanni River region, Northwest Territories: Initial results. in COOK, F. AND ERDMER, P (compilers) Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordillera Tectonics Workshop Meeting (1-3 March), University of Calgary. *Lithoprobe Report* 50 22-24.
- MORRIS, G.A., NESBITT, B.E., MUEHLENBACHS, K. AND FRASER, S. 1996b Paleohydrogeology of the Nahanni River region, Northwest Territories. . *GAC/MAC Joint Annual Meeting, Program with Abstracts* 21 A-67.
- MORRIS, G.A., NESBITT, B.E., AND MUEHLENBACHS, K. 1996c Paleo-hydrogeology of the Nahanni River region, NWT, Canada: Resolving multiple events from a long and complex fluid history. *GSA Abstracts with Programs* 28 (7).
- MORROW, D.W., CUMMINGS, G.L. & AULSTEAD, K.L. 1990 The gas-bearing Devonian Manetoe facies, Yukon and Northwest Territories. *Geological Survey of Canada, Bulletin*, 400, 54pp.
- NESBITT, B.E., MUEHLENBACHS, K., MORRIS, G.A., AND PROCHASKA, W. 1996 Geology, Geochemistry and Genesis of Late Hydrothermal Dolomite in the Western Canadian Sedimentary Basin. *GSA Abstracts with Programs* 28 (7).
- VEIZER, J. 1983 Trace elements and isotopes in sedimentary carbonates. *Reviews in Mineralogy*, 11, 265-300.

Table 1 Summary of events

	Event	Economic Importance	Petrological Features	Geochemical Features
Oldest	Sedimentary Exhalative	Pb-Zn	banded chert / dolomite fine grained sulphides	High $\delta^{18}\text{O}$ Low $\delta^{13}\text{C}$
	Diagenetic Dolomite		fine grained grey matrix dolomite	High $\delta^{18}\text{O}$
	Manetoe / Presqu'ile Facies	Pb -Zn, Hydrocarbon Reservoirs and Pathways	White sparry dolomite breccia fill, minor quartz and calcite	CaCl_2 fluid inclusion comp. High δD Low $\delta^{13}\text{C}$
	Vug Fill event		Calcite and dolomite vug and vein fill	Low δD High $\delta^{18}\text{O}$, $\delta^{13}\text{C}$
	Laramide events	Pb-Zn-Ag	High angle brittle quartz / calcite veins. Low angle calcite fault fill	NaCl fluid inclusion comp. tight range of salinity Low δD
Youngest	Calcite / Barite event		Caves rimmed by euhedral barite and filled by megacrystic calcite.	low salinity Low δD

Cambrian-Devonian Tectonic Framework, Canadian Cordillera and SNORCLE

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TECTONIC FRAMEWORK

Upper Proterozoic to Lower Devonian rocks in westernmost Canada accumulated within the Canadian Cordilleran and southwestern Franklinian miogeoclinal belts. The Franklinian, lying north of Ogilvie Arch, includes the Richardson Trough, a northward opening failed arm or aulacogen, and west and east of it the Porcupine and Lac des Bois platforms. South of it is the Canadian Cordilleran Miogeocline, which formed in Late Proterozoic as the result of Atlantic-type rifting. Rifting continued along with alkaline volcanism, throughout its history. The Cordilleran Miogeocline is divided by numerous northeast-trending linear features interpreted to reflect the position of ancestral strike-slip or transfer faults (Fig. 1). More than six major block segments are recognized; south to north they are: the Montana Block, bordered north by the Moyie-Dibble Creek fault systems; the Alberta Block bordered north by the Hay River and Great Slave Lake fault systems, and divided into the Peace and Southern Prairies sub-blocks along the Rimbey Magnetic - Snowbird Tectonic zones; the Macdonald Block, bordered north by the Liard Line; the Blackwater Block, bordered north by the Fort Norman Line; and the Mackenzie Block, bordered north by the southwestern Franklinian Miogeocline. Many facies changes occur across these blocks and their bounding ancestral transfer or strike-slip fault zones. These faults are likely keys to independent tectonic histories, such as that demonstrated by Peace River Arch. The most prominent northeast-trending lineament is the Liard Line. Apparent on the geological map of Canada is a northeastward swing of structural trends north of this line (Fig. 1). Lower Paleozoic rocks are extensively preserved far to the north and north east of this line, whereas to the south the same rocks are generally preserved in only the Cordilleran deformed belt. Although Lower Paleozoic rocks in the south have been substantially cut by younger erosional events, facies and thickness patterns, in fringing Lower Paleozoic strata, indicate that the pattern of erosion and non deposition, is as much due to Lower Paleozoic tectonics and paleogeography as it is due to younger exposure or erosion. This line, and the connection to the Franklinian, divide the Canadian Cordilleran Miogeocline into three fundamental parts. The Liard Line is interpreted to have been an ancient transfer fault zone across which there was a reversal in the direction of asymmetry within the master separation fault system that formed the ancestral margin in Late Proterozoic. The wide area north of the Liard line has a large outer miogeoclinal basin (Selwyn Basin), discrete rift systems (e.g. Misty Creek Embayment), a peculiar zone of high crustal attenuation (Liard Depression), and is complicated by several different arches or highs (e.g. Mackenzie Arch.). This northern half of the Canadian Cordilleran Miogeocline has the characteristics of a lower plate margin and is here defined as the Northern Cordilleran Lower Plate Zone. The Canadian Cordilleran Miogeocline south of the Liard Line is narrowly preserved in the Cordillera and consists of the Marginal basins and platforms (e.g. White River Troughs, Bow platform), fringed east by paleotopographic highs (e.g. West Alberta Ridge). This southern zone has the characteristics of an upper plate margin and is here defined as the Southern Cordilleran Upper Plate Zone.

SNORCLE

Although there will be east-west lines planned or shot, north and south of the Liard Transfer Fault, there are no plans to connect the two down Liard Highway. Such a cross line would have directly crossed the boundary of the Northern Cordilleran Lower Plate and Southern Cordilleran Upper Plate. In addition the north line is located on the platform side of the miogeocline and the south line is mainly located over basin facies of the outer miogeocline. In spite of this, we should see more preserved Phanerozoic stratigraphic section, with more facies and framework complexity, on the north line in comparison to the south line, and crustal thicknesses may be thinner on the north than in the south.

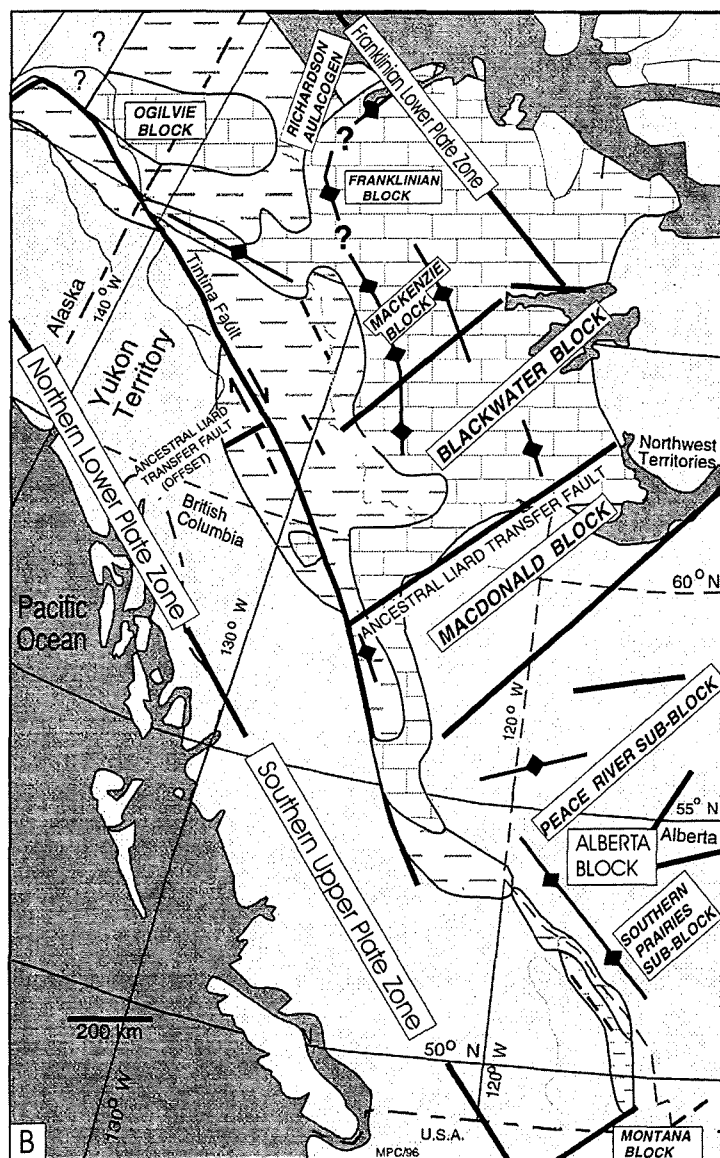
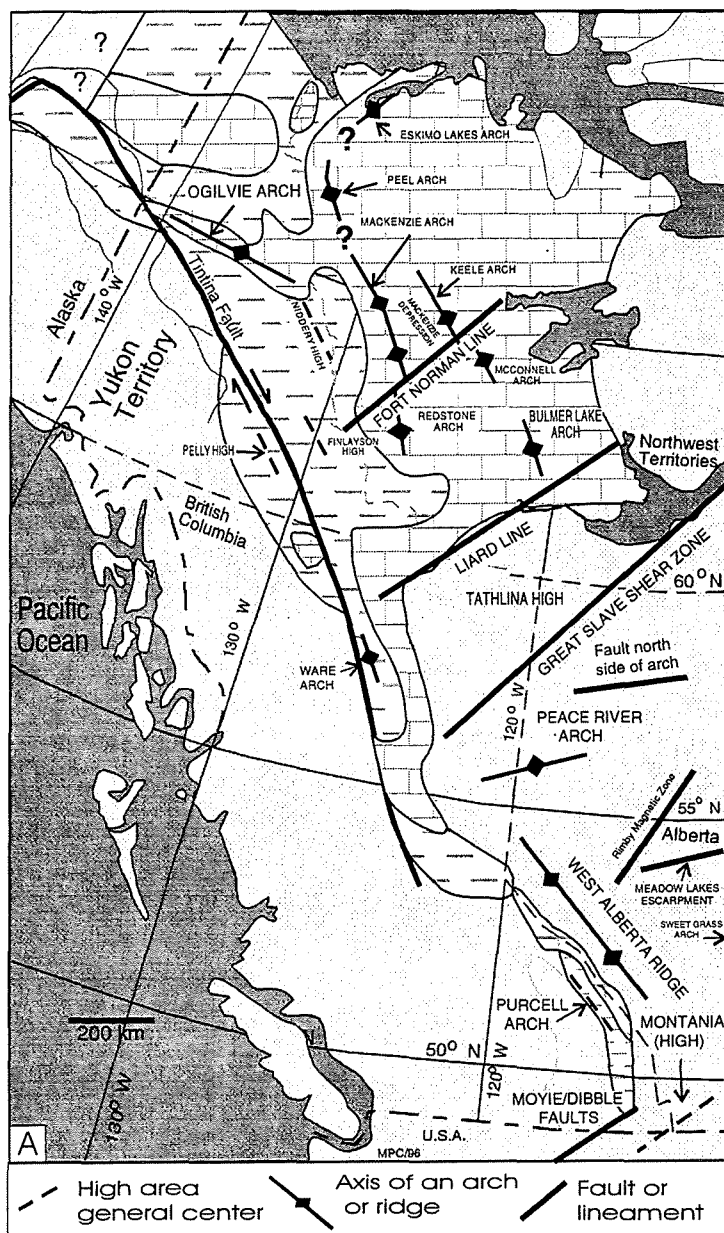


Fig. 1. Maps showing 'structural' paleogeographic features (A) and, block and upper and lower plate divisions (B) of the Lower Paleozoic Canadian Cordillera. Northeast-trending faults and lineaments are interpreted to reflect the position of ancestral transfer and strike-slip faults. They are used to divide the cordillera into 'tectonic blocks', and into upper and lower plate zones. (From Cecile, Morrow and Williams, 1997, CSPG Bulletin v. 45, #1)

Mixed signals from the Miogeocline: Geochemical and Nd isotopic constraints from the Selwyn Basin.

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The temporal variation of Nd isotopic composition of Cordilleran miogeoclinal clastic sediments has been examined in detail for southern BC (Boghossian et al., 1995), northern BC, and Yukon (Garzzone et al., 1996). All stratigraphic sections show a marked shift during the Paleozoic from values typical of detritus derived from the Canadian Shield ($\epsilon\text{Nd}_{600\text{ Ma}} = -20 \pm 5$), toward more juvenile isotopic compositions, reaching $\epsilon\text{Nd} \sim -8$ by the Middle Paleozoic. The timing of this shift appears to be a function of latitude, with the southern BC sections recording this shift in Devonian - Mississippian time (Boghossian et al., 1996), and the Yukon section showing this effect by the Middle Ordovician (Garzzone et al., 1996). If the same process is responsible for these effects, a dominant influence from the north is indicated. Boghossian et al. (1996) considered that this isotopic shift could result from northerly-derived detritus, ultimately derived from either Grenville-aged crust from the east, or the Innuitian Orogen. Isotopic mixing of shield-derived detritus with juvenile (arc) material was considered unlikely from a mass balance and petrographic standpoint by Boghossian et al. (1996). Garzzone et al. (1996) showed that the middle Ordovician isotopic shift for the northern Cordilleran miogeoclinal strata makes sediment derivation solely from the Innuitian Orogen (Devonian) impossible.

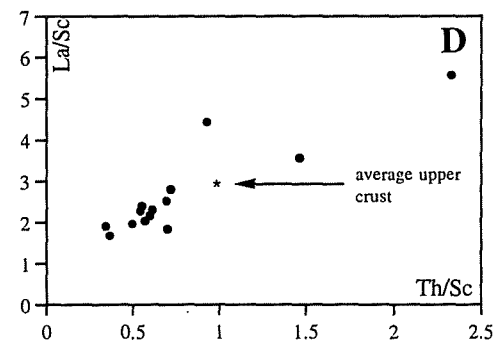
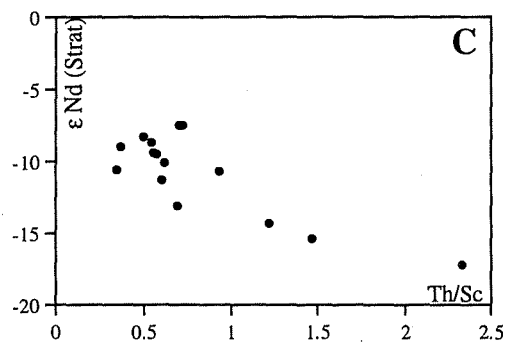
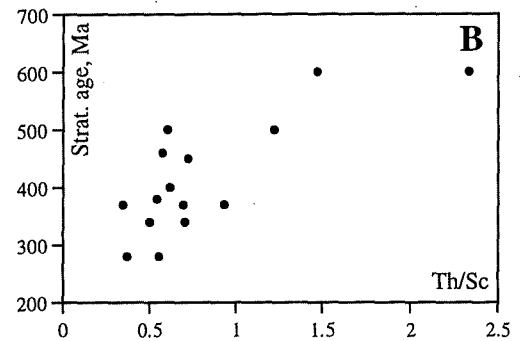
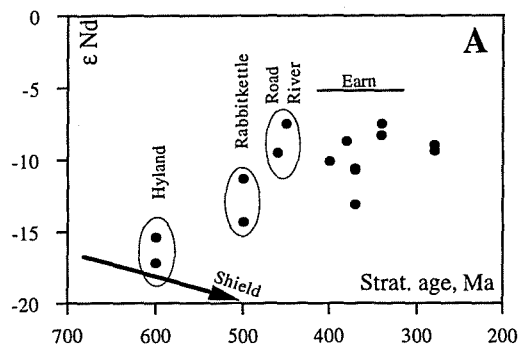
In order to constrain the origin of this major isotopic temporal effect, we have analyzed clastic sedimentary rocks from the Selwyn Basin (Ross River to MacMillan Pass) for Nd isotopic composition and geochemical characteristics. The application of trace element geochemistry is crucial for the resolution of this problem, as Nd isotopes cannot distinguish the degree of geochemical evolution of sediment provenance, but ratios such as Th/Sc and La/Sc, when coupled with Nd isotopic compositions should reveal this information. The stratigraphic sections examined range include late Proterozoic (Hyland), Cambrian (Rabbitkettle), Ordovician (Road River), Siluro-Devonian (Earn) and Carboniferous strata. The temporal evolution in Nd isotopic composition is similar to the Yukon section of Garzzone et al. (1996), with a shift to more juvenile compositions by the Middle Ordovician (Fig. 1a). However, with this age and isotopic progression is a distinct shift in provenance-sensitive trace element ratios such as Th/Sc (Fig. 1b,c). As the sedimentation age becomes younger and ϵNd become more juvenile, Th/Sc drops from typical felsic upper crustal values (1-2), toward lower values more characteristic of intermediate crustal compositions (Th/Sc ~ 0.3); a similar trend is seen for La/Sc (Fig. 1d). The Nd isotopic shift parallels these trends in trace element geochemistry, which indicates the input of crust chemically more mafic than shield-derived detritus in the provenance of these sediments. Thus, although the Nd data are consistent with derivation of the detritus from crust simply than the shield (e.g., Grenville-Ouachita crust; Boghossian et al., 1996), our trace element data indicate the requirement of mafic-intermediate crust in explaining the temporal variations.

Given a northerly driving force for these variations, it is worthwhile to consider possible mafic crustal material which could be a component in the provenance of the sediments. If mafic crust is the source for these variations, it is important to realize that its age must be pre-Middle Ordovician. There is no requirement that the origin of this crust be contemporaneous with the sedimentation. One candidate source may be the extensive flood basalts of the Coppermine group, and the equivalent and extensive Mackenzie dike swarm (1267 Ma; LeCheminant and Heaman, 1989). The Nd contents of the Coppermine lavas are high for mafic crust, averaging 27 ppm Nd and ranging up to 41 ppm (Dupuy et al., 1992), have ϵNd_{1270} values up to +4 and Th/Sc values averaging <0.10 (Dostal et al., 1983); ϵNd values at 500 Ma are ~ 0 . With these Th/Sc values, a miogeoclinal sediment with Th/Sc of 0.5 would comprise a $\sim 50:50$ mix of shield-derived detritus and mafic crust-derived detritus. Given the approximately equal Nd contents of average felsic crust and these mafic lavas, the ϵNd of a 50:50 mix would be ~ -10 , adequately accounting for the observed isotopic shift. In addition to the Coppermine lavas and related Mackenzie dikes, extensive mafic flows of the Late Proterozoic Natkusiak continental basalts exist in the northern Arctic (Dostal et al., 1986) and well as local basaltic volcanics of the Road River Fm. in the Selwyn Basin ($\epsilon\text{Nd}_{500} = +4$, Nd ppm = 30.5; this study). Our Selwyn Basin miogeoclinal sediment data require

detrital input from crust more primitive than upper continental crust, and numerous possibilities in northern North America exist.

References:

- Boghossian et al., 1996, *J. Geology*, 104, 259-277.
 Dostal et al., 1983, *CJES*, 20, 684-698
 Dostal et al., 1986, *CJES*, 23, 622-632
 Dupuy et al., 1992, *CJES*, 29, 1937-1943.
 Garziona et al., LITHOPROBE report 50, SNORCLE, 16.
 LeCheminant and Heaman, 1989, *EPSL*, 96, 38-48.



Westerly-Derived Upper Triassic Clastic Sedimentary Rocks in Southeastern Yukon: Evidence for Early Mesozoic Terrane Interaction with the Western Margin of Ancestral North America

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A sequence of siltstone, sandstone, and limestone of Late Triassic age occurs sporadically along the western edge of ancestral North America in the northern Canadian Cordillera. These strata are regionally observed or inferred to rest unconformably on older strata of the miogeocline. They commonly contain abundant detrital mica, and coarsen locally and possibly thicken to the west. In southeastern Yukon, the sedimentary rocks are intercalated with basaltic flows of uncertain tectonic affinity. In several localities, polymictic pebble to boulder conglomerate comprises most of the exposed sequence. Clasts in the conglomerates in these localities include: 1) massive greenstone, gabbro, anorthosite, and serpentinite; 2) metamorphic rocks including quartzite, quartz-mica schist, amphibolite, eclogite, and blueschist; and 3) massive dacite and andesite. Metamorphic clasts and massive dacite clasts have yielded mid-Permian to earliest Triassic K-Ar mineral ages. None of the clasts in the conglomerate have obvious sources to the east, suggesting that the Triassic detritus were derived at least in part from a composite terrane to the west which included an ophiolitic assemblage, a metamorphic assemblage with subduction-zone rocks, and a LatePaleozoic volcanic arc.

The Yukon-Tanana and Slide Mountain terranes, which are presently in fault contact with the Triassic clastic strata on the west, are possible sources of the metamorphic and ophiolitic clasts, respectively. The Triassic sedimentary sequence is cut by dykes and sills of intermediate composition that have yielded an Early Jurassic U-Pb age. The Late Triassic sequence and associated igneous rocks appear to record some of the earliest stages of terrane accretion in the northern Cordillera. Petrologic studies of the metamorphic clasts indicate differences with known in-situ eclogites and blueschists of the Yukon-Tanana terrane to the west. A strong glaucophane overprint affected both eclogitic rocks and upper crustal greenstones, and some eclogites were retrogressed in the amphibolite facies, and possibly in the greenschist facies, before blueschist facies metamorphism. If the Yukon-Tanana terrane was the source of the clasts, the source area(s) may not be presently exposed and the clasts may be the only record of subduction-zone assemblages that followed a different P-T-t path from known in-situ rocks. If the source was not the Yukon-Tanana terrane, high-pressure rock clasts in proximal sedimentary deposits record the existence of tectonostratigraphic assemblages that interacted with the ancestral continental margin and that have yet to be identified.

PALEOMAGNETIC DETERMINATION OF THE GEOTECTONIC DISPLACEMENT OF THE NORTHERN INTERMONTANE BELT: PROGRESS REPORT AND RECENT RESULTS

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A: PROGRESS REPORT

During the summer of 1994, prior to LITHOPROBE funding, collections were made from the 112 Ma Whitehorse tonalite pluton and the 109 Ma Mount McIntyre granodiorite pluton in the Whitehorse Trough of Stikinia in the Intermontane Belt (Fig. 1). Both the paleomagnetic and geobarometric analyses for both studies have been completed. Preliminary results for the Whitehorse Pluton were given in last year's Transect report. The final results have been reported in abstract form (Harris et al. 1996a) and written up in a paper that is currently under revision in light of referee's comments (Harris et al. 1997). A brief abstract of those results is given later in this report. Also a final report has been prepared and published giving the results of the Mount McIntyre study (Harris et al. 1996b). The results of this study are also outlined in the second part of this note.

Three collections, totalling ~960 specimens, were made during the summer of 1995 from the: 1) 103 Ma Cassiar batholith (26 sites) in the pericratonic Cassiar terrane; 2) 172 Ma Fourth-of-July plutonic complex (34 sites) in the Cache Creek terrane; and, 3) ~50 Ma Skagway mafic dikes (32 sites) in the easternmost Coast Plutonic complex (CPC) next to the Intermontane Belt (Fig. 1). The paleomagnetic measurements have been completed on these collections, giving apparently good results. The geobarometry measurements have also been completed for the Fourth-of-July pluton with excellent results, and are now underway for the Cassiar batholith.

This past summer, cores were collected for a further three studies that are all located in the Whitehorse Trough of Stikinia. They are the: 1) ~185 Ma Teslin Crossing granitic

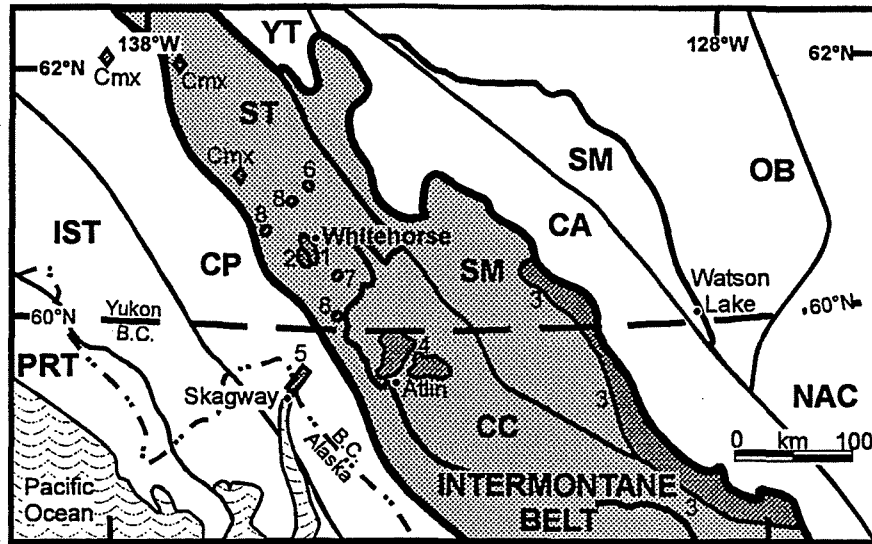


Figure 1 - Tectonic subdivisions of the northern Cordillera. Abbreviations: North American craton (NAC); Omineca fold belt (OB); Cassiar terrane (CA), displaced craton; Yukon-Tanana terrane (YT); Intermontane Belt includes Slide Mountain (SM), Cache Creek (CC) and Stikinia (ST) terranes; Coast plutonic complex (CP); Insular superterrane (IST); Pacific Rim terranes (PRT); Target units: 1) Whitehorse pluton; 2) Mount McIntyre pluton; 3) Cassiar batholith; 4) Fourth of July batholith; 5) Skagway dykes; 6) Teslin Crossing pluton; 7) Mount Lorne pluton; 8) Laberge conglomerate; and Cmx) Carmacks paleomagnetic sites of Johnston et al. (1996).

pluton and associated sills (19 sites); 2) ~78 Ma Mount Lorne felsic pluton (20 sites) ; and, 3) Lower Jurassic Laberge conglomerate (three localities) (Fig. 1). About 635 specimens have been prepared and measured paleomagnetically from these collections during the past few months, again giving apparently good results. The Mount Lorne pluton was collected specifically to check the result reported for the ~70 Ma Carmacks volcanics (Fig. 1) (Johnston et al. 1996) which have given an anomalously large northward translation distance and anomalously rapid translation rate relative to the few other results that are available for the terranes underlying the Intermontane Belt. The object of the Teslin Crossing pluton collection is to provide geotectonic motion estimates for the Early Jurassic in northern Stikinia that can be compared with estimates from the Guichon and Copper Mountain plutons in the southern Intermontane, and that can be combined with data from the other collections to give a reliable apparent polar wander path (APWP) segment for the Whitehorse Trough. This APWP segment may then be compared to the North American craton's APWP segment to provide much more reliable displacement and rotation estimates through time for the northern

Intermontane terranes. Preliminary results are given for the Laberge conglomerate collection in the second part of this report. In addition, samples were collected from the Guichon batholith, Copper Mountain pluton and Francois Lake (Topley) intrusives in the southern Intermontane Belt for geobarometry. The purpose is to see if these plutons have been subjected to tilt after acquiring their characteristic remanent magnetization (ChRM) directions (Symons 1983 a, b; Symons and Litalien 1984).

B: RECENT RESULTS

B-1: Whitehorse Pluton

The Whitehorse pluton is ovate and crops out over an area of $\sim 160 \text{ km}^2$. It intrudes sediments of the Late Triassic Lewes River Group in the Whitehorse Trough of Stikinia. It is dominantly tonalite but ranges in composition from gabbro to granodiorite, and it is a massive post-orogenic pluton with minor primary magmatic foliation near its contacts (Hart 1995). Two sets of K-Ar ages on biotite and hornblende give minimum and maximum ages of 109 ± 4 and 112 ± 4 Ma, respectively, that are reinforced by a Rb-Sr isochron age of 116 ± 20 Ma and a minimum U-Pb zircon age on a cross-cutting intrusive of 109 ± 1 Ma (Morrison et al. 1979; Hart and Pelletier 1989; Hart 1995). Contact attitudes from drilling and geophysical data indicate near-vertical contacts, indicating negligible post-emplacement tilt. Eight reliable determinations from around the perimeter of the pluton using the aluminum-in-hornblende geobarometer with a plagioclase temperature correction give depths in the 5.6 to 7.5 km range (mean 6.6 ± 0.6 km) with no bias trend, consistent with the geologic evidence that this is a high-level intrusion that has not suffered post-emplacement tilting. Paleomagnetic results from 22 of 24 sites in the felsic rocks of the pluton and other evidence define a mean ChRM direction of $D = 16.7^\circ$, $I = 76.2^\circ$ ($\alpha_{95} = 3.1^\circ$, $k = 101$). Comparison of its pole position to the 112 Ma reference pole of Besse and Courtillot (1991) indicates that the Whitehorse Trough has been translated poleward or generally northward by $11.0^\circ \pm 4.8^\circ$ or by 1220 ± 530 km and rotated clockwise by $59^\circ \pm 17^\circ$ since emplacement of the Whitehorse pluton. This estimate is similar to results from the latest Jurassic Francois Lake intrusives, and Early Cretaceous Spences Bridge volcanics and Axelgold mafic pluton in terranes of the southern Intermontane Belt. Our analysis indicates that the terranes underlying the Intermontane Belt moved northward along the margin of the North American craton as a relatively coherent unit

from ~ 142 Ma to ~ 45 Ma at a minimum velocity of 2.3 ± 0.4 cm/a with a clockwise rotation of $\sim 60^\circ \pm 15^\circ$ between ~ 100 and 70 Ma. Until supported by a second result, we consider the result from the Carmacks volcanics to be anomalous for some reason because its estimated minimum velocity is a high 9.2 ± 2.6 cm/a from ~ 70 to 45 Ma.

B-2: Mount McIntyre Pluton

The Mount McIntyre Pluton is a dominantly granitic body which is exposed over ~ 25 km². The pluton has intruded clastic and carbonate sediments along its western margins and the ~ 112 Ma Whitehorse Pluton along its eastern margins. Between the two plutons is a band that is one to four kilometres wide of undifferentiated intrusive rocks that may be margin rocks for either pluton (Fig. 2) (Hart and Pelletier 1989; Harris et al. 1997). A concordant U-Pb zircon age of $108.6^{+1.2}_{-0.4}$ has been determined from the northern portion of the pluton.

Aluminum-in-hornblende geobarometry techniques was attempted for horizontal control of the pluton. However, the results are inconsistent, both within the pluton and in comparison to estimates derived from the Whitehorse Pluton (Fig. 2). Despite these inconsistencies, the larger older Whitehorse Pluton has been shown to be horizontal (Harris et al. 1997) and therefore the Mount McIntyre Pluton is probably also horizontal.

Twenty-one sites were collected across the pluton for paleomagnetic study (Fig. 2). Thermal unblocking temperatures for all sites are preferentially in the 520° to 570°C range which shows that magnetite is the dominant magnetic mineral (Fig. 3). SIRM testing further shows the magnetite to mostly be pseudosingle to multidomain magnetite. AF demagnetization was used on the majority of the specimens, and ChRM directions were isolated after removal of a viscous component with an ~ 25 mT field. The 160 granitoid specimens all have normal polarities as expected for rocks formed in the Late Cretaceous normal superchron. The site mean ChRM directions of the granitoids are distributed in three clusters that have a geographical relationship (Fig. 4). Sites 01 and 02 are in the undifferentiated igneous rocks and thus are not included in the Mount McIntyre Pluton averages. The other 11 northern sites (03-10 and 19-21) give a ChRM direction that is steeply down and to the northeast (Fig. 4). The seven sites in the southern part of the pluton give a ChRM direction that is steeply down and to the northwest (Fig. 4). The two populations of ChRM directions were shown to be

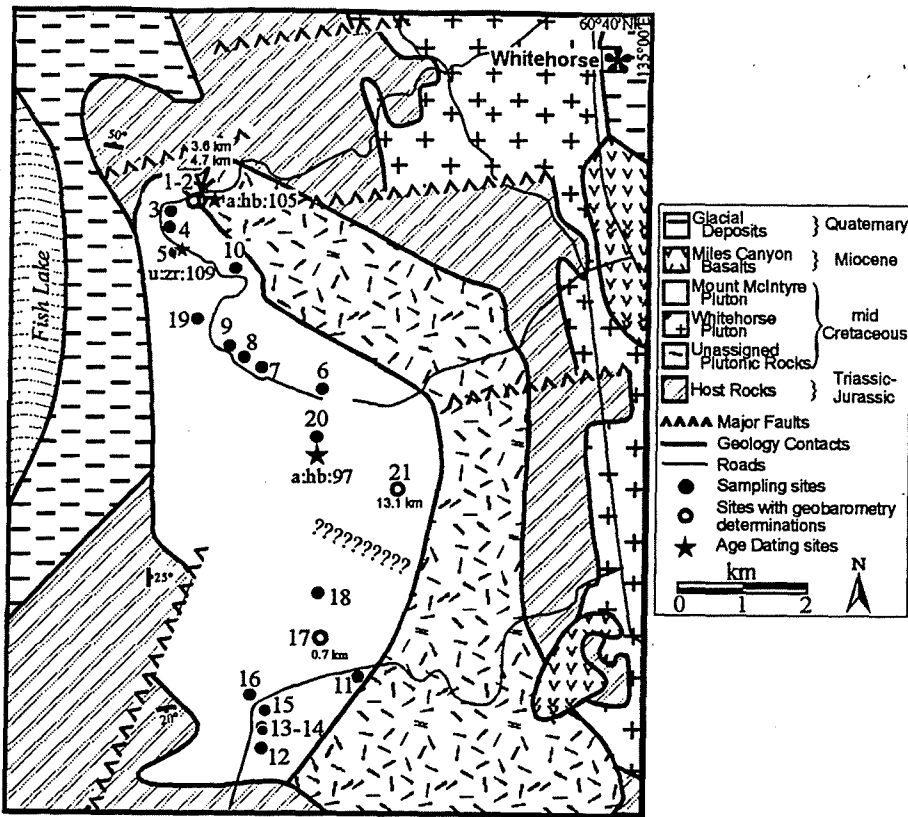


Figure 2 - Geology of the Mount McIntyre Pluton, modified from Hart and Radloff (1990) with sample sites added. Sites with geobarometry analyses have crystallization depths shown in kilometres. Age dating sites: a:hb:97 refers to K-Ar age dating on hornblende in Ma; u:zr:109 refers to U-Pb age dating on zircon in Ma. Question marks refer to zone of possible tectonic motion between northern and southern sections of pluton.

statistically different by calculating the F-statistic of McFadden and Lowes (1981). A paleomagnetic contact test on a mafic dike cutting the pluton is shown to be negative, as the ChRM direction for the dike and the baked zone are almost identical to the ChRM of the other southern plutonic sites (Fig. 4).

To estimate the geotectonic motions of the Mount McIntyre Pluton and the enclosing northern Stikine terrane, three sets of calculations were done: one for the southern sites, one for the northern sites, and one for the combined average assuming more collecting would fill in the gap between the two populations to make one population. The ChRM direction from the southern sites suggests that the pluton has been translated poleward ~3900 km with no rotation over a 74 Ma time period. This estimate is similar to that from the younger Carmacks volcanics (~70 Ma) that estimates ~2300 km of translation and ~20° of clockwise rotation from 70 Ma to 45 Ma (Johnston et al. 1996). The ChRM direction for the northern sites

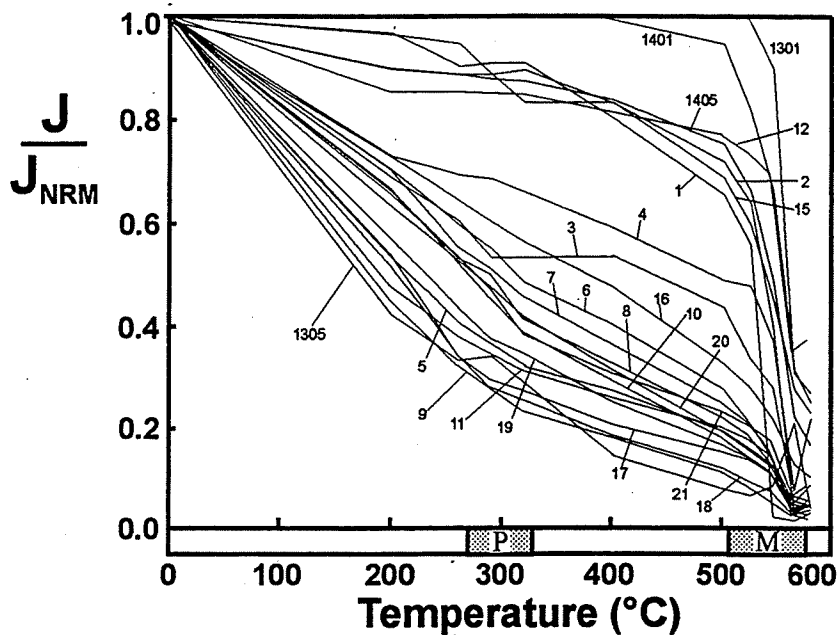


Figure 3 - Thermal demagnetization decay curves of thermal pilots for the Mount McIntyre Pluton. Numbers refer to the site (and core) of the treated specimen. The preferential unblocking temperatures diagnostic of pyrrhotite and magnetite are indicated at the bottom by the P and M respectively.

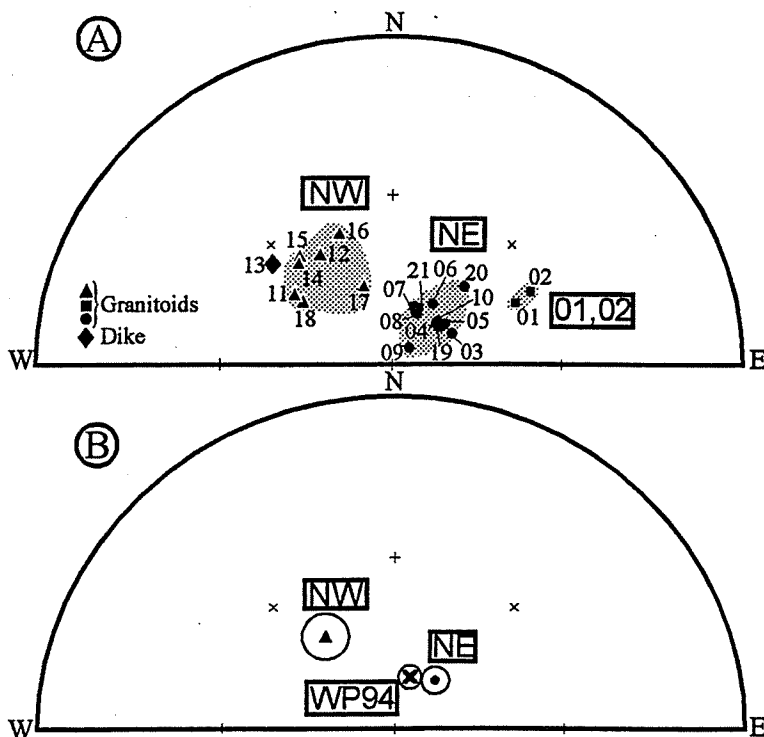


Figure 4 - Equal area stereonet plots of; a) site mean ChRM directions and b) cluster mean ChRM directions with their respective 95% cone of confidence. NW - northwest cluster; NE - northeast cluster; 01,02 - sites 01 and 02; WP94 - pluton mean ChRM direction of the Whitehorse Pluton.

suggests ~ 1600 km of poleward motion with $\sim 80^\circ$ of clockwise rotation. This estimate is similar to the neighbouring Whitehorse Pluton (Fig. 4) which gives an estimate of 1200 km of translation and $\sim 60^\circ$ of clockwise rotation, and to other Late Jurassic to mid Cretaceous rocks of central and southern British Columbia (Harris et al. 1997). The combined mean ChRM direction for all the granitoid sites suggests ~ 2500 km of translation with $\sim 27^\circ$ of clockwise rotation but has an uncertain geological significance at this point. Age dating from the southern part of the pluton, structural reconnaissance of the pluton to find any undiscovered faults and more geobarometric and paleomagnetic data are needed before any conclusive results may be made.

B-3: Preliminary Results from the Laberge Conglomerate

Critics of paleomagnetic results from large plutons in the Cordillera have sometimes attributed their ChRM to a secondary remagnetization rather than accept the geotectonic consequences of a primary origin. They suggest, often without evidence, that the ChRM may have been reset by regional metamorphism, by chemical reaction from subsurface fluids, or by the overriding dominance of a Quaternary viscous remanence. This study of the Laberge conglomerate was undertaken to assess the potential for remagnetization in the four plutons that we are currently studying in detail in the Whitehorse Trough.

The Lower to Middle Jurassic Laberge Group is composed of conglomerates and sandstones, and it infills the upper half of the 500 km long Whitehorse Trough. The Group rests both conformably and unconformably on the Upper Triassic to Lower Jurassic Lewes River Group. The conglomerate member forms the entire thickness of the Laberge Group on the west side of the Trough and it undergoes a lateral facies change eastwards so that the sandstone member forms the entire thickness on the east side. The Laberge conglomerate has been described in considerable detail by Hart et al (1995). The conglomerate is polymictic with well rounded clasts of cobble to boulder size. The clasts are derived predominantly from felsic plutons ($\sim 67\%$) with minor percentages from mafic volcanics, intermediate plutons and clastic sediments, and with trace percentages of a variety of other lithologies. Four U-Pb zircon dates for felsic clasts from two locations range between 208 and 215 Ma. These and other evidence indicate that the clasts were derived from the west from the Lewes River arc,

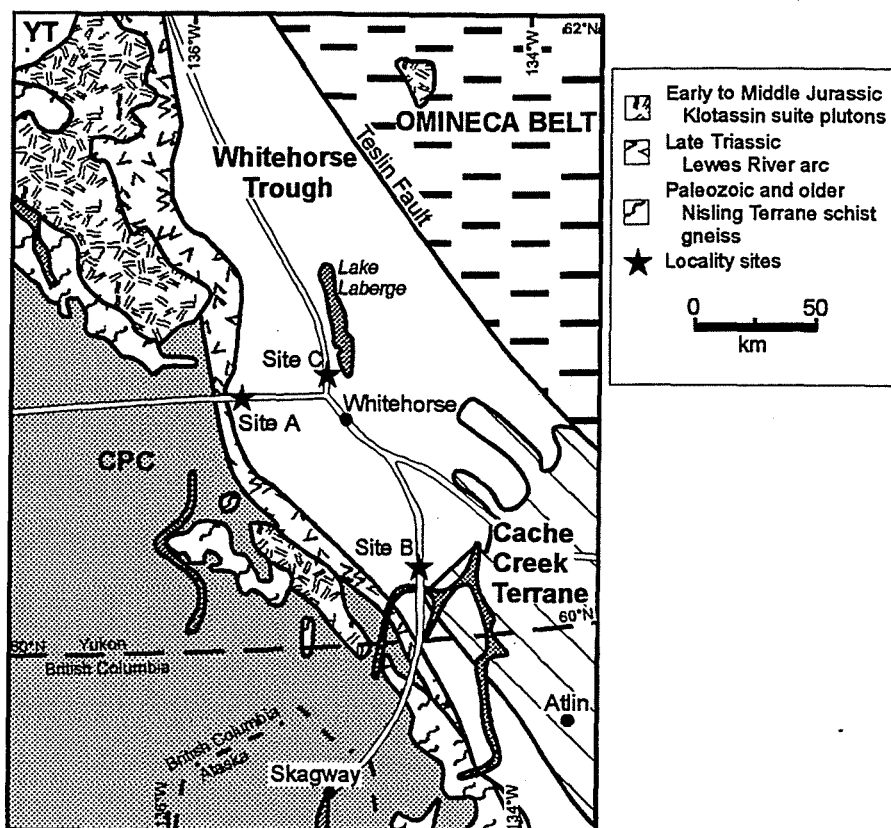


Figure 5 - Generalized tectonic map of south-central Yukon Territory showing the Laberge conglomerate localities (modified from Hart et al. 1995).

and that they were deposited as a coastal fan from debris flows into a fore-arc basin that evolved into the Whitehorse Trough.

Localities A, B and C are ~ 5, 20 and 40 km, respectively, from the western margin of the Whitehorse Trough (Fig. 5) where rocks of the Lewes River arc are deformed by the abutting Coast Plutonic Complex (CPC) that was formed during the Cretaceous-Paleocene Laramide Orogeny. At each locality cores were drilled from 40 clasts and a further 8 cores were drilled from the sandstone matrix. The grain size of the latter ranged from silt to very coarse sand size. Most of the clasts, ~75%, were from felsic plutons whereas sedimentary clasts were avoided.

The matrix at locality A does not give a coherent direction, probably because it is still very coarse grained with pea-sized pebbles. Contrarily the matrix at localities B and C give very coherent steeply-inclined Laramide directions. They appear to reside in pyrrhotite from thermal demagnetization analysis, and are thought to have been emplaced as a chemical

remanent magnetization. At all three sites in the magnetite unblocking temperature range (500°-585°C), the clasts give random directions, thereby providing a positive paleomagnetic conglomerate test. In the pyrrhotite unblocking temperature range (260°-325°C), the clasts in the center of the Whitehorse Trough at locality C are also randomly oriented, giving a positive contact test. In contrast the clasts closest to the CPC at localities A and B give moderately coherent populations of Laramide ChRM directions and thus give a negative paleomagnetic test result.

The results from the Laberge conglomerate thus lead to three conclusions. First, large plutons anywhere in the Whitehorse Trough will probably preserve a primary ChRM in the magnetite unblocking temperature range. Second, these plutons may have a thermally reset ChRM up to the pyrrhotite unblocking temperature range if they are within ~20 km of the CPC orogenic belt, but not in this range further eastwards in the Trough. Third, sedimentary and some volcanic strata within the Whitehorse Trough are apt to have a reset chemical remanent magnetization as a result of subsurface fluid flow during the Laramide, perhaps related to volcanic activity of the ~70 Ma Carmacks event.

REFERENCES

- Besse, J., and Courtillot, V. 1991. Revised and synthetic apparent polar wander paths of the African, Eurasian, North American and Indian Plates, and true polar wander since 200 Ma. *Journal of Geophysical Research*, **96**, B3: pp. 4029-4050.
- Harris, M.J., Symons, D.T.A. and Hart, C.J.R. 1996a. Geotectonic Displacement of the Stikinia Terrane: Evidence from paleomagnetic measurements on the Whitehorse Pluton, Yukon Territory. *In* Annual Spring Meeting, American Geophysical Union (AGU), May 1996, Baltimore, MD: p. S90.
- Harris, M.J., Symons, D.T.A., Blackburn, W.H. and Hart, C.J.R. 1996b. Paleomagnetic study of the mid-Cretaceous Mount McIntyre pluton, Whitehorse map area (105D), southern Yukon Territory. *Yukon Exploration & Geology* 1996, pp122-130.
- Harris, M.J., Symons, D.T.A., Blackburn, W.H. and Hart, C.J.R. 1997. Paleomagnetic and geobarometric study of the mid Cretaceous Whitehorse Pluton, Yukon Territory. Submitted to the *Canadian Journal of Earth Sciences*.
- Hart, C.J.R. 1995. Magmatic and tectonic evolution of the Intermontane Superterrane and Coast Plutonic Complex in southern Yukon Territory. M.Sc. thesis, University of British Columbia, Vancouver.

- Hart, C.J.R., and Pelletier, K.S. 1989. Geology of Whitehorse (105D/11) map area. Indian and Northern Affairs Canada, Yukon Region, Open File 1989-2.
- Hart, C.J.R., Dickie, J.R., Ghosh, D.K. and Armstrong, R.L. 1995. Provenance constraints for Whitehorse Trough conglomerate: U-Pb zircon dates and initial Sr ratios of granitic clasts in Jurassic Laberge Group, Yukon Territory. *In* Jurassic Magmatism and Tectonics of the North American Cordillera. *Edited by* D.M. Miller and C. Busby. Geological Society of America Special Paper 299: pp. 47-63.
- Johnston, S.T., Wynne, P.J., Francis, D., Hart, C.J.R., Enkin, R.J., and Engebretson, D.C. 1996. The Whitehorse hotspot: The Late Cretaceous Carmacks Group. *In* 1996, Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary. *Edited by* F. Cook and P. Erdmer. Lithoprobe Report No. 50: p. 117.
- McFadden, P.L., and Lowes, F.J. 1981. The discrimination of mean directions drawn from Fisher distributions. *Geophysical Journal of the Royal Astronomical Society*, **67**: pp 19-33.
- Morrison, G.W., Godwin, C.I., and Armstrong, R.L. 1979. Interpretation of isotopic ages and $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratios for plutonic rocks in the Whitehorse map area, Yukon. *Canadian Journal of Earth Sciences*, **16**: pp. 1988-1997.
- Symons, D.T.A. 1983a. Further paleomagnetic results from the Jurassic Topley Intrusions in the Stikinia subterrane of British Columbia. *Geophysical Research Letters*, **10**, pp. 1065-1068.
- Symons, D.T.A. 1983b. New paleomagnetic data for the Triassic Guichon batholith of south-central British Columbia and their bearing on Terrane I tectonics. *Canadian Journal of Earth Sciences*, **20**, pp. 1340-1343.
- Symons, D.T.A., and Litalien, C.R., 1984. Paleomagnetism of the Lower Jurassic Copper Mountain intrusions and the geotectonics of Terrane I, British Columbia. *Geophysical Research Letters*, **11**, pp. 685-688.

EARLY TECTONIC EVOLUTION OF THE NORTHERN LAURENTIAN MARGIN: LITHOSTRATIGRAPHIC AND CONODONT BIOSTRATIGRAPHIC DATA FROM A TRANSECT ACROSS THE MACDONALD PLATFORM, KECHIKA TROUGH AND CASSIAR TERRANE

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Lower Paleozoic strata of the Canadian Cordilleran Miogeocline document the early tectonic evolution and syn-rift to post-rift phases of the northern margin of Laurentia. The stratigraphic units examined accumulated in the Southern Cordilleran Upper Plate Zone south of Liard Line which includes the Kechika Trough and Macdonald Platform (Cecile et al., in press). Stratigraphic and conodont biostratigraphic studies across an east-west platform-miogeocline-basin transect, which approximates to part of line 2 of the LITHOPROBE/SNORCLE transect, are in progress. These will complement similar transects in the southern Cordillera and across the Laurentian margin of the Newfoundland Appalachians.

Twelve principal sections of the shallow-water platform facies (Skoki Formation; lower to middle Ordovician), the shelf to basin facies (Kechika Group; late Cambrian to lower Ordovician) and the slope to basin facies (Road River Group; lower Ordovician to Silurian) have been described, measured and sampled for conodonts in remote alpine regions of northeastern British Columbia over three field seasons. The shallow-water shelf carbonates of the Kechika Gp. and overlying Skoki Fm. accumulated on the Macdonald Platform and comprise a 380m thick section located in the eastern part of the study area (Ware map-area).

A thick (2000m), fault-repeated succession of deeper shelf facies comprising Kechika limestone and shale and Skoki dolostone and limestone was collected south of Mount Sheffield. This expanded, complete section will form the template to which data from other sections are compared.

Successions of shelf to outer miogeocline and upper slope facies along the western edge of Macdonald Platform were examined at several sections. A thick, spectacular section is preserved at Grey Peak in Kwadacha Wilderness Park which includes the platform to deeper shelf transition. Thin bedded carbonate and deeper basinal shale of the Kechika Group (1400m) abruptly overlie Cambrian shallow-water sandstone, carbonate and breccia and indicates the initiation of thick packages of Kechika Group sediments developed as the Kechika Trough subsided rapidly. The Road River Group (500m) conformably overlies the Kechika Group and comprises breccia debris flows which contain clasts of Skoki lithologies interbedded with Road River black, anoxic shale indicating further extensional phases and a steepening of the platform edge.

In addition to these key sections, a complete exposure of Road River Group has been sampled north of the Akie River where it is underlain by the Kechika Group and overlain by higher Silurian clastics. A nearly complete succession of Skoki Formation has also been collected west of the Prophet River. Over 300m of calcareous Road River Group were sampled in a core from the Akie prospect of Inmet Mining Corporation.

Basinal facies within the Kechika Trough were examined in condensed sequences of Kechika and Road River groups such as at Driftpile Creek (400m thick) and Bluff Creek (700m thick) in the Kechika map-area. The distinction of lithologic units is difficult at Bluff Creek and requires further investigation. In other regions of the Kechika Trough, sequences of the Kechika Group thicken to over 1000 m at Gataga Mountain and suggest a positive tectonic element west of the trough (Ferri et al., 1994, 1995).

The Kechika Trough is bounded on the west by the Northern Rocky Mountain Trench, beyond which lies the parautochthonous Cassiar Terrane that has been displaced at least 450 km from the south (Gabrielse, 1985), possibly representing a segment of the Kakwa Platform. An east-west transect across the Cassiar Terrane has been accomplished by sampling Kechika and Road River facies from three sections at Moodie Creek, Deadwood Lake and Cassiar to examine similar changes from shallow-water to deeper-water facies.

To date over 400 4kg conodont samples have been collected with about one-third remaining to be processed. Insoluble residues are large and picking time considerable. Many samples contain hundreds of specimens; picking and sorting is advanced and taxonomic identifications in progress. Conodont abundance and diversity ranges from high in the platform facies to low in the deep basinal environments. Initial identifications show that the deepening phases to give the onset of Kechika and Road River groups lie in the uppermost Cambrian and latest Tremadoc, respectively. A sequence of zonal faunas occurs in these units with, for example, *Cordylodus*, *Iapetognathus*, *Rossodus*, *Scolopodus* and *Paracordylodus* species as Tremadoc zonal indicators in the Kechika. In the lower Road River Group, *Paracordylodus*, early platform genera, *Periodon* and *Protopanderodus* species provide zonal indices for the Arenig through Caradoc interval. A substantial amount of taxonomic work remains followed by the establishment of the detailed biostratigraphic and paleoecologic framework. These aspects will be undertaken over the next 15-18 months to complete the project.

Lateral ecological differentiation is evident, especially with the onset of a pronounced shelfbreak separating anoxic Road River basinal facies from equivalent shallow platform carbonates of the Skoki Formation. Conodont paleoecologic patterns (i.e., provinces and communities) across the platform-shelfbreak-slope-basin transect will be documented by studying biofacies relationships. Subtle changes in faunal patterns through time caused by tectonic and eustatic events will help interpret the details of regional sequence stratigraphy and

tectonic evolution. Conodont colour alteration index (CAI) values across the transect are also being assessed and lie mainly in the 4-5 range indicating a burial temperature range of 190-400°C, above the oil window.

The rifted upper-plate segment of the continental margin of ancestral North America, although characterized as Atlantic-type, has undergone several phases of rifting and extensional phases as indicated by initiation of Kechika Group sedimentation in the Kechika Trough and by the facies transitions to deep basinal Road River Group. The conodont biostratigraphy, integrated with lithostratigraphic and paleoecologic data, will constrain regional interpretations of events and contribute to an understanding of the nature and timing of these tectonic events.

References:

- Cecile, M.P., Morrow, D. W., and Williams, G. K., in press, Early Paleozoic (Cambrian to Early Devonian) tectonic framework, Canadian Cordillera.
- Ferri, F., Nelson, J., and Rees, C., 1994, Geology and mineralization of the Gataga River Area, northern Rocky Mountains (94I/7,8,9 and 10): British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1995, Paper 1995-1, p. 277-295.
- Ferri, F., Nelson, J., and Rees, C., 1995, Geology and mineralization of the Gataga River Area, northern Rocky Mountains (94L/10, 11, 14 and 15): British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1996, Paper 1996-1, p. 137-154.
- Gabrielse, H., 1985, Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia: Geological Society of America Bulletin, v. 96, p. 1-14.

PRELIMINARY CONSTRAINTS ON THE STRUCTURAL AND METAMORPHIC EVOLUTION OF THE ST. CYR KLIPPE, SOUTH-CENTRAL YUKON.

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The St. Cyr klippe preserves two allochthonous assemblages, the Anvil allochthonous assemblage (ANV) and the Nisutlin allochthonous assemblage (NIS), which have been obducted onto North American shelf strata of the Cassiar terrane (Tempelman-Kluit, 1979). The klippe lies between the Tintina fault on the northeast and the Teslin tectonic zone on the southwest (Fig.1). The ANV has been regionally correlated with the Slide Mountain terrane, and the NIS has been correlated with the Yukon-Tanana terrane (Wheeler and McFeely, 1991). Most rock types in the klippe have also been correlated with rocks of the Teslin tectonic zone, the inferred suture zone between North America and the accreted terranes.

The ANV comprises dominantly mafic to ultramafic metaigneous rocks of lower to middle amphibolite grade with local lenses of micaceous quartzite or eclogite. Ten currently known eclogite localities (Fig.1) show that eclogite is more widespread within the ANV than the two localities known from previous work suggested (Erdmer, 1992). Gradational contacts with garnet amphibolite host rock suggest that eclogite facies metamorphism was more widespread in the past and large volumes of rock have since been overprinted with an amphibolite facies metamorphism. Garnet-hornblende geothermometry from amphibolites within the ANV record peak metamorphic temperatures in the range of 500-650°C (Fig.1). Future microprobe studies will constrain pressures.

The interpretation of ANV as oceanic crust (Tempelman-Kluit, 1979) and its position relative to other accreted terranes, has lead people to correlate it with the Slide Mountain terrane (Wheeler and McFeely, 1991). This correlation is problematic with rocks of the ANV in the Teslin tectonic zone because these rocks do not show MORB like geochemical patterns which are typical of the Slide Mountain terrane (R. Creaser, pers. Comm. 1996). A geochemical study in progress of rocks from the ANV of the St. Cyr klippe will establish whether or not the correlation with Slide Mountain is correct.

Detailed mapping (1:50 000 scale) in the summer of 1996 has expanded upon the mapping of the northwest end of the St. Cyr klippe in 1995 (Fallas, 1996) to include exposures of the NIS and ANV to the southeast. The NIS can be subdivided into two structural panels: an upper panel which comprises coarse grained muscovite schist with garnet or plagioclase porphyroblasts, and a lower panel which comprises phyllite, chlorite schist, micaceous quartzite, marble and metaconglomerate. The rocks of the upper panel have a penetrative L-S tectonite fabric much like rocks of the ANV, whereas rocks of the lower panel are massive in some places where they preserve original sedimentary structures. When traced along strike from the Quiet Lake map area (105F) into the Teslin map area (105C), the rocks of the lower panel are identified as Proterozoic Ingenika Group sediments belonging to the Cassiar terrane (Gordey and Stevens, 1994). This along-strike correlation is problematic and in conjunction with the difference in metamorphic grade and state of deformation between the two panels sheds some doubt about assigning the lower panel to the NIS. To help clarify the relationship between the two panels of the NIS and the Cassiar terrane, a Nd study is being conducted to look at the provenance of these sediments and metasediments.

The St. Cyr klippe can be subdivided into three separate thrust slices of which the uppermost comprises the ANV, the middle slice comprises the upper panel of the NIS, and the lowermost comprises the lower panel of the NIS (Fig.1). To the southwest of the St. Cyr klippe is a smaller klippe which lies in the hangingwall of a normal fault and outcrops along the east shore of Quiet Lake. This smaller klippe is herein referred to as the Quiet Lake klippe (informal terminology). Each of these four structural domains is made up to varying degrees of L-S tectonites with strong foliations and weak

to strong extension lineations. Equal area stereonet plots are shown in Figure 2 to summarize the orientations of these fabrics within each domain. The steep to moderately NE or SW dipping foliations of the three St. Cyr klippe domains do not conform to the shallow orientation of the basal thrust fault of the St. Cyr klippe, and demonstrate that the foliation is not related to thrusting. In the field the basal thrust can be seen to cut the foliation at a high angle, indicating that the thrust fault is younger than the ductile fabric. The NE-SW dipping pattern of the foliations is similar to that seen in the Teslin tectonic zone (Stevens and Erdmer, 1996). The shallow SE and E dips of foliation within the Quiet Lake domain may be due to rotation during normal faulting, or it may be a reflection of a separate fabric domain which predates thrusting.

Extension lineations within the ANV and the upper panel of the NIS are plunging shallowly to the NW or SE and therefore record dominantly strike-slip motion. This differs from the Teslin tectonic zone in that there is very little evidence for dip-slip motion. Although extension lineations within the lower panel of the NIS are not common, where measured they have a shallow to steep plunge to the S or SW which reflects a combination of dip-slip and strike-slip motion. The extension lineations of the Quiet Lake domain are few and highly scattered but plunge generally E and SE. If the extension lineations were related to NE directed thrusting, a NE-SW lineation would be expected. Since this is not seen, the extension lineations also predate the thrusting event. Transpression in the Teslin tectonic zone before NE directed thrusting could explain these lineations (Stevens and Erdmer, 1996).

Shear sense indicators such as C'-type shear bands, rotated porphyroblasts, and preferred crystallographic alignment are present in some lithologies. Usually only one type of shear sense indicator is present in a given sample. Most shear sense indicators are found in quartz rich lithologies of the ANV and reveal both top-to-the-NW and top-to-the-SE shear in both the St. Cyr and the Quiet Lake klippen. The shear sense indicators found in schists of the upper panel of the NIS generally agree with those from the ANV. No reliable shear sense indicators were found in the lower panel of the NIS. The split between top-to-the-NW shear and top-to-the-SE shear is equal throughout the study area, and an explanation for this has yet to be established. Two samples, one from the immediate footwall of the St. Cyr basal thrust and one from the immediate footwall of the Quiet Lake basal thrust, record top-to-the-NE shear, showing that thrusting was NE directed.

Preliminary age constraints on the timing of metamorphism within the ANV have been established by two zircon fractions from the Deer Creek eclogite within the St. Cyr klippe (Fig.3). The first fraction made up of small, clear, elongate prisms, and the second is made up of small, equant prisms or faceted spheres. Both fractions are slightly discordant and give an average age of approximately 266 Ma. Subsequent analyses will further constrain this age. The metamorphic reaction which took place to form zircon is not known so the age is interpreted to record peak eclogite facies metamorphism. This pins eclogite facies metamorphism in the St. Cyr klippe to the Early Permian. Importantly, this age is very similar to the 269 Ma age of the Last Peak eclogite from the Teslin tectonic zone (Creaser et al., 1996). This is the first geochronological link between rocks of the St. Cyr klippe and the Teslin tectonic zone and strengthens previous correlations based on lithology.

In order to establish the time of cooling for rocks of the St. Cyr klippe, a ^{40}Ar - ^{39}Ar study of micas from lithologies within both the ANV and the NIS is in progress. A preliminary analysis of a garnet metabasite boulder within the ANV of the St. Cyr klippe has returned a plateau age of 256 $\pm$ 1.8 Ma (P. Erdmer, pers. comm., 1996). This date indicates cooling of ANV rocks in the St. Cyr klippe by the Late Permian. It is not known whether or not these two dates also reflect the metamorphic history of the NIS.

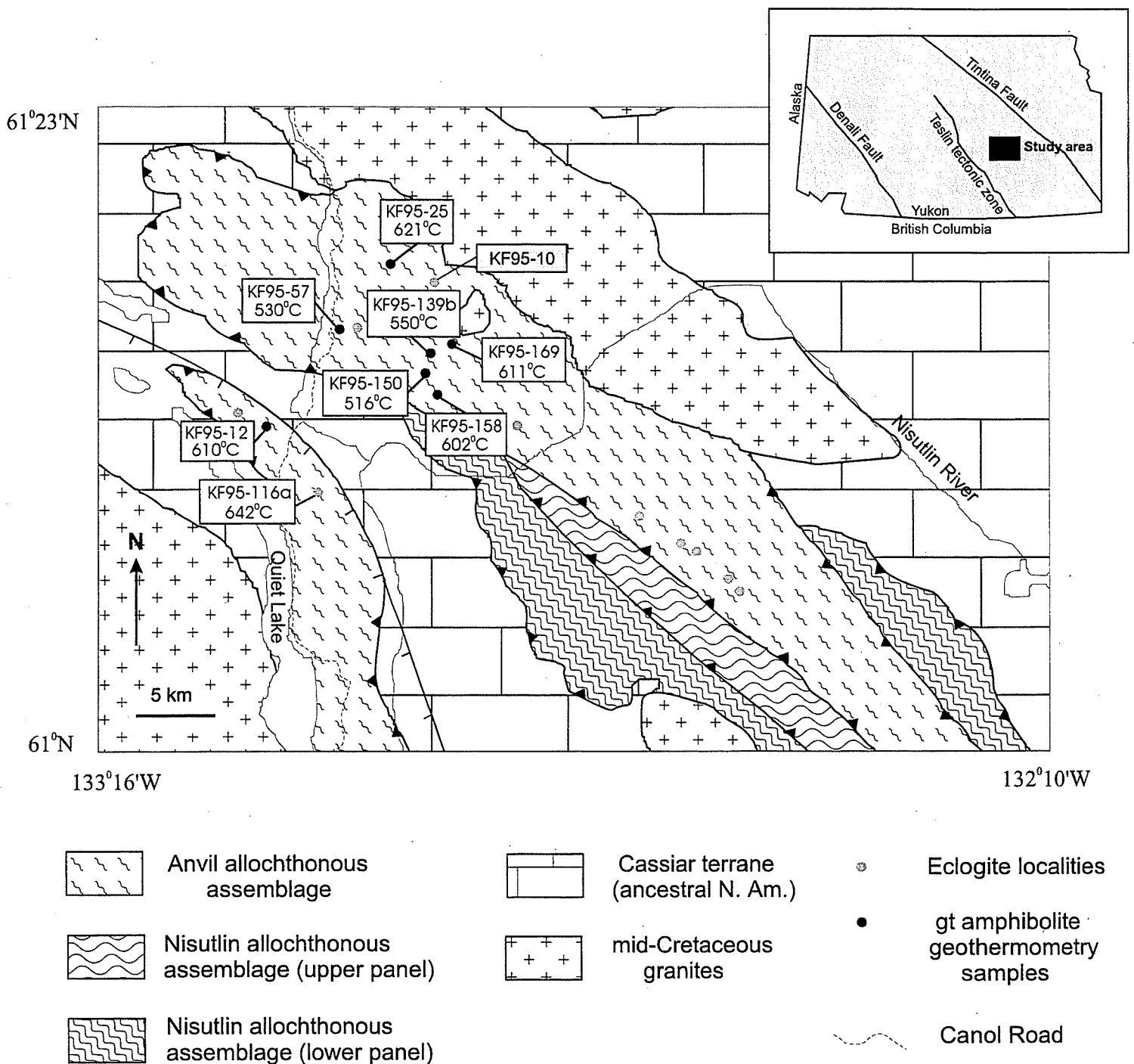


Figure 1. Simplified geology of the St. Cyr klippe showing the results of gt-hb geothermometry of the Anvil allochthonous assemblage. Eclogite sample used for U-Pb zircon geochronology is labelled with a grey box (see Fig.3). The outcrop of the Anvil allochthonous assemblage on the east side of Quiet Lake is herein referred to as the Quiet Lake klippe (informal terminology).

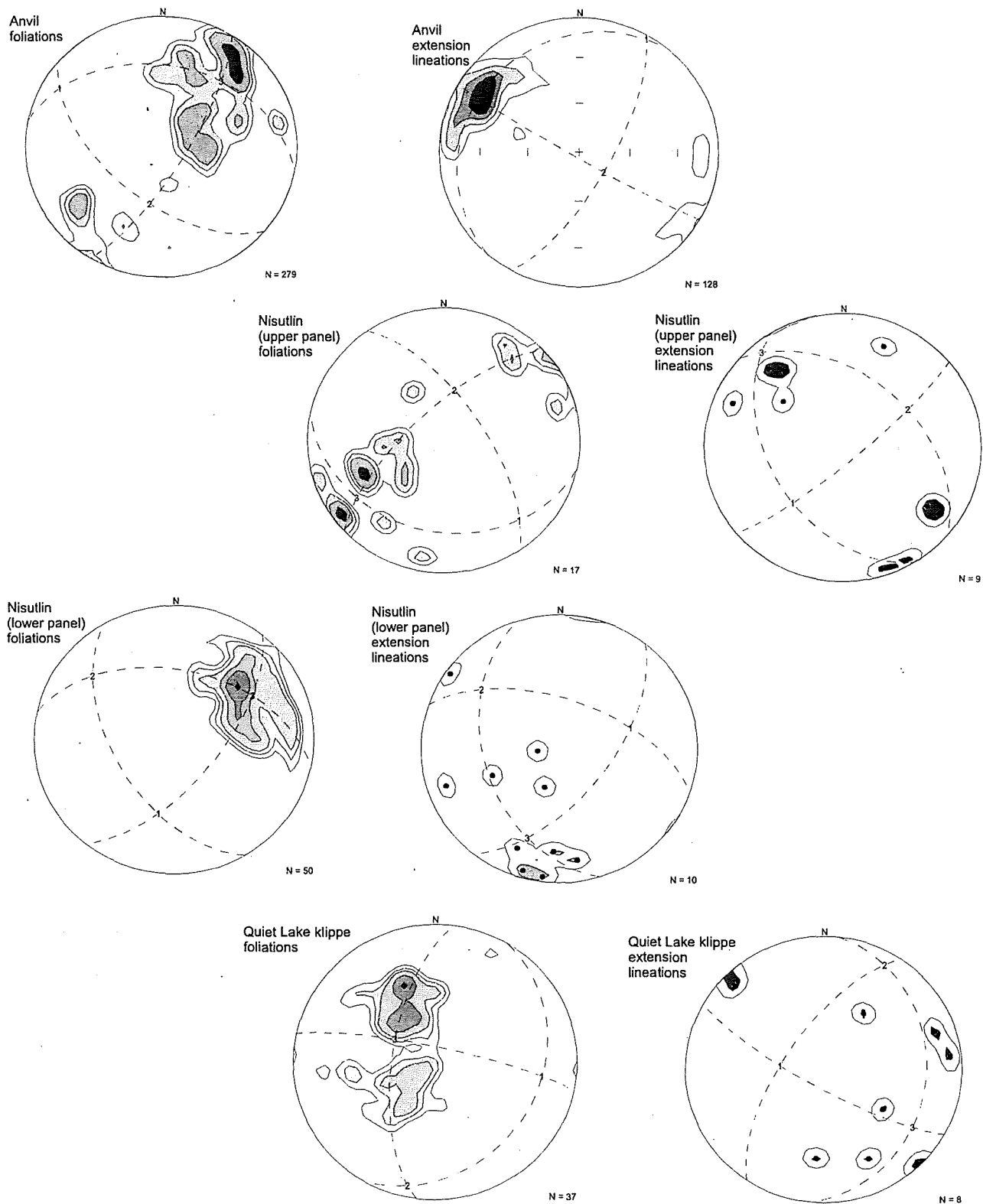


Figure 2. Contoured equal area plots of foliation and lineation orientations within 3 domains of the St. Cyr klippe (the Anvil allochthonous assemblage and both upper and lower panels of the Nisutlin allochthonous assemblage), and one domain within the Quiet Lake klippe. Contours are at 1,2,3,5,7, and 10 sigma for foliations and at 2,4,6, and 8 sigma for extension lineations.

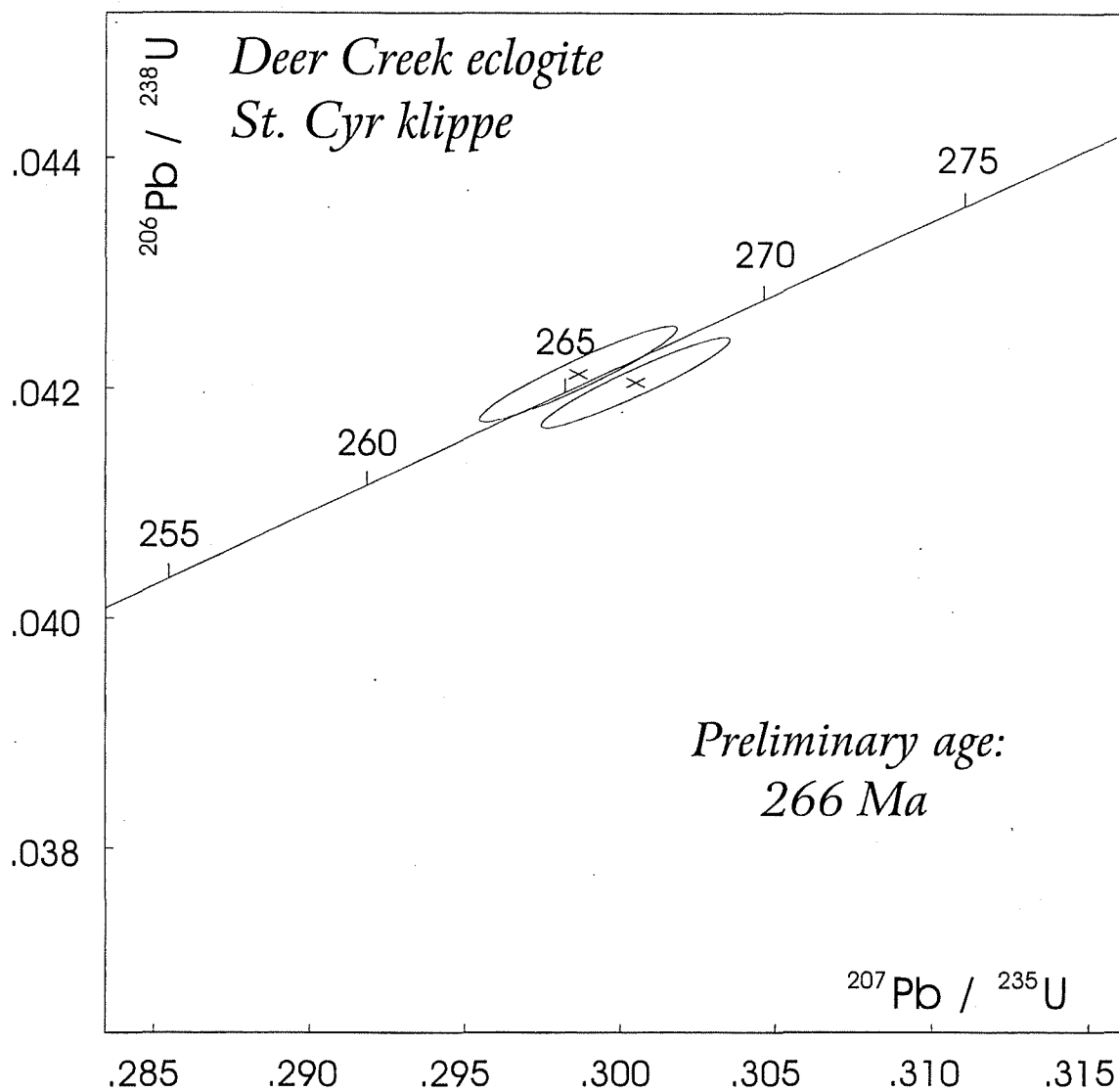


Figure 3. U-Pb concordia diagram showing the results of 2 zircon analyses from sample KF 95-10, the Deer Creek eclogite from the St. Cyr klippe. Future analyses will provide sufficient data to calculate a regression line for locating intercepts and for calculating errors.

References:

- Creaser, R.A., Heaman, L.M., and Erdmer, P. (1996) U-Pb zircon dating of eclogite from the Teslin tectonic zone: Constraints for the age of high-pressure metamorphism in the Yukon-Tanana terrane. *in* F. Cook and P. Erdmer (compilers), *Slave-Northern Cordilleran Lithospheric Evolution (SNORCLE) and Cordilleran Tectonics Workshop Meeting (March 1-3)*, University of Calgary, *Lithoprobe Report No. 50*, pp. 58-60.
- Erdmer, P. (1992) Eclogitic rocks on the St. Cyr klippe, Yukon, and their tectonic significance. *Canadian Journal of Earth Sciences* vol.29, pp.1296-1304.
- Fallas, K.M. (1996) The structural and metamorphic evolution of the St. Cyr klippe, south-central Yukon: a progress report. *in* F. Cook and P. Erdmer (compilers) *Slave-Northern Cordilleran Lithospheric Evolution (SNORCLE) and Cordilleran Tectonics Workshop Meeting (March 1-3)*, University of Calgary, *Lithoprobe Report No. 50*, p.69.
- Gordey, S.P., and Stevens, R.A. (1994) Preliminary interpretation of bedrock geology of the Teslin area (105C), southern Yukon, *GSC Open File 2886* (map, scale 1:250 000).
- Stevens, R.A., and Erdmer, P. (1996) Structural divergence and transpression in the Teslin tectonic zone, southern Yukon Territory. *Tectonics* vol.15, pp.1342-1363.
- Templeman-Kluit, D.J. (1979) Transported cataclasite, ophiolite, and granodiorite in Yukon: evidence of arc-continent collision. *Geological Survey of Canada Paper* 79-14.
- Wheeler, J.O., and P. McFeely (1991) Tectonic Assemblage Map of the Canadian Cordillera and adjacent parts of the United States of America. *Geological Survey of Canada Map* 1712A.

A NEW VIEW ON THE STRUCTURAL FRAMEWORK OF THE TESLIN ZONE, SOUTH-CENTRAL YUKON

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Note: During this meeting a compilation (scale 1:25 000) of the structural and lithologic observations as recorded in 1995 and 1996 by MdK and Harvey (this volume) is on display.

Introduction

The Teslin zone (TZ) in south-central Yukon is the easternmost of a collage of allochthonous rocks that has accreted to parautochthonous rocks of the Middle to Late Paleozoic continental margin of western North America (the Cassiar terrane in the study area, hereafter the CT). The TZ is considered the southern extension of the Yukon-Tanana terrane (Tempelman-Kluit 1979, Hansen 1989). In the study area (Fig. 1) west of the D'Abbadie fault system (DFS) the TZ is composed mainly of Yukon-Tanana terrane rocks with subordinate oceanic Slide Mountain terrane (SMT) rocks (Wheeler and McFeely 1991). Tempelman-Kluit (1979) named SMT and YTT rocks in the TZ the Anvil and Nisutlin allochthons, respectively. East of the DFS klippen of SMT rocks with subordinate YTT rocks are believed to be 'derived' from the TZ and overlie the CT.

A new view of the structural framework of the TZ is presented together with some lithological and metamorphic observations. The results, which mainly focus on the TZ proper, are part of a larger database that includes mapping in the CT, the [Dunite] klippe, and the transition zone separating the TZ and the CT (Fig. 2). The working model is based on microstructural and field observations (1995 and 1996 mapping; see display), and will be tested during the 1997 field season. Geochronological (Harvey, Carleton University) and thermobarometrical (MdK) results, together with SNORCLE subsurface and existing geophysical and geological data, will be incorporated in the current working model when these data become available. This in order to propose a new model, or improve existing models, for the tectonic evolution of the boundary zone between the NACM and easternmost accreted terranes in south-central Yukon Territory

Results

Four mappable units are distinguished in the TZ. These are (i) quartz-muscovite and quartz-muscovite-chlorite schists (+/- pyrite, calcite, siderite) and quartzite (unit MQ), (ii) calcareous phyllite (unit CP), (iii) chloritic schist, greenschist and greenstone (unit GG), and (iv) marble and dolomite (unit MD). A body of unit GG with a structural thickness > 1.5 km, unit GG-W, delineates the western margin of the study area. Unit GG and variably serpentinized ultramafic rocks (unit SU) are the dominant lithologies in the klippe. Unit GG-W is separated from unit CP and unit MQ by a relatively thin (< 75 m thick) marble package. Map scale domains underlain by unit MQ or unit CP are separated by domains that contain alternations of these lithologies. These alternations occur on a dm - 100 m scale. In most cases the dominant lithology is shown on the map because of (a) insufficient mapping and/or a lack of 2D control

to further constrain the lithologic distribution, and (b) the map scale being the limiting factor. In some instances lithologic alternations could represent preserved stratigraphy. Most commonly, however, the alternations are shown to be the result of intense transposition.

The structure of the TZ is typified by multiple generations of folding. Knowledge of the characteristics and spatial distribution of the four generations of folds that were recognized during the 1995 field season (De Keijzer and Williams 1996) has greatly improved during the 1996 season.

At least two generations of intense transposition (T1TZ and T2TZ) have affected primary (sedimentary/volcanic) layering up to a km scale. The existence of km scale F1TZ, F2TZ and F3 folds has been demonstrated in the eastern part of the TZ (Fig. 2). There, mapping of the contact between unit MQ and unit CP has been successful despite intense transposition. The designation 'T' specifies all fabrics (for example an S2 axial plane crenulation cleavage that commonly defines a differentiated layering) that developed concurrent with transposition *sensu* Sander (1911).

Development of F3 structures is most prominent in the northeastern part of the TZ and in the transition zone. There, mesoscopic F3 structures indicate a km scale overturned ENE-verging synform, the Grizzly Synform (Fig. 2). The axial plane of the Grizzly Synform and the S3 cleavage, typically defined as an axial plane crenulation cleavage with 1-30 cm wide microlithons, are shallow to moderately NW-dipping. In the western part of the TZ, evident F3 structures are less common. The vergence of F3 structures as observed throughout the TZ is striking. West of the Grizzly hinge zone F3 structures invariably show S-type asymmetries viewed N-NW (i.e. down plunge). The TZ west of the Grizzly hinge therefore comprises the overturned upper limb of the Grizzly Synform. Assuming an average W-dip of 60°, the minimum structural thickness of the overturned limb in the Last Peak area is 8-10 km.

Transposition fabrics in the klippe are overprinted by isolated mesoscale folds similar in style and orientation to F3 folds in the TZ. The predominant asymmetry of these folds indicates a lower limb setting, consistent with that to be expected for parasitic F3 folds related to the Grizzly Synform.

Fourth generation structures in the TZ are manifested differently on both limbs of the Grizzly Synform. During F4, the orientation of the gently inclined lower limb favoured folding of the transposed layering. E-verging upright F4 folds generally lack an axial plane cleavage. The vergence of these folds is opposite to that observed for F3 structures on the lower limb. North of Last Peak the upper limb of the Grizzly Synform preserves open folds of the shallow to moderately NW-dipping S3 cleavage on a 100 meter scale. Apart from (i) locally observed late dm- to m-scale conjugate folds, and (ii) complex meso- and macroscopic deformation in few areas of both S3 and the transposed layering, the composite T1TZ-T2TZ fabrics generally show no apparent evidence for F4 related deformation. Folding of S3, however, requires straining of the upper limb during F4. The transposed layering on the upper limb is believed to have accommodated strain by homogeneous E-W shortening (i.e. the upper limb was in a relatively steep orientation) and probably to some extent by steepening. South of Last Peak, the transposed sequence and S3 are both relatively steeply dipping (>60°) and the acute angle between S2 and S3 in a number of

outcrops is less than 20°. This is believed to indicate that both fabrics have been rotated towards each other during F4, and that both fabrics were in a relatively steep orientation (i.e. S3 on average more steeply dipping than S3 north of Last Peak) prior to F4 deformation.

Second, third, and fourth generation fold axes and crenulation lineations are predominantly colinear (shallow to moderately N-NW plunging).

Apart from the eastern part of the TZ and part of the transition zone, the composite T1TZ-T2TZ fabrics are predominantly dipping between 40° - 90°E and 70° - 90°W. These fabrics are correlated with the cataclastic foliation of Tempelman-Kluit (1979) and Erdmer (1985), the mylonitic foliation of Hansen (1989), and L-, L-S-, and S-tectonites of Stevens (1994). According to these authors, the steep orientation of these fabrics is regarded the primary distinction between the TZ and more flatlying fabrics and lithologic units of the remainder of the YTT north of the TZ and the CT to the east. The enveloping surface of TZ rocks (composite T1tz-T2tz fabrics) on the lower limb of the Grizzly Synform is, however, shallowly dipping to horizontal. Therefore, the orientation of fabrics is considered an invalid criterion for distinguishing the TZ from adjacent rock packages.

To date field and thin section observations lack evidence of metamorphic conditions above greenschist facies in the TZ area studied. No garnet-bearing assemblages have been observed in this part of the TZ. No eclogite has been observed during the 1995 and 1996 season, and this confines known eclogite occurrences in the TZ proper to one (Erdmer and Helmstaedt 1983).

A km wide transition zone between the TZ and the CT is made up predominantly of fine-grained graphitic schists (quartz - muscovite - biotite - graphite +/- pyrite). These schists are believed to have accommodated strain preferentially to adjacent TZ and CT lithologies. The weakness of the transition zone implies that very likely most, if not all, of the early fabrics (e.g. early accretionary thrust faults) have been obliterated by younger fabrics.

The N-S trending DFS (Fig. 2), situated in the transition zone, is manifested by brecciated zones up to 50 m wide and possibly by a marble mylonite. The DFS has previously been considered the principal boundary between the TZ and the CT. To date there is no positive evidence that the DFS represents a terrane boundary. The sense and amount of displacement of the fault system are unconstrained. In the study area, however, similar lithologies and structural fabrics on either side of the DFS in the transition zone suggest that the DFS is not a regionally important transcurrent fault. South of the present study area, Harvey (pers. comm.) has evidence for approximately 4 km horizontal separation along the inferred trace of the DFS. Again, evidence for a terrane boundary is missing. In the same area, Harvey et al. (1996) reported orthogneiss mylonite with a dextral sense of movement (intrusive age 115 Ma U-Pb zircon, and 98Ma monazite ages, pers. comm.) which could be related to activity of the DFS.

A working model for the structural framework and kinematics of the TZ is briefly outlined below. Figure 3 shows an interpretative, simplified vertical E-W section (north of Last Peak) of the structure of

the TZ and the klippe lithologies. The working model (i) explains most of the structural observations and the large scale lithological distribution in the TZ, and (ii) relates the klippe and transition zone rocks to fabrics and lithologies in the TZ proper.

The F3 Grizzly Synform is believed to be a key element in the large scale structure of the TZ. F3 vergence relationships (fold asymmetry and axial plane cleavage relationships) indicate that apart from the NE-part of the TZ (i.e. the lower limb of the Grizzly Synform) the remainder of the TZ in the study area represents the overturned limb of the Grizzly Synform. An F3 lower limb setting of the klippe rocks, and at least part of the transition zone, is indicated by mesoscopic structures and the orientation of lithological units.

Unit GG-W delineates the western margin of the TZ. In the present model, unit GG-W (F3 upper limb) and unit GG in the klippe (F3 lower limb) are considered to be the same unit (i.e. unit GG and unit SU are believed to extend, continuous or dismembered, in the subsurface beneath unit MQ and unit CP). They describe a large scale synformal structure that agrees with the observations in the TZ in which unit MQ and unit CP occupy the core of the Grizzly Synform. S3 development is largely restricted to unit MQ and unit CP, i.e. the less competent units during F3 folding. It is the current belief that unit GG acted as the competent unit during F3 folding and thus controlled the wavelength of the Grizzly Synform.

Although early thrusting probably affected TZ lithologies, the symmetry of lithologies across the TZ (see Fig. 3) is striking and likely indicates the presence of a macroscopic F1 fold.

The macroscopic F3 structure is E-verging. F2 folds on the overturned F3 limb are also predominantly E-verging, as are F4 folds on the lower F3 limb. Macroscopic folding of S3 on the upper F3 limb describes a more complex structure, but again an easterly vergence component is indicated. The structural observations fit in a kinematic model that involves superposed folding (inclusive F1?) in a single kinematic framework, possibly during one progressive deformation event. This model elegantly explains the vergence relationships in the TZ. As an example, overturning of recumbent to shallowly inclined E-vergent F2 structures during F3 will result in E-vergent F2 structures on the overturned F3 limb. On the lower limb, E-vergent F2 structures will be overprinted, or obliterated, by F3 structures with a similar vergence.

The graphitic schists in the transition zone likely acted as an easy slip surface/unit (high strain zone) at some stage of the accretion process (contemporaneous with, or temporally distinct from deformation in unit MQ and unit CP). The klippe occupies a structural position similar to that of the transition zone. According to the present view the klippe and (part of) the transition zone may in fact be the frontal part (considering the present erosional surface), or the basal portion, of the 'TZ fold and thrust nappe'.

One of the proposed tectonic models for the TZ involves the formation of fabrics in a subduction complex (Tempelman-Kluit 1979, Erdmer 1985, Hansen 1988, 1989, 1992). One implication the presented structural framework has for the subduction model is described here. Arguments for a westward dipping

subduction complex included regional geologic relations and the spatial distribution of metamorphic facies (Tempelman-Kluit 1979, Hansen 1988). As suggested by Ernst (1971), subduction zone polarity can be established from the metamorphic field gradient (increase in metamorphic grade in the direction of subduction). An inverted metamorphic gradient (i.e. higher grade rocks in the west) for the TZ is inferred by qualitative (Tempelman-Kluit 1979) and quantitative results (Hansen 1988, 1992). In the present scenario, however, the inverted metamorphic gradient has been established on the overturned limb of a large scale fold structure (with peak metamorphic conditions pré-F3). The subduction argument therefore is not valid. Unfolding of the F3 macrostructure results in higher grade rocks at lower structural levels. This is realistic in the working model as higher grade rocks are expected towards the base of the TZ nappe.

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References

- Berthé, D., Choukroune, P., and Jégouzo, P., 1979. *Journal of Structural Geology*, 1, 31-42.
- De Keijzer, M., and Williams, P.F. 1996. Lithoprobe report No. 50, 45-53.
- Erdmer, P. 1985. *Journal of Structural Geology*, 7, 57-72.
- Erdmer, P. and Helmstaedt, H. 1983. *Canadian Journal of Earth Sciences*, 20, 1389-1408.
- Ernst, W.G. 1971. *Contributions to Mineralogy and Petrology*, 34, 43-59.
- Hansen, V.L. 1988. *Tectonics*, 7, 1167-1177.
- Hansen, V.L. 1989. *Journal of Structural Geology*, 11, 717-733.
- Hansen, V.L. 1992. *Journal of Metamorphic Geology*, 10, 239-263.
- Harvey, J.L., Brown, R.L., and Carr, S.D. 1996. Lithoprobe report No. 50, 33-41.
- Sander, B. 1911. *Tschermacks Mineralogische und Petrografische Mitteilungen*, 30, 281-314.
- Tempelman-Kluit, D.J. 1979. Geological Survey of Canada, Paper 79-14, 27p.
- Wheeler, J.O. Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W. and Woodworth, G.J. (comp.) 1991. Geological Survey of Canada, Map 1713A, scale 1:2 000 000

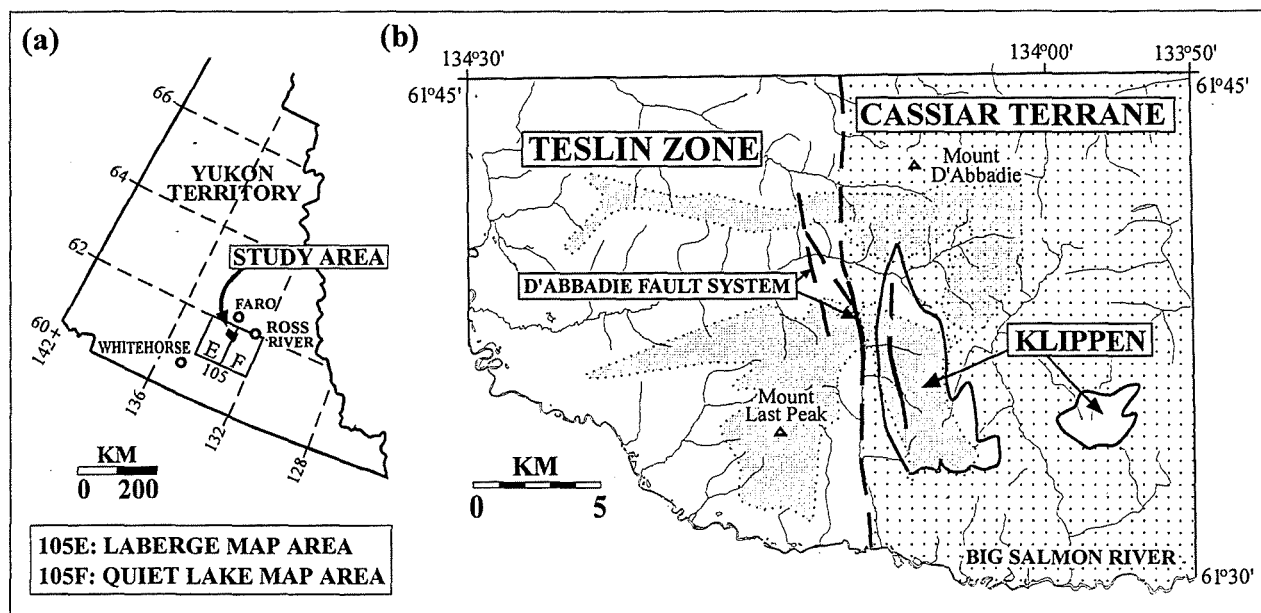


Figure 1. (a) Location map. (b) Study area showing the geographic position of the Teslin zone, the Cassiar terrane, and the [Dunite] klippen. Grey represents the areas mapped in 1995 and 1996.

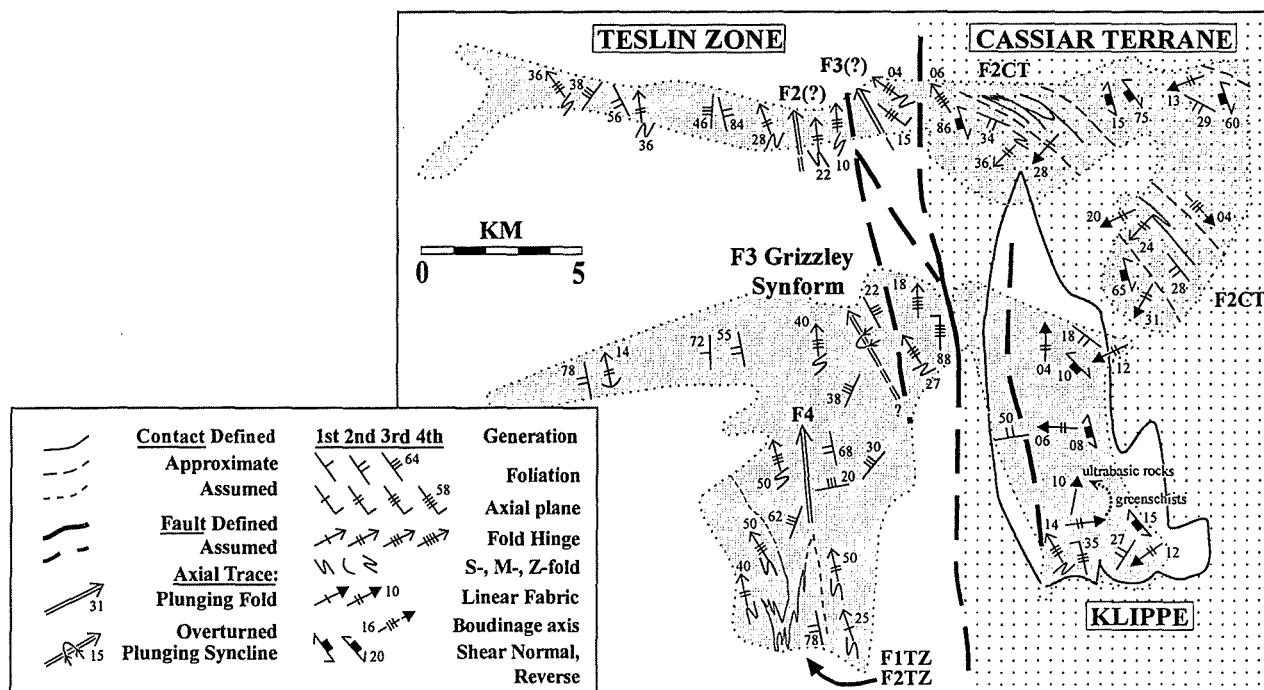


Fig. 2. Simplified map showing some of the large-scale structures described in the text and representative measurements. **Note:** Similar generations of structures in the three units need not have formed during the same event. For example, it is unclear whether T1CT correlates with T1TZ or T2TZ.

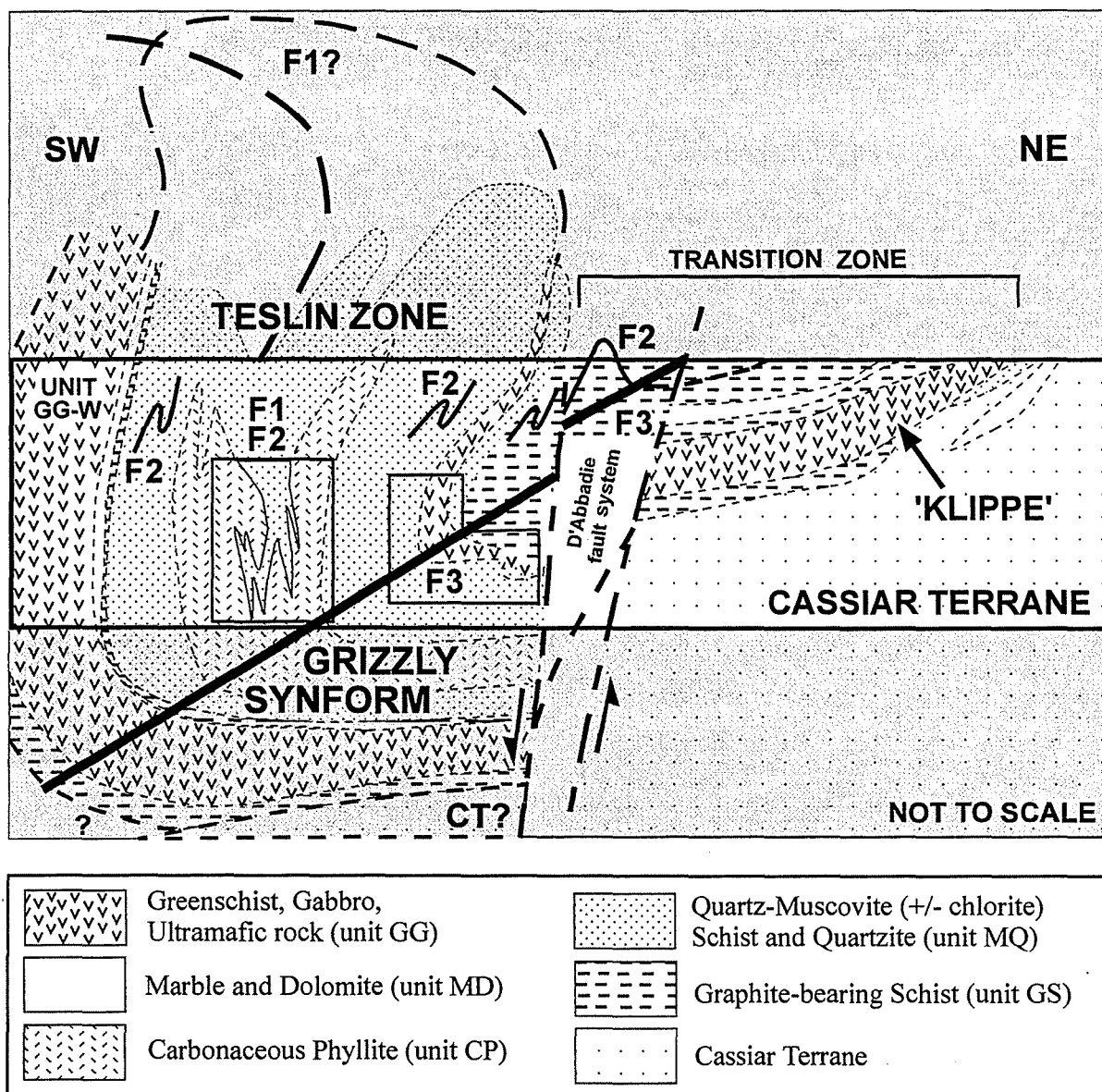


Figure 3. Schematic vertical section showing the current working model for the structural framework of the Teslin zone in the Last Peak area. The section has an approximate length of 20 km. The model is based on structural observations and the generalized distribution of lithologic units. The middle window is schematically drawn from field observations. Boxes within the window represent some of the areas where the structure has been well established. Because the main structures are NNW-plunging, the vertical section resembles the map view. For simplicity F4 is not shown in the diagram and thus the F3 axial trace is drawn as a straight line. The transition zone between the Teslin zone and the Cassiar terrane largely coincides with the graphite-bearing schists. The structure in the transition zone is complex (possible early thrusting, activity along the D'Abbadie fault system, and abundant F4 folding) and requires follow up work in 1997. Primary contact relationships between the different units are largely unconstrained. According to this model, it is likely that the D'Abbadie fault system has accommodated normal displacement. See text for more details.

Deformation history and geochronology of plutonic rocks near the d'Abbadie fault, Big Salmon Range, Yukon.

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INTRODUCTION

The nature and timing of deformation along the d'Abbadie fault zone (Figure 1) are not well constrained, yet the d'Abbadie fault zone plays an important role in many tectonic models of the evolution of the Teslin zone. The d'Abbadie fault zone has been interpreted as the boundary between the Teslin zone, interpreted as a subduction-mélange complex by many workers (Templeman-Kluit 1979; Erdmer, 1985; Hansen, 1989, 1992a,b; and Hansen *et al.*, 1991), and the Cassiar terrane, which is widely accepted as part of the North American continental margin. New mapping has delineated two deformed granitic plutonic bodies along the d'Abbadie fault, herein named the Last Peak granite and the Mendocina orthogneiss (Figure 2). Analysis of the field relationships and fabrics in the granitic rocks, combined with data from regional mapping, indicates that 1) movement along the d'Abbadie fault zone is limited to right-lateral strike-slip displacement of about 4 km; 2) at the level of exposure, the deformation in the fault zone occurred in a cool, upper-crustal environment; and 3) the inception of movement follows initial intrusion of the Last Peak granite at *ca.* 98 Ma. In this report, we present a summary of our conclusions from regional mapping, describe field relationships and fabrics of the Last Peak granite and reconstruct its deformation and emplacement history, and briefly discuss ongoing work on the Mendocina orthogneiss. Finally, we discuss the implications of our data set for the timing and conditions of deformation along the d'Abbadie fault.

GEOLOGICAL SETTING AND SUMMARY OF PROGRESS

TESLIN ZONE

The Teslin zone consists of steeply dipping panels of medium-grade fine-grained rocks. It comprises predominantly metasedimentary rocks that have affinity with continental margin strata of North America and a heterogeneous sequence of metasedimentary and metavolcanic rocks associated with mafic and ultramafic bodies (termed "Anvil", "Slide Mountain", or "Teslin-Taylor Mountain" terranes) that have been interpreted as ocean crust. In contrast to the view of the Teslin zone as a tectonic mélange (Templeman-Kluit, 1979; Hansen, 1989, 1992a,b) formed in a subduction zone, our 1:25,000 scale mapping of >300 km² demonstrates that there is a coherent stratigraphic sequence which has undergone several episodes of isoclinal or nearly isoclinal folding, resulting in strongly attenuated fold limbs and isolated fold closures (Figure 2).

Rocks in the Teslin zone are divided into three informally named packages (Figure 2): the Last Peak, Mendocina, and Livingstone Creek assemblages. The Last Peak assemblage is a heterogeneous sequence of metasedimentary and metavolcanic rocks that contains marbles, calcareous and phyllitic schists, minor pelites and quartzite, and greenschists, as well as Devonian orthogneisses (including the Mendocina orthogneiss) with transposed intrusive contacts. The assemblage is probably correlative with the Nisutlin assemblage of Stevens *et al.* (1996) and may be part of the North American miogeoclinal. The Mendocina assemblage comprises fine-grained

mafic schists with minor serpentinized ultramafic rocks. Mafic schists contain rare bodies of weakly deformed gabbro, suggesting that they are in part derived from gabbroic rocks. The contact between the Last Peak and Mendocina assemblages is parallel to S_2 but appears to cross-cut S_0/S_1 transposed compositional layering, perhaps indicating a transposed pre- D_2 fault boundary. The Livingstone Creek assemblage contains mafic and felsic volcanics, pelites, granitoids and related pegmatites, and a quartzite-carbonate sequence. It is possible that the mafic volcanics of this unit grade into the mafic schists of the Mendocina assemblage, but the contact is poorly exposed. The Livingstone and Mendocina assemblages may have formed in an arc and arc-root tectonic setting.

There are at least three generations of structures and associated penetrative fabrics in the Teslin zone (Harvey *et al.* 1996, de Keijzer and Williams, 1996). Compositional layering and contacts between units (S_0) are generally concordant with the early transposition foliation (S_1). D_1 structures usually occur as rare intrafolial isoclinal folds, but mapping at 1:5,000 scale south of Last Peak has shown that these folds do occur in some areas at map scale. S_2 , a penetrative transposition fabric, is the dominant structure in the Teslin zone. It consists of a NNW-trending, steeply dipping ($75-90^\circ$) cleavage that parallels the axial surfaces of F_2 folds. Map-scale west-vergent, tight to isoclinal F_2 antiforms and synforms have highly attenuated limbs and rare closures. They control the gross geometry of the Teslin zone. Post- D_2 structures vary in character throughout the region. Near Last Peak there is a NE to NNE trending, moderately west-dipping penetrative crenulation cleavage that is axial planar to NW-plunging, open to tight asymmetric folds. From the Big Salmon River to Livingstone Creek, there are few manifestations of D_3 deformation. South of Livingstone Creek, gentle to open S_3 folds gently warp S_2 , and are not associated with a penetrative fabric.

EASTERN MARGIN OF THE TESLIN ZONE

The Cassiar terrane comprises Proterozoic through Devonian strata of North American affinity and mafic and ultramafic rocks (Anvil, Slide Mountain) that have been metamorphosed and deformed at medium to high grade. Most plutons and $^{40}\text{Ar}-^{39}\text{Ar}$ cooling ages are Cretaceous (Hansen *et al.*, 1989, 1991), but Hansen *et al.* (1989) have obtained ca. 350-370 Ma U-Pb zircon ages on some orthogneiss bodies similar to the Mendocina orthogneiss described in this paper (see below). Previous work has suggested that there are significant lithologic, structural and thermal differences between the Cassiar terrane and the Teslin zone and that the change occurs across the d'Abbadie fault (Tempelman-Kluit, 1979, Hansen, 1989).

New mapping by Harvey and M. de Keijzer (personal communication, 1996) indicate that there is lithologic, metamorphic and structural continuity across the d'Abbadie fault, and that the Teslin zone and Cassiar terrane share many common features and that transitions in style and character occur to the east of the d'Abbadie fault within what is known as Cassiar terrane. In the Cassiar terrane (Figure 1), de Keijzer and Williams (this volume) have found what is apparently a transposed but continuous stratigraphic sequence that appears to correlate with the North American miogeoclinal sequence. It apparently includes Proterozoic Windermere clastics, Cambrian quartzite and marble, calcareous schists, clastic grits and felsic volcanics of unknown age. There is no apparent structural discontinuity between these rocks and those of the Teslin zone in the Mt. d'Abbadie area. To the south, near Mendocina Creek, our preliminary mapping shows that neither structural style nor lithology changes significantly across the d'Abbadie fault (Figure 2). Everywhere south of Dycer Creek, both F_1 and F_2 are recognized, and the eastern limb of the large antiform north of Dycer Creek is apparently present on both sides of the d'Abbadie fault (Figure 2).

Previous workers have interpreted the mafic and ultramafic rocks as fragments of ocean crust which were thrust eastward over the Cassiar terrane and are exposed as klippen. However, de Keijzer's data from the Last Peak area (Figure 2) indicate that both lithologic packages have experienced the same transposition and folding history, suggesting emplacement prior to regional deformation.

D'ABBADIE FAULT ZONE, THE MENDOCINA ORTHOGNEISS AND THE LAST PEAK GRANITE

Interpretations of the style of deformation on the d'Abbadie fault zone have varied. Tempelman-Kluit (1979) originally mapped the d'Abbadie fault as a thrust fault, while Hansen (1989) interpreted it as a dominantly strike-slip structure. Stevens and Erdmer (1996), working south of the Quiet Lake batholith, did not recognize the d'Abbadie fault. Mapping by Harvey near Mendocina Creek during the summer of 1996 revealed similar stratigraphic sequences in polydeformed supracrustal rocks on both sides of the d'Abbadie fault, with a right-lateral offset of approximately 4 km.

Both the Last Peak granite and the Mendocina orthogneiss occur as tabular NNW-trending bodies both along and within the d'Abbadie fault zone, but the Last Peak granite was not recognized by previous workers. Hansen (1989) included all deformed plutonic rocks along the d'Abbadie fault zone within the peraluminous orthogneiss assemblage of Dusel-Bacon and Aleinikoff (1985), and assigned them a Devonian age based on U-Pb zircon data from similar rocks east of the d'Abbadie fault (Hansen *et. al.*, 1989). On the basis of ductile deformation fabrics in these rocks, ~97 Ma ^{40}Ar - ^{39}Ar data on muscovite and biotite (presumably from samples of the Mendocina orthogneiss), and white mica compositions, Hansen *et. al.* (1991) and Hansen (1992b) concluded that deformation along the d'Abbadie fault occurred under ductile conditions at depth. The Quiet Lake batholith, which apparently truncates the d'Abbadie fault zone, has a K-Ar age of ~83 Ma (Tempelman-Kluit, 1984).

THE LAST PEAK GRANITE

The Last Peak granite is a NNW-trending, tabular, variably deformed biotite-bearing leucogranite that crops out for a strike length of about 15 km straddling the Big Salmon River and along the western margin of the d'Abbadie fault zone. K-feldspar megacrysts are elongate, and occur in a light-colored fine-grained matrix of quartz, K-feldspar and plagioclase. Foliation is generally NNW-trending, steeply dipping, and sub-parallel to the S_2 foliation in the country rocks on either side of the unit. Stretching lineations are well-developed, shallowly NNW- or SSE-plunging, and defined by quartz rods.

FIELD RELATIONSHIPS.

The Last Peak granite is in contact with, on the west, the Last Peak assemblage of the Teslin zone and, on the east, the Cassiar terrane. Foliations are generally sub-parallel to the S_2 fabric in the Teslin zone. However, in one well-exposed location, an array of parallel, bayonet-shaped, apophyses containing aplitic material sharply cross-cuts the S_2 fabric of the Teslin zone, demonstrating an intrusive relationship. Aplitic textures indicative of a chilled margin occur along the contact, and rocks of the Last Peak assemblage have been recrystallized, indicating that they have been affected by weak contact metamorphism. Both the aplite in the chilled margin and the apophyses that cut the country rock lack foliation in hand specimen. No cross-cutting features have been observed along the eastern contact but, adjacent to the contact, country rocks are very fine-grained and very strongly foliated. In some locations, recrystallization in the country rock near

the margin indicates that there is a thin metamorphic aureole.

FABRICS

The unit can be divided into three zones with characteristic fabrics. The contact region, adjacent to the country rocks on the western margin of the pluton, which generally contains fine-grained rocks with igneous fabrics at the outcrop scale. In the main body of the pluton, K-feldspar megacrysts occur in a medium to fine-grained matrix, and foliation is well-developed. Finally, the eastern shear zone comprises mylonitic rocks with very well developed foliations and syn-kinematic muscovite porphyroclasts.

In the field, rocks adjacent to the western contact appear to have igneous textures. However, in thin section specimens from the apophyses, both quartz and feldspar have microstructures indicative of ductile deformation. Ductile deformation features in feldspar include flame perthite, fine-grained K-feldspar along the margins of larger grains (mortar texture), and some poorly developed subgrains with strongly seriate grain boundaries. Quartz grains typically have moderate to extensive subgrain development, with moderate geometric preferred orientation of subgrain boundaries. Where subgrains do not occur in quartz, strongly undulose extinction is common. Original grain boundaries are easily distinguished in quartz, and original quartz grains are nearly equidimensional (i.e., quartz is not deformed into ribbons).

Weakly foliated, medium grained granite occurs immediately adjacent to the chilled margin. In thin section both quartz and K-feldspar exhibit ductile deformation fabrics. K-feldspar grains are elongate (up to 8 mm long) and subgrains are well developed on their margins, and poorly developed in the cores. Some of the larger grains are separated into several smaller grains by ductile pull-aparts, which are commonly filled with strongly deformed quartz and K-feldspar. Brittle fractures also occur in K-feldspar, and are commonly filled with both quartz and chlorite. Quartz occurs as weakly to strongly developed ribbons, with poorly to well developed subgrains. Chlorite is the only Fe-Mg silicate.

The main body of the pluton consists of penetratively deformed K-feldspar megacrystic granite or granitic protomylonite. The matrix comprises medium- to fine-grained quartz, plagioclase, and biotite. Both quartz and K-feldspar exhibit microstructures indicative of ductile deformation, and K-feldspar is often fractured. K-feldspar megacrysts are highly elongate (up to 2 cm) and subgrains are well-developed on both the margins and in the cores of the grains. Ductile pull-aparts are filled with K-feldspar and quartz, which are strongly deformed, while brittle fractures are dominantly filled with undeformed quartz and/or biotite and chlorite. Quartz ribbons are very well developed. Internally, the ribbons consist of very fine dynamically recrystallized subgrains with no geometric preferred orientation. In all of the samples analyzed thus far, comminuted fine-grained biotite and quartz ribbons define the foliation. Where biotite occurs in aggregates, it is commonly partially replaced by fine-grained, post-kinematic muscovite and opaques. In some specimens, relatively coarse biotite (1 mm) may occur as deformed original grains or as undeformed grains in strain shadows, which we interpret to be post-kinematic. Chlorite is also common as post-kinematic grains, growing in strain shadows and fractures, and replacing larger biotite grains. S-C fabrics and σ and δ porphyroclasts of K-feldspar and plagioclase indicate dextral shear-sense during deformation.

The eastern margin of the pluton is a distinctive mylonite about 100 m wide. The transition in fabrics from the main body to the mylonite appears to be abrupt, although it is not exposed. This zone is characterized by well-developed S-C fabrics, with the stretching lineations defined by both quartz and feldspar rods. The bulk of the rock consists of fine-grained quartz and K-feldspar, with

K-feldspar porphyroclasts up to 5 mm in diameter and coarse (5 mm) syn- to post-kinematic muscovite porphyroclasts. S-C fabrics, σ and δ porphyroclasts, and muscovite fish all indicate dextral shear. In thin section, K-feldspar occurs as porphyroclasts within ribbons of fine-grained, comminuted K-feldspar. Most porphyroclasts and ribbons are mantled with fine-grained muscovite and biotite. Brittle deformation is absent in K-feldspar. Quartz also occurs in ribbons, with well-developed geometric preferred orientation of recrystallized subgrains. Muscovite occurs as coarse, fish-shaped grains. In some cases these grains replace biotite or K-feldspar. Muscovite fish are variably deformed, and many have multiple subgrains, strong undulose extinction, kink-bands, and even pull-aparts. Foliations are defined by fine-grained muscovite and biotite, the orientation of ribbon grains, and geometric preferred orientation of recrystallized subgrains in quartz. Rare hand-specimen-scale folds generated during mylonitization deform the S-C fabrics, and have axes oblique to the stretching lineation.

EMPLACEMENT AND DEFORMATION HISTORY.

A viable tectonic model for the deformation of the Last Peak granite must reconcile several important observations. Firstly, the presence of a chilled margin, a thin metamorphic aureole, and apophyses which cross-cut the S_2 fabric in the country rock indicates that it intruded into a cool upper-crustal environment, following regional shortening. Secondly, ductilely deformed K-feldspar occurs throughout the pluton, and indicates deformation at temperatures exceeding 450-500°C. Thirdly, fabrics in the pluton indicate an increased importance of ductile deformation across strike to the east. K-feldspar and quartz are weakly deformed in rocks along the western margin, but both are strongly deformed in the main body. However, the main body lacks the K-feldspar ribbons that occur in the eastern mylonite. Finally, the grade of syn-kinematic mineral assemblages decreases eastward. In the area of the contact, no syn-kinematic metamorphic reactions are observed. In the main body, there is evidence for both syn- and post-kinematic crystallization of biotite, while muscovite and chlorite are entirely post-kinematic. In the eastern mylonite, syn-kinematic muscovite appears to develop from the replacement of biotite and/or K-feldspar.

We suggest that the Last Peak granite intruded immediately prior to or synchronous with the onset of dextral deformation and continued to intrude during deformation. The apophyses that cross-cut the country rock indicate that, at the onset of intrusion, no deformation was occurring. However, the presence of ductilely deformed K-feldspar within the apophyses suggests that deformation occurred between the time of intrusion and the time the apophyses cooled below ~450°C. These observations are consistent with rapid cooling of the pluton. Deformation in the main body of the pluton ceased before it reached temperature conditions at which muscovite could replace biotite and K-feldspar, although the rocks cooled slowly enough for some replacement to occur post-kinematically. In the eastern mylonite, deformation continued subsequent to cooling through the temperature at which muscovite becomes the stable replacement of biotite and K-feldspar.

GEOCHRONOLOGY.

A U-Pb geochronology sample of coarse-grained protomylonitic granite was collected about 50 m from the margin of the pluton near the locality where cross-cutting apophyses were observed in the country rock (Figure 2, sample YT95/BS107). Two fractions of monazite and eight fractions of zircon have been analyzed. Monazite includes multiple grains of euhedral, somewhat cloudy, pale golden-yellow grains with several minor inclusions in each grain. Most of the zircon in the sample occurs in the <75 μ size range, and only a few grains, cracked and riddled

with inclusions, occur in the $>149 \mu$ range. U-Pb analytical methods follow those described in Krogh (1973, 1982), Roddick (1987) and Roddick *et. al.*, (1987), and Parrish *et. al.* (1987).

Two reversely discordant monazite fractions gave $^{207}\text{Pb}/^{235}\text{U}$ ages of 97.6 ± 0.4 and 98.2 ± 0.7 Ma (Table 1, Figure 3). The monazite grains are of igneous origin. Together with field data indicating rapid cooling after intrusion into cool country rocks, we interpret the age of the monazite to represent the age of the pluton at 98 ± 1 Ma. Zircon data are discordant. Fractions A, B, D, E, and F are interpreted to have components of inherited Pb, which is consistent with the fact that most zircon grains in the sample have cores. A regression line through these five fractions gives a lower intercept of 115 Ma with MSWD of 37. Fractions G and H both were portions of tips, and fraction C underwent a short abrasion time. All of these fractions are interpreted to have undergone recent Pb loss.

THE MENDOCINA ORTHOGNEISS

The Mendocina orthogneiss comprises a NNW-trending tabular body that crops out between the Last Peak granite and supracrustal rocks of the Teslin zone, and extends from just south of the Big Salmon River to Mendocina Creek. The unit is bounded on the east both by supracrustal rocks of the Last Peak assemblage and by the Last Peak granite. On the west, it is everywhere in contact with the Last Peak assemblage. Near the northern extent of the unit (Figure 2), undeformed dikes of the Last Peak granite cross-cut the foliations in the Mendocina orthogneiss. In most areas, the fabrics in the unit are parallel to the S_2 foliation in the Teslin zone and Cassiar terrane. South of Dycer Creek, the contact between the Mendocina orthogneiss and the Last Peak assemblage is discordant to the S_2 fabric of the Teslin zone, but in most places the contact is parallel to the Teslin zone S_2 fabric, suggesting that it is a transposed intrusive contact. Most specimens of the Mendocina orthogneiss have coarse white K-feldspar porphyroclasts (up to 2 cm in diameter) set in a very fine-grained brown matrix which includes biotite.

Typically, the unit has a strong NNW-trending, steeply dipping foliation and shallowly plunging lineation. Foliation is defined by the orientation of biotite, flattened quartz and feldspar, and a variably developed cleavage. Often, both a strong cleavage and grain shape foliation are observed in a given specimen. In many locations, in sections containing the lineation and perpendicular to the foliation, the rock exhibits well-developed shear bands and σ and δ porphyroclasts, as well as S-C fabrics, which suggest a right-lateral shear-sense. However, in several locations, the unit exhibits a strong, steeply dipping cleavage and subhorizontal lineation. There is no fabric asymmetry in the plane containing the stretching lineation and perpendicular to the foliation, and the strongest fabric asymmetry occurs in the plane *perpendicular* to the lineation. The grain-shape foliation occurs as sigmoidally shaped domains between the cleavage planes, the lineation is created by the intersection of the cleavage planes with the grain-shape foliation, and is parallel to fold axes in the grain-shape foliation. No stretching lineation is readily apparent. Although their geometry resembles that of S-C fabrics, the relationships between the fabric elements at this location are more indicative of a crenulation cleavage than an S-C fabric, and result from the superposition of an axial planar cleavage on a pre-existing foliation. In thin section, both K-feldspar and quartz exhibit microfabrics indicative of ductile deformation, suggesting a high temperature of deformation, but some quartz veins are only weakly internally deformed, despite being parallel to the foliation.

The age of the Mendocina orthogneiss is not precisely known. Hansen *et. al.* (1989, 1991) obtained U-Pb, Rb-Sr, K-Ar, and ^{40}Ar - ^{39}Ar data from two samples of the Mendocina orthogneiss.

U-Pb analysis revealed several strongly discordant fractions of zircon, and regression of the discordant fractions gave a lower intercept of $355.5 \pm 49/-54$ Ma. Thus, the body cropping out south of Mendocina Creek may be Early Mississippian in age. However, Rb-Sr (muscovite-whole rock), K-Ar and $^{40}\text{Ar}-^{39}\text{Ar}$ analyses (biotite and muscovite) all yielded middle Cretaceous ages (102-97 Ma) consistent with the monazite ages from the Last Peak granite. Work is in progress to obtain a precise U-Pb zircon age on the two bodies of the Mendocina orthogneiss.

Many of the fabrics in the Mendocina orthogneiss are similar to fabrics elsewhere in the Teslin zone, suggesting that the fabrics visible in the Mendocina orthogneiss result from regional deformation. Previous suggestions that ductile deformation occurred at depth in Mendocina orthogneiss during middle Cretaceous time (98 Ma, Hansen *et al.*, 1991) are inconsistent with the data from the Last Peak granite, which show that ductile deformation in that body occurred along its cooling path. Regional temperatures were too low for prolonged ductile deformation of K-feldspar even in the chilled margin of the granite. If this interpretation is correct, then ductile deformation of K-feldspar in the Mendocina orthogneiss must have occurred earlier, either during regional deformation of the Teslin zone, or even during the intrusion of the pluton. We are currently conducting a detailed analysis of the fabrics in the Mendocina orthogneiss to better establish their style, conditions of deformation, and origin.

SYNTHESIS AND CONCLUSIONS

The Last Peak assemblage comprises a coherent stratigraphic sequence which has undergone several episodes of isoclinal or nearly isoclinal folding, resulting in strongly attenuated fold limbs and isolated fold closures. Although the steep foliations of the Teslin zone give way to more shallowly dipping fabrics in the Cassiar terrane within a few km of the fault zone, structural style, metamorphic grade, and lithology in this assemblage are all continuous across the d'Abbadie fault zone, indicating that the Last Peak assemblage is continuous with the North American miogeoclinal rocks of the Cassiar terrane. The contact between the Last Peak assemblage and mafic and ultramafic rocks of the Mendocina assemblages is parallel to S_2 , but appears to truncate S_1/S_0 in the Last Peak assemblage, suggesting that the Mendocina assemblage was tectonically juxtaposed against the Last Peak assemblage prior to or during the D_2 deformation event.

The relationship between the Mendocina assemblage and the Livingstone Creek assemblage is not clear. The Livingstone Creek assemblage contains metamorphic rocks whose protoliths are indicative of an island or continental margin arc setting, while the Mendocina assemblage contains highly deformed mafic and ultramafic rocks, which could represent ocean floor or island-arc basement rocks. It is possible that the Livingstone Creek and Mendocina assemblages represent a contiguous section of an island arc.

The intrusion of the Last Peak granite occurred prior to or synchronous with the onset of movement along the d'Abbadie fault, in a cool upper crustal environment, at ca. 98 Ma. Mylonitic fabrics in the Last Peak granite and the offset of compositional layering in the Last Peak assemblage each indicate that movement along the fault was dextral. The orientation of stretching lineations in the Last Peak granite also suggests that movement was dominantly strike-slip. Finally, apophyses of the Last Peak granite which cut the S_2 fabric the Last Peak assemblage indicate that deformation along the d'Abbadie fault zone post-dated regional shortening, which probably ended sometime in the early Jurassic (Stevens *et al.*, 1996). Our interpretation of fabrics in the Last Peak granite suggests that deformation in this unit was restricted to the time required for the unit to intrude and cool, certainly less than a few million years, depending on the time required for intrusion. It is not

clear whether the intrusion of the granite facilitated deformation along the fault, or vice-versa. If the intrusion facilitated deformation along the fault, then movement along the fault is probably restricted to within a short interval following intrusion. Most data indicate that deformation along the d'Abbadie fault zone occurred in a cool upper crustal environment, with ~4 km of right-lateral strike-slip displacement. Deformation occurred during the middle Cretaceous, following the intrusion of the Last Peak granite, and prior to the intrusion of the Quiet Lake batholith.

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REFERENCES

- de Keijzer, M., and Williams, P.F. (1996). Structural analysis in the Teslin Tectonic zone, south-central Yukon. LITHOPROBE Report No. 45 (1996 SNORCLE Transect Meeting), p. 45-53.
- Dusel-Bacon, C., and Aleinikoff, K. (1985). Petrology and tectonic significance of augen gneiss from a belt of Mississippian granitoids in the Yukon-Tanana terrane. *Geological Society of America Bulletin*, 96:411-425.
- Erdmer, P. (1985). An examination of the cataclastic fabrics and structures of parts of Nisutlin, Anvil, and Simpson Allochthons, central Yukon: test of the arc-continent collision model. *Journal of Structural Geology*, 7:57-72.
- Harvey, J.L., Brown, R.L., and Carr, S.D. (1996). Progress in structural mapping in the Teslin Suture Zone, Big Salmon Range, central Yukon Territory. LITHOPROBE Report No. 45 (1996 SNORCLE Transect Meeting), p. 33-43.
- Hansen, V.L. (1989). Structural and kinematic evolution of the Teslin suture zone, Yukon: record of an ancient transpressional margin. *Journal of Structural Geology*, 11:717-733.
- Hansen, V.L. (1992a). Backflow and margin-parallel shear within an ancient subduction complex. *Geology*, 20:71-74.
- Hansen, V.L. (1992b). P-T evolution of the Teslin suture zone and Cassiar tectonites, Yukon, Canada: evidence for A- and B-type subduction. *Journal of Metamorphic Geology*, 10:239-263.
- Hansen, V.L., Mortensen, J.K., and Armstrong, R.L. (1989). U-Pb, Rb-Sr, K-Ar isotopic constraints for ductile deformation and related metamorphism in the Teslin suture zone, Yukon-Tanana terrane, south-central Yukon. *Canadian Journal of Earth Sciences*, 26:2224-2235.
- Hansen, V.L., Hiezler, T.M. and Harrison, T.M. (1991). Mesozoic thermal evolution of the Yukon-Tanana composite terrane: New evidence from ^{40}Ar - ^{39}Ar data. *Tectonics*, 10:51-76.
- Krough, T.E. (1982). Improved accuracy of U-Pb ages by the creation of more concordant systems using an air abrasion technique. *Geochimica et Cosmochimica Acta*, 46:637-649.
- Krough, T.E. (1973). A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. *Geochimica et Cosmochimica Acta*, 37:485-494.
- Parrish, R.R., Roddick, J.C., Loveridge, W.E., and Sullivan, R.W. (1987). Uranium-lead analytical techniques at the geochronology laboratory, Geological Survey of Canada. Geological Survey of Canada, Paper 87-2:3-7.
- Roddick, J.C. (1987). Generalized numerical error analysis with applications to geochronology and thermodynamics. *Geochimica et Cosmochimica Acta*, 51:2129-215
- Roddick, J.C., Loveridge, W.D., and Parrish, R.R. (1987). Precise U/Pb dating of zircon at the sub-nanogram Pb level. *Chemical Geology*, 66:111-121.
- Stevens, R.A., Erdmer, P., Creaser, R.A., and Grant, S.L. (1996). Mississippian assembly of the Nisutlin

assemblage: evidence from primary contact relationships and Mississippian magmatism in the Teslin tectonic zone, part of the Yukon-Tanana terrane of south-central Yukon. *Canadian Journal of Earth Sciences*, 31:103-116.

Stevens, R.A., and Erdmer, P. (1996). Structural divergence and transpression in the Teslin Tectonic zone, southern Yukon Territory. *Tectonics* 15:1342-1363.

Tempelman-Kluit, D. (1979). Transported cataclasite, ophiolite, and granodiorite in Yukon: Evidence of arc-continent collision. *Geological Survey of Canada, Paper 79-14*, 27 pp.

Tempelman-Kluit, D. (1984). Geology, Laberge (105E) and Carmacks (115I), Yukon Territory. *Geological Survey of Canada, open file report O.F. 1101*.

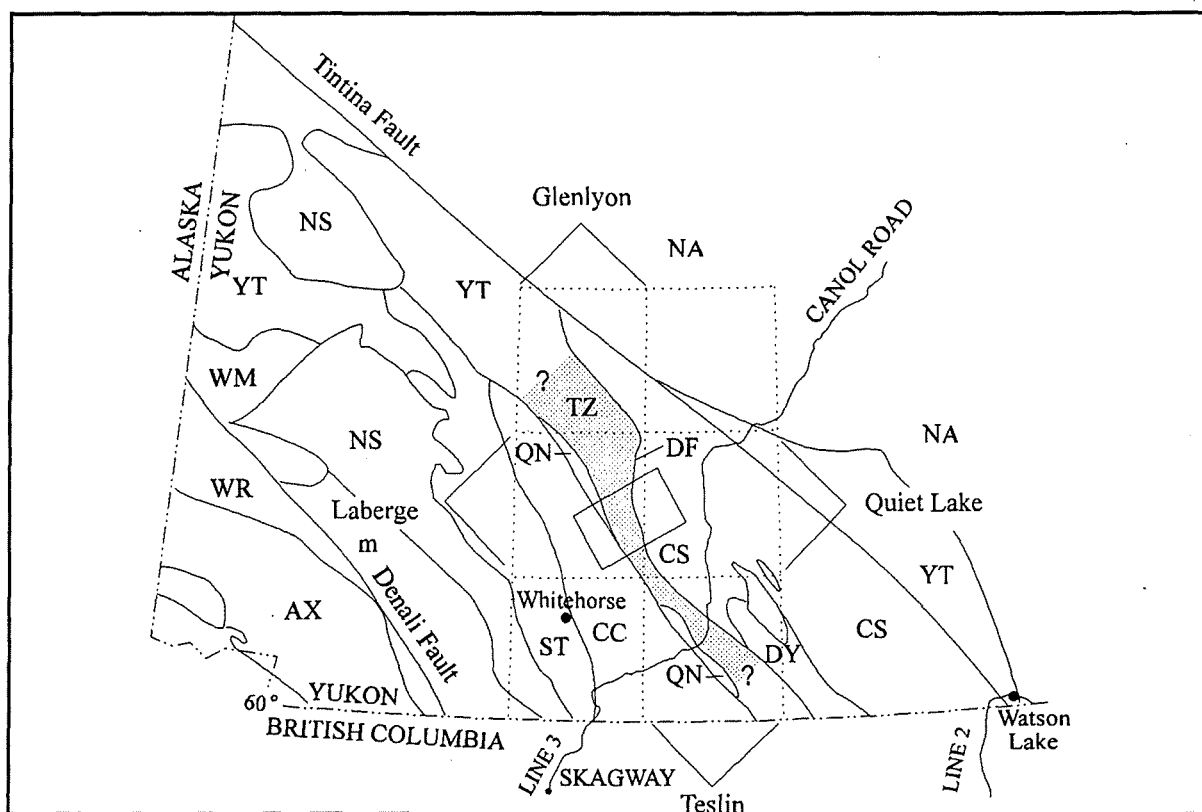


Figure 1. Map showing location of study area and major terranes in the Yukon. AX, Alexander terrane; CC, Cache Creek terrane; CS, Cassiar terrane; DF, d'Abbadie fault; DY, Dorsey terrane; m, undivided; NA, North America; NS, Nisling terrane; QN, Quesnellia; ST, Stikinia; TZ, Teslin zone; WM, Windy McKinley terrane; WR, Wrangellia; YT, Yukon-Tanana terrane. Also shown are SNORCLE transect lines 2 and 3.

TABLE 1. U-Pb analytical data for YT95/BS107, Last Peak granite

Fraction ^a , Size(μ), Abr. Time(hr)	Mass (mg)	U, (ppm)	Pb ^b , (ppm)	$\frac{^{206}\text{Pb}}{^{204}\text{Pb}^c}$	Pb _c ^d (pg)	%208 ^e	$\frac{^{206}\text{Pb}^f}{^{238}\text{U}}$	$\frac{^{206}\text{Pb}^g}{^{238}\text{U}}$ age, (Ma)	$\frac{^{207}\text{Pb}^f}{^{235}\text{U}}$	$\frac{^{207}\text{Pb}^g}{^{235}\text{U}}$ age, (Ma)	Corr. coeff.	$\frac{^{207}\text{Pb}^f}{^{206}\text{Pb}}$	$\frac{^{207}\text{Pb}^g}{^{206}\text{Pb}}$ age, (Ma)
A, 105-149, 5	0.0938	365	14	4984	16	8.3	0.0377 $\pm 0.102\%$	238.5 ± 0.5	0.4997 $\pm 0.119\%$	411.5 ± 0.8	0.852	0.09615 $\pm 0.062\%$	1550.6 ± 2.3
B, 105-149, 6	0.1449	701	15	374	311	5.6	0.0213 $\pm 0.156\%$	136.1 ± 0.4	0.1839 $\pm 0.753\%$	171.4 ± 2.4	0.5034	0.06253 $\pm 0.688\%$	692.4 $+29.1/-29.6$
C, <74, 2	0.0198	4781	25	2827	9	4.7	0.0055 $\pm 0.139\%$	35.3 ± 0.1	0.0391 $\pm 0.187\%$	39 ± 0.1	0.8053	0.05163 $\pm 0.112\%$	269 ± 5.1
D, <64, 5	0.0520	293	5	884	17	5.7	0.0192 $\pm 0.094\%$	122.4 ± 0.2	0.4206 $\pm 0.369\%$	129.9 ± 0.9	0.4916	0.0538 $\pm 0.333\%$	361 ± 15
E (tips), <64, 5	0.030	1313	24	2911	16	6.1	0.019 $\pm 0.086\%$	123.3 ± 0.4	0.1395 $\pm 0.163\%$	132.5 ± 0.5	0.648	0.05323 $\pm 0.126\%$	338 ± 7.5
F, <64, 5.5	0.050	602	13	2019	25	6.1	0.0225 $\pm 0.472\%$	143.2 ± 1.3	0.1887 $\pm 0.435\%$	175.6 ± 1.4	0.6388	0.0609 $\pm 0.287\%$	636.4 $+16.6/-16.7$
G(tip), 74-105, 6.5	0.003	1045	13	83	43	3.3	0.0136 $\pm 0.53\%$	87.1 ± 0.9	0.0937 $\pm 5.129\%$	91 ± 8.9	0.6213	.04994 $\pm 4.818\%$	192.4 $+209.9/-240.4$
H(tip), 74-105, 6.5	0.003	362	7	25	206	-2.0	0.0192 $\pm 22.98\%$	122.6 ± 55.8	0.4132 $\pm 43.807\%$	351.2 ± 260.1	0.6576	0.1560 $\pm 33\%$	2413 $+837.2/-2153$
M1, >149, 0	0.0148	1458	36	1891	12	44	0.0155 $\pm 0.095\%$	98.9 ± 0.2	0.1009 $\pm 0.215\%$	97.6 ± 0.4	0.5321	0.04793 $\pm 0.183\%$	64.2 $+8.7/-8.8$
M2, 105-149, 0	0.0068	2858	385	1162	17	64	0.0157 $\pm 0.102\%$	100.4 ± 0.2	0.1015 $\pm 0.397\%$	98.2 ± 0.7	0.4465	0.04691 $\pm 0.363\%$	44.7 $+17.3/-17.5$

^a Letters are zircon fractions, monazite fraction begin with M^b Radiogenic Pb, corrected for spike, fractionation, blank, and common Pb^c Measured ratio, corrected only for spike and fractionation^d Total common Pb in analysis; fractions B and H contaminated during chemistry^e Radiogenic ²⁰⁸Pb expressed as a percent of total radiogenic Pb^f Uncertainties are 1 σ , expressed in percent^g Uncertainties are 2 σ , expressed in millions of years

Legend

Last Peak assemblage

- cgs Orange weathering muscovite-quartz schist, commonly calcareous or graphitic
mq muscovite-bearing quartzite, commonly with minor graphitic phyllite
gpq graphitic phyllite; layers of dark grey quartzite
bs fine-grained biotite schist
m clean white to gray marble
ms3 chlorite+amphibole schist with euhedral spinel
ms2 chlorite schist with euhedral spinel and epidote

Mendocina assemblage

- ms1 dark green phyllite with euhedral spinel and small bodies of gabbro
um strongly serpentinized ultramafic rocks

Livingstone Creek assemblage

- qc,q,c quartzite-carbonate sequence, mapped together where very thin
mv metavolcanics, dominantly mafic but with some felsic or intermediate layers.
dmg deformed muscovite, K-spar quartz granite
dtg deformed tonalitic granitoid

d'Abbadie Intrusives

- 1 Mendocina orthogneiss
2 Last Peak granite

Lithologic contacts, dashed where inferred, dotted where uncertain, dotted and queried where speculative

Faults, displacement unknown; dashed where inferred, dotted where uncertain, dotted and queried where speculative

Thrust fault; dashed where inferred, dotted where uncertain, dotted and queried where speculative; barbs on hanging wall

1st 2nd 3rd



Penetrative foliation

Penetrative cleavage

S- and Z-folds



mylonitic foliation and stretching lineation



geochronological sampling locations



UTM grid locations (x1000 m)

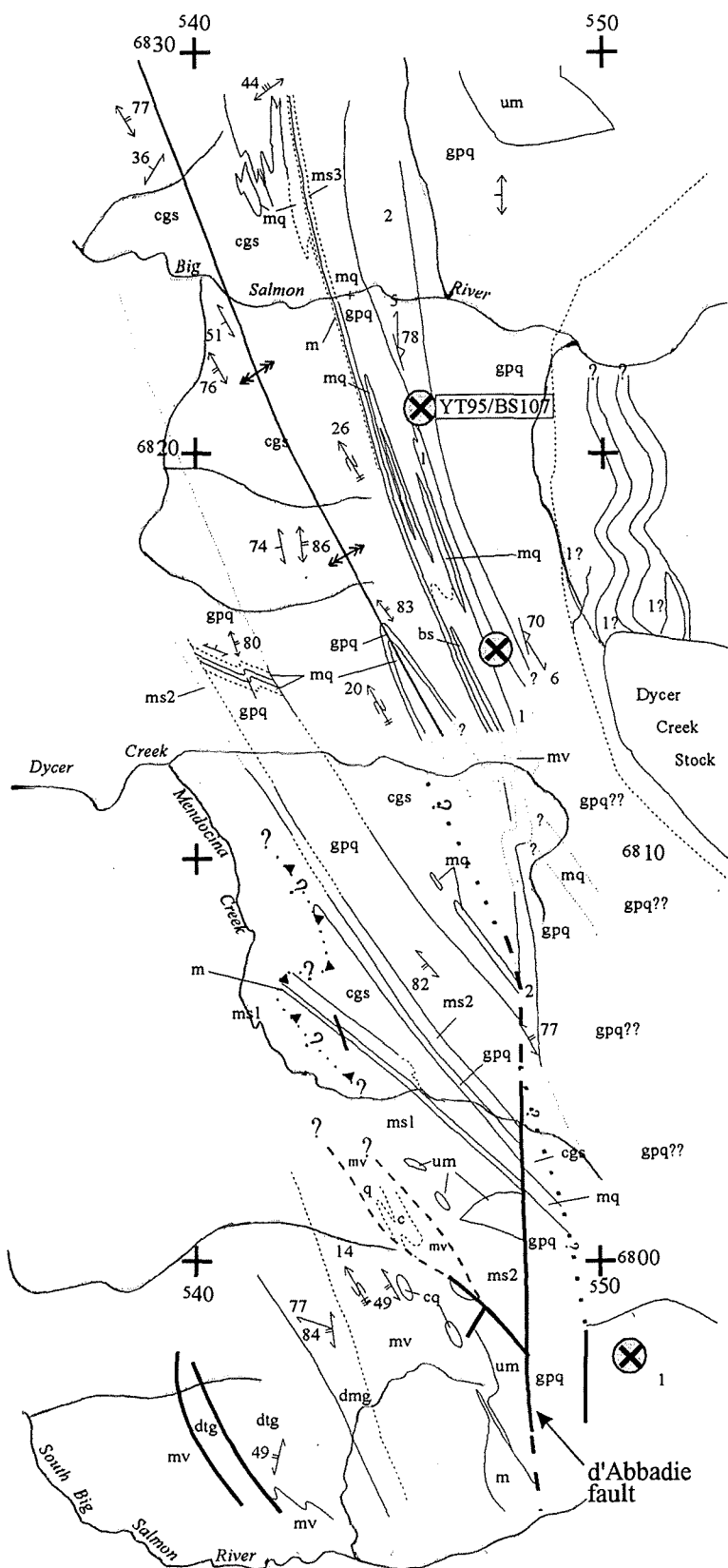


Figure 2. Geologic map of the Teslin zone between Last Peak and the South Big Salmon River. Includes some mapping by Templeman-Kluit (1977, 1984) and Hansen (1987) east of the d'Abbadie fault. Geochronology sampling localities for this study (YT95/BS107) and Hansen *et al.* (1989, 1991) are also shown.

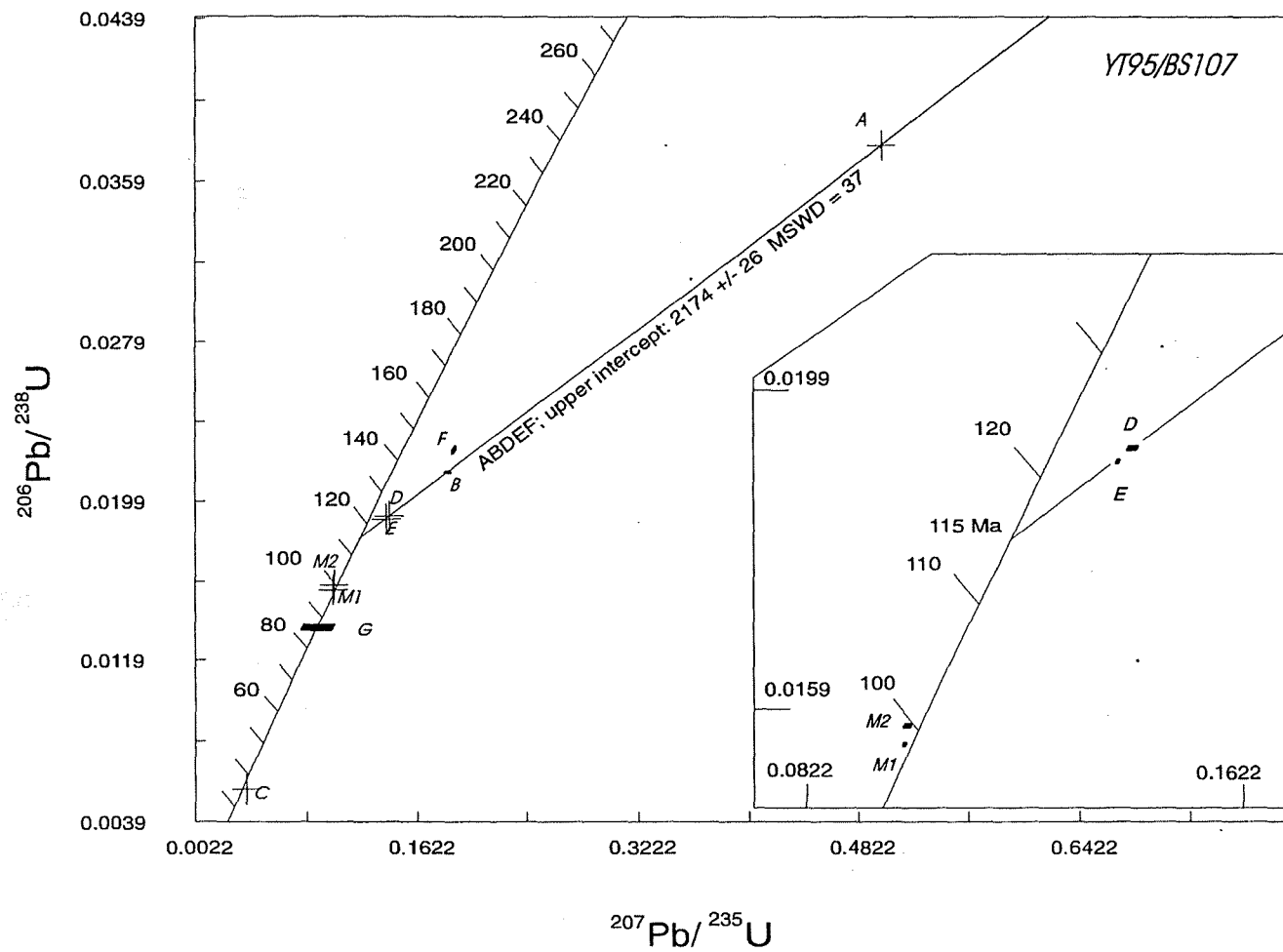


Figure 3. Concordia Plot of U-Pb geochronological data for the Last Peak granite.

A geochemical and radiogenic isotopic study of eclogites from the Yukon-Tanana terrane: A progress report.

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The Yukon Tanana terrane of the Yukon and east-central Alaska is one of the largest and most enigmatic of the suspect terranes in the northern Cordillera (Mortensen, 1992). It fringes allochthonous or paraautochthonous strata of the North American continental margin along a 1500-km-long contact (Mortensen and Jilson, 1985). The terrane has been interpreted to have accreted to the North American craton during a Mesozoic arc-continent collision with most of the rocks being interpreted as trench material involved in late Paleozoic subduction-zone metamorphism (Tempelman-Kluit, 1979). Eclogites are found in a number of lenses within the terrane. Samples collected from eclogites near Faro, Last Peak, Ross River and Stewart Lake are the focus of a geochemical and Sm-Nd isotopic investigation and preliminary results are presented here.

The tectonic setting of the basaltic protoliths of the eclogites is being determined using trace element abundances and ratios (Pearce and Cann, 1973; Pearce, 1983; Shervais, 1983). Multielement diagrams normalized to n-MORB (Pearce, 1983) are also being utilized. Initial results using these techniques indicate that the samples can be divided into three distinct groups, with samples from Faro and Ross River forming group 1, Stewart Lake eclogites group 2, and Last Peak group 3. The Ti/100-Zr-Y diagram (Pearce and Cann, 1973) discriminates between "within-plate" basalts (continental and oceanic) and other basalt types for altered or metamorphosed samples. Groups 1 and 2 do not plot in the "within-plate" basalt field. The Ti-Zr diagram (Pearce and Cann, 1973) distinguishes basalt type, with group 1 plotting in the ocean floor basalt field (MORB) and group 2 in the low-K tholeiite and calc-alkaline basalt field. The Ti/V ratio can also be used for tectonic discrimination (Shervais, 1983). It varies from 10-20 for arc related magmas to ~30 for n-MORB and to >50 for within-plate basalts. Ti/V ratios for group 1 range from 21-33 similar to MORB and from 8-16 for group 2. These results support other geochemical evidence indicating group 1 has a n-MORB type protolith and group 2 eclogites were derived from an oceanic-arc setting.

Basalts from various tectonic settings have well-defined patterns on MORB-normalized multielement diagrams (Pearce, 1983; Pearce and Parkinson, 1993; and Pearce et al., 1995). Samples from group 1 (Faro and Ross River) are similar to n-MORB (fig. 1D, E and F), with mainly flat patterns. Group 2 samples from Stewart Lake resemble patterns for oceanic arcs but can be further subdivided into low-K tholeiites and calc-alkaline basalts. PE-85-10 and PE-85-11-1 (figure 1A) show enrichment in Ta, Zr and Nb. The rare earth element plot (figure 1B) indicates LREE enrichment with a flattened HREE pattern. This is comparable to low-K tholeiitic arc basalt patterns from Pearce et al. (1995) (figure 1C and D). PE-85-17 and PE-85-18 are less enriched in Th, La and Ce than the preceding samples (figure 1A) but are more enriched in Ti, Y and Yb. A plot of rare earth elements (figure 1B) displays a pattern similar to calc-alkaline arc basalts (Figure 1C and D; Pearce et al., 1995) with LREE depletion and HREE enrichment. Results for group 3 are more ambiguous but may indicate a "within-plate" protolith, showing high LREE enrichment and HREE depletion.

Th/Yb and Ta/Yb (Pearce, 1983) and Zr/Y (Pearce and Norry, 1979) are also useful tectonic discriminators. The Th/Yb ratios for calc-alkaline arc basalts are between 0.3 and 3, whereas tholeiitic basalts have Th/Yb <0.3. The groups range from 0.04-0.48 and when plotted against Ta/Yb ratios, group 1 plots in the MORB field compared to group 2 which displays strong arc characteristics. The Zr/Y-Zr diagram also separates group 1 into MORB basalts and group 2 into volcanic-arc basalts.

Whole rock and garnet-pyroxene separates are being analyzed for Sm-Nd isotopes for each of the eclogite sample locations. The analysis of one sample, PE-80-F1, using whole rock, garnet and pyroxene data, results in an age of 275 Ma $\pm$ 30 Ma for high-pressure metamorphism. This age is consistent with Ar-Ar mica cooling ages from the same location and the age obtained from U-Pb zircon dating of the Last Peak eclogite (Big Salmon River) reported by Creaser et al. (1996).

The eclogites from Faro and Ross River (group 1) appear to be MORB or ocean floor basalts. Group 2 from Stewart Lake can be divided into both low-K tholeiites and calc-alkaline arc basalts. Samples from Faro underwent a high-pressure metamorphic event in 275 $\pm$ 30 Ma, but results from some Stewart Lake eclogites indicates an age of ~345 Ma (Ar-Ar mica; Erdmer, unpublished data). Based on the preliminary results, the eclogites preserved in the Yukon-Tanana terrane represent diverse tectonic

environments and possibly differing ages of high-pressure metamorphism.

References

- Creaser, R.A., Heaman, L.M., and Erdmer, P., 1996. U-Pb dating of eclogite from the Teslin tectonic zone: constraints for the age of high-pressure metamorphism in the Yukon Tanana terrane. *in* Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting, Lithoprobe Report no. 50, Cook, F and Erdmer, P. editors, p. 58-60.
- Mortensen, J.K., 1992. Pre-Mesozoic tectonic evolution of the Yukon-Tanana Terrane, Yukon and Alaska. *Tectonics*, 11, pp. 836-853.
- Mortensen, J.K. and Jilson, G.A., 1985. Evolution of the Yukon-Tanana terrane evidence from southeastern Yukon Territory. *Geology*, 13, pp. 806-810.
- Pearce, J.A. and Cann, J.R. 1973. Tectonic setting of basaltic rocks determined using trace element data. *Earth and Planetary Science Letters*, 19, pp. 290-300.
- Pearce, J.A., 1983. Role of the sub-continental lithosphere in magma genesis and continental margins. *in* Continental Basalts and Mantle Xenoliths, edited by C.J. Hawkesworth and M.J. Norry, Shiva, Cambridge, Ma., pp. 230-249
- Pearce, J.A. and Norry, M.J., 1979. Petrographic implications of Ti, Zr, Y and Nb variations in volcanic rocks. *Contributions to Mineralogy and Petrology*, 69, pp. 33-47.
- Pearce, J.A. and Parkinson, I.J., 1993. Trace element models for mantle melting: Application to volcanic arc petrogenesis. *in* Magmatic Processes and Plate Tectonics, edited by H.M. Pritchard et al., Geological Society Special Publication, 76, pp. 373-403.
- Pearce, J.A., Baker, P.E., Harvey, P.K. and Luff, I.W., 1995. Geochemical evidence for subduction fluxes, mantle melting and fractional crystallization beneath the South Sandwich Island arc. *Journal of Petrology*, 36, pp. 1073-1109.
- Shervais, J.W., 1983. Ti/V plots and the petrogenesis of modern and ophiolitic lavas. *Earth and Planetary Science Letters*, 59, pp. 101-108.
- Tempelman-Kluit, D., 1979. Transported cataclasite, ophiolite, and granodiorite in Yukon: evidence of an arc-continent collision. Geological Survey of Canada, Paper 79-1A, pp. 1-12.

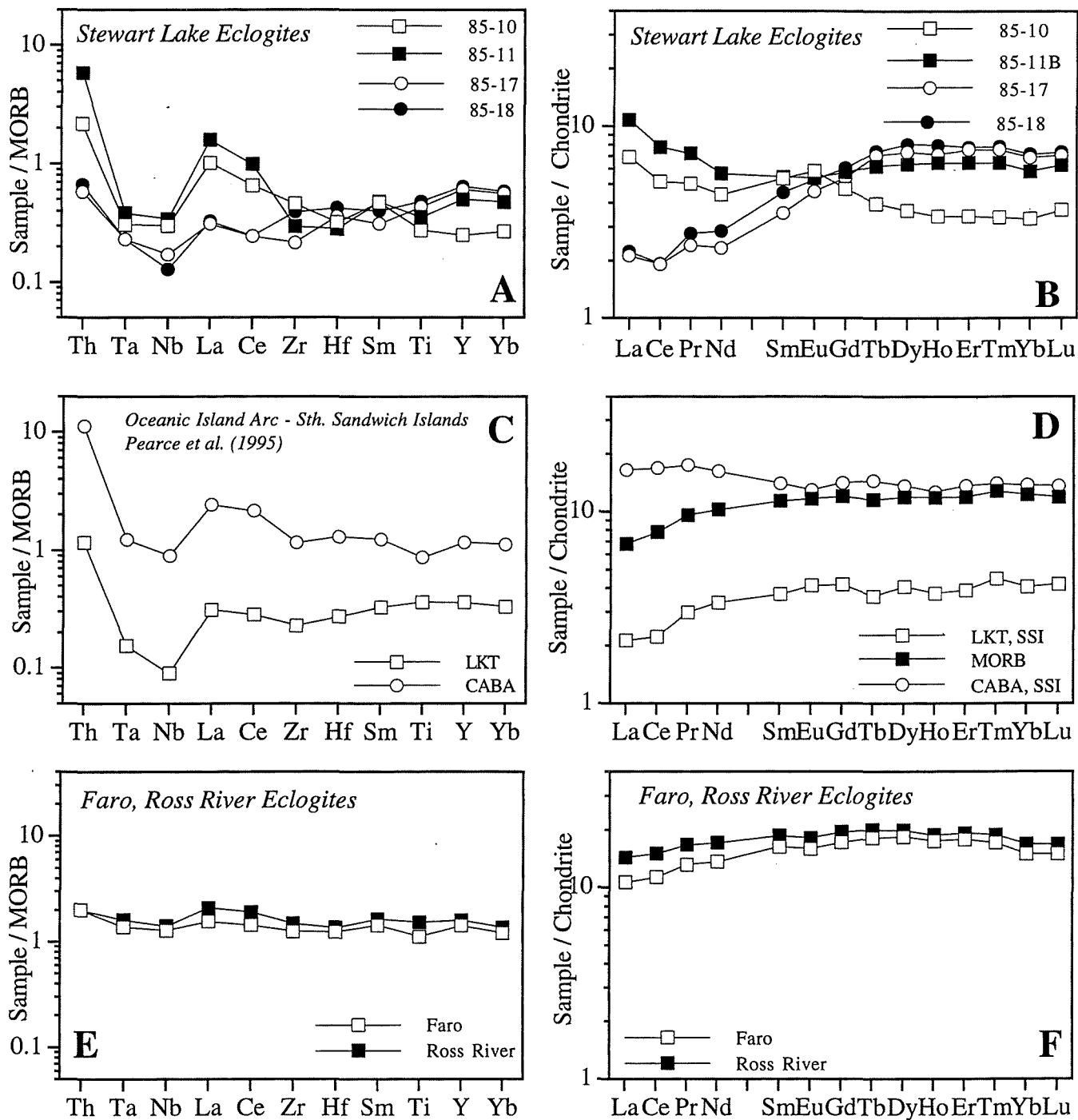


Figure 1. MORB-normalized incompatible element diagrams and REE diagrams for Cordilleran eclogites (A, B, E, F). Normalizing values from Pearce and Parkinson (1993). C = Incompatible element diagram for low-K tholeiite (LKT) and calc-alkaline basaltic andesite (CABA) from an oceanic arc setting. D = REE diagrams for average n-MORB and LKT, CABA from 1C.

Paleozoic and Early Mesozoic high-pressure metamorphism at the margin of ancestral North America in central Yukon

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Abstract

Eclogite and blueschist in or tectonically interleaved with the Yukon-Tanana and Slide Mountain terranes from Yukon to Alaska preserve a partial record of Middle Paleozoic, Late Paleozoic, and Early Mesozoic subduction and subsequent unroofing. Eclogites contain garnet-clinopyroxene-rutile-quartz with epidote, micas, and amphiboles. They are commonly mylonitized and partially retrogressed. The analysis of Fe-Mg exchange between garnet and clinopyroxene suggests temperatures in the 400-500 °C range for eclogite near Faro, and jadeite (~ 40 mol %) + quartz suggest minimum pressures of 11-13 kbar at that temperature range; clinopyroxene-garnet-epidote-quartz suggests pressure near 15 kbar ($P_{H_2O} = P_j$). Rocks near Last Peak, which contain brown hornblende, late-stage oligoclase, and biotite yielded P-T estimates up to 625 °C at a minimum pressure of 14 kbar. Eclogite near Ross River yielded temperatures near 525 °C and a minimum pressure near 13 kbar. Isotopic $^{40}\text{Ar}/^{39}\text{Ar}$ age determinations on white mica from eclogite in the Simpson range yielded an age of 344 ± 1 Ma. Eclogite and blueschist from Ross River yielded $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 267 ± 3 Ma and 273 ± 3 Ma, respectively. White mica in eclogite from Faro was dated at 260 ± 3 Ma. White micas in two eclogites from Stewart Lake, about 2 km apart, yielded $^{40}\text{Ar}/^{39}\text{Ar}$ ages of 228 ± 1 Ma and 346 ± 3 Ma, respectively. White mica in Last Peak eclogite for which the U-Pb zircon age is 269 Ma yielded an apparently undisturbed age of 236 ± 1 Ma. The Yukon high-pressure terrane(s) differs from other Cordilleran occurrences because (a) eclogite occurs in bedrock exposures, (b) these exposures are locally large coherent bodies, and (c) blueschist overprinting in some localities predates eclogite metamorphism in others. At least two distinct periods of peak metamorphism are recorded, one early Carboniferous or earlier, and one early Permian. A Triassic event may also be preserved. This is a significant departure from the assumption of a single collided arc which has guided investigations of regional tectonics until now. The cooling ages indicate significant convergence as early as the Carboniferous and the existence of more than one subduction zone. When this is considered together with the range of ages of other high-pressure occurrences in western North America, the Cordillera is seen to be unique among orogens in the multi-episodicity and diachronism of high-pressure metamorphism.

INTRODUCTION

Eclogite and blueschist in the North American Cordillera are preserved in accretionary, arc, and oceanic terranes fringing the ancestral continental margin from Mexico to Alaska. As in other orogens, their high-pressure metamorphic record is the only direct physical evidence of subduction among the numerous tectonostratigraphic assemblages involved in plate convergence and collision. Unlike other orogens, the Cordillera is characterized by multi-episodic and

diachronous high-pressure metamorphism.

In this report, we present new pressure-temperature constraints and $^{40}\text{Ar}/^{39}\text{Ar}$ results indicating separate Mississippian, Permian, and Triassic eclogite or blueschist metamorphism and cooling for parts of the Cordillera in the Yukon.

Most of the data are presented as figures. The details of the analytical results form part of a manuscript submitted and are not included here. We offer a discussion of the implications of the juxtaposition of

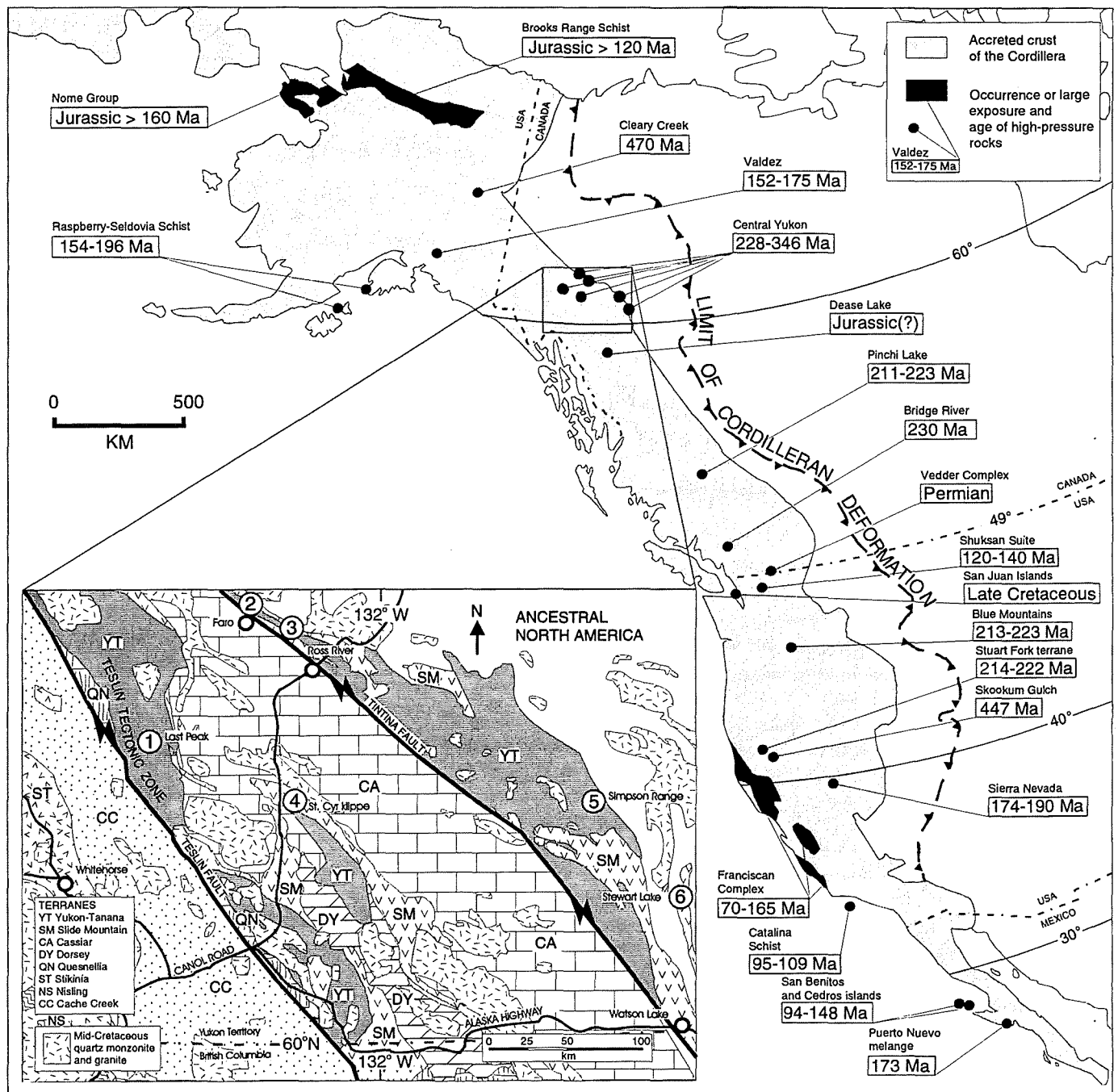


Figure 1. Location and age of high-pressure metamorphic rocks in the North American Cordillera, with inset map modified from Wheeler and others (1991) showing the location of high-pressure rocks studied (circled numbers). Occurrences at Faro and Ross River are hosted by quartzofeldspathic rocks of the Yukon-Tanana terrane and are interpreted to be in primary contact with host rocks, occurrences near Stewart Lake and in the St. Cyr klippe are in mafic-ultramafic rocks assigned to the Slide Mountain terrane and are inferred to be in tectonic contact with surrounding units, and occurrences near Last Peak and in the Simpson Range are surrounded by rocks of the Yukon-Tanana terrane but are petrologically similar to Slide Mountain terrane occurrences and have ambiguous contacts. See text for sources of age data.

products of more than one subduction event for both regional and Cordilleran tectonics.

SETTING OF YUKON ROCKS AND PREVIOUS WORK

Coherent blueschist and more than 20 *in situ* eclogite lenses in more than 10 high-pressure localities in the Yukon (Tempelman-Kluit 1970; Erdmer and Helmstaedt 1983; Erdmer 1987, 1992) and in Alaska (Brown and Forbes 1986, and earlier work) have been interpreted as primary units or tectonic slices within the structurally complex and metamorphically heterogeneous Yukon-Tanana terrane (YTT), an incompletely mapped and poorly understood tectonic element of the orogenic hinterland (Fig. 1). However, the exact relations of high-pressure rocks with their hosts are not clear everywhere. While some occurrences are in primary contact with quartzofeldspathic host rocks of the YTT, some have ambiguous contact relations with YTT rocks and others are surrounded by mafic and ultramafic rocks previously assigned to the Slide Mountain terrane (SMT) (see Wheeler and others, 1991). Irrespective of their terrane affinity, eclogite bodies in both quartzofeldspathic and mafic-ultramafic hosts in the Yukon and Alaska are unique in the Cordillera because they are coherent exposures in contact with surrounding rock units. This is in contrast to the Franciscan eclogites of California which commonly are blocks displaced from bedrock by geomorphic processes, or within *mélange* (see Cloos, 1986).

Previous knowledge of the age, petrology, and P-T history of the Yukon high-pressure rocks was the result of reconnaissance work and was based on geothermobarometers which have undergone significant refinement. In particular, the age of high-pressure tectonism for the entire YTT in the Yukon had been inferred until now from isotopic dating of both eclogite and blueschist in a single locality. Existing data consisted of concordant Rb-Sr dates of approximately 246 Ma and K-Ar dates around 260 Ma for muscovite in blueschist near Ross River and an indicated 344 Ma whole rock age (Erdmer and Armstrong 1989), and a K-Ar age of 258 Ma for muscovite in eclogite at Faro (Wanless and others, 1978; recalculated from reported age of 255 Ma using new constants). Zircon from eclogite near Last Peak in this study has recently yielded a concordant U-Pb age of 269 ± 2 Ma (Creaser and others, 1997); zircon in one of the eclogites in the St. Cyr klippe (see below) has yielded a preliminary concordant age identical within error to the Last Peak age (K. Fallas,

personal communication, 1996); zircon has been identified in other Yukon eclogites and is being analyzed. In the YTT in Alaska, a Late Cambrian or Early Ordovician age of metamorphism may be recorded by a 470 Ma K/Ar age on amphibole in eclogite near Fairbanks (Swainbank and Forbes, 1975); however, muscovite from marble associated with the eclogite has yielded K/Ar ages of 113 and 140 Ma (Hunt and Roddick, 1993) and the amphibole age may have little geological significance.

The eclogites occur typically as metre- to several hundred metre-sized or larger boudins, inclusions, or conformable layers in greenschist-, amphibolite-, and blueschist-facies rocks. They contain garnet-clinopyroxene-rutile-quartz assemblages with additional epidote, micas, and amphiboles. Subsequent metamorphism under greenschist to blueschist facies conditions overprinted most eclogites and locally the enclosing metasedimentary and (or) metabasic rocks. In contrast to other Cordilleran occurrences such as in California or near Pinchi Lake in British Columbia, no lawsonite or aragonite is present in either overprinted eclogite or blueschist. In contrast to the Franciscan eclogites which are not generally mylonitized, various degrees of mylonitization characterize the Yukon rocks. The high-pressure rocks are now largely compositionally layered S- and L-S tectonites (see Erdmer and Helmstaedt 1983, Erdmer 1992). Both eclogite and blueschist metamorphism are locally synkinematic with respect to the mylonitic fabrics. In some occurrences, the highest-pressure minerals are pre-kinematic: clinopyroxene is commonly recrystallized as elongate idioblasts into the main foliation and (or) stretching lineation; garnet porphyroblasts are draped by the foliation and have pressure-shadow tails parallel to the stretching lineation on foliation planes. We interpret the overprinting greenschist to blueschist metamorphism to be related to the juxtaposition of tectonic slices of peak metamorphic rocks with country rocks, i.e., the collision and uplift of the accreted rocks to a crustal depth at or above the ductile-brittle transition. Final emplacement above younger, lower grade rocks was as allochthonous slices underlain by sharp, brittle fault zones. The field occurrence of the Yukon eclogites is similar to the Type C rocks of Coleman and others (1965) but some of the temperature estimates we obtained, e.g. near Last Peak, are similar to some estimates from Type B eclogites (see estimation of pressure and temperature below).

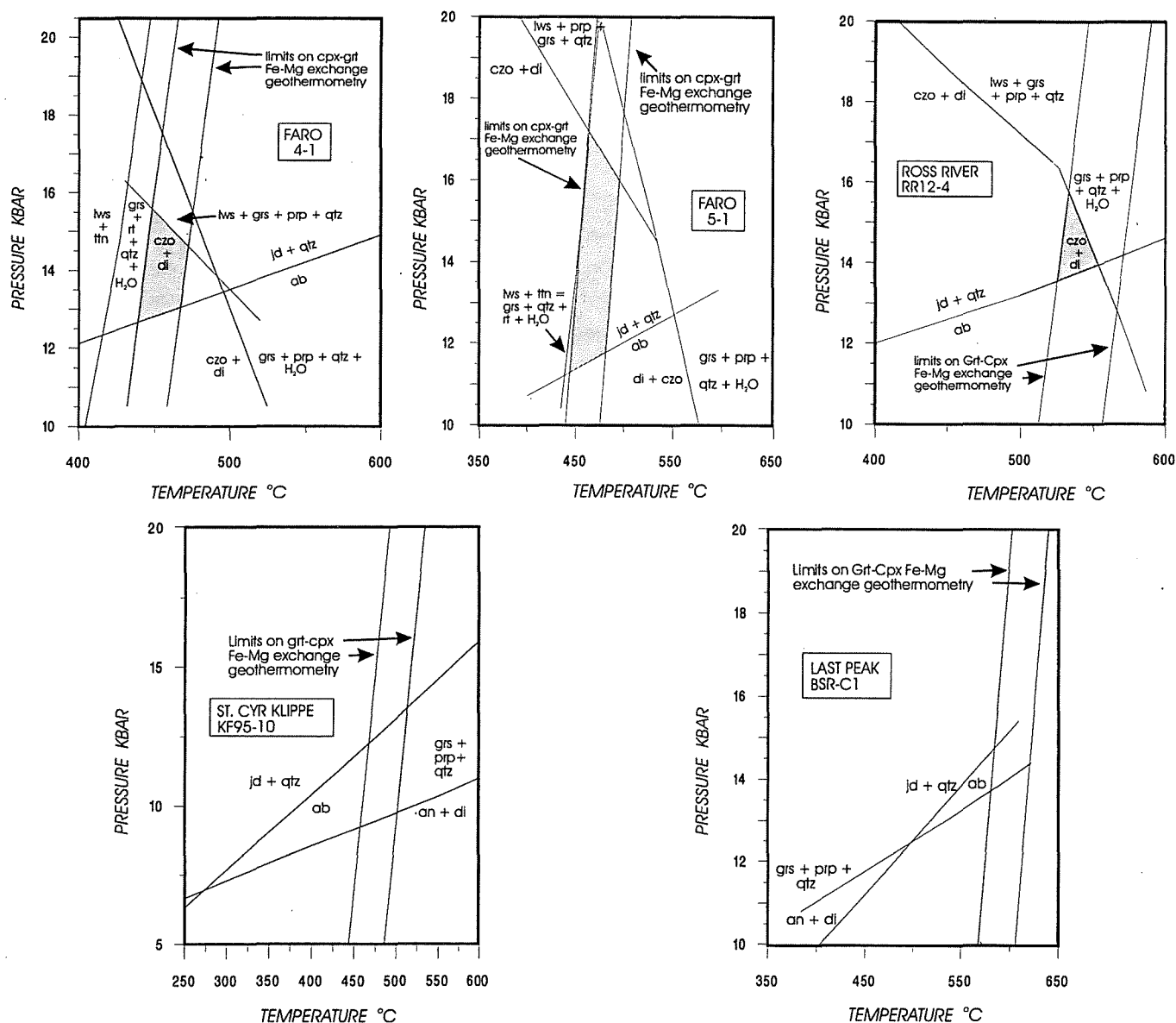


Figure 2. Pressure-temperature constraints for five eclogites from the Yukon-Tanana terrane. Lines are equilibrium curves for phases listed. Shaded areas are limits on *P* and *T* for Faro samples. Abbreviations: *ab* = albite, *an* = anorthite, *cpx* = clinopyroxene, *czo* = clinozoisite, *di* = diopside, *grs* = grossular, *grt* = garnet, *jd* = jadeite, *lws* = lawsonite, *prp* = pyrope, *qtz* = quartz, *rt* = rutile, *ttn* = titanite.

ESTIMATION OF PRESSURE AND TEMPERATURE

Eclogites typically have high-variance mineral assemblages (e.g. Ghent and others 1993) and the activity-composition relations as a function of pressure and temperature of some of the crystalline solutions are not well calibrated. We used the

programs and database of Berman (1988, 1990, 1991), Berman and others (1995), and Brown and others (1988). For the majority of our pressure-temperature (*P-T*) (Fig. 2) results we estimated temperature using the garnet-clinopyroxene Fe-Mg exchange geothermometer (Ellis and Green, 1979; Berman and others, 1995) calculated at several

pressures. The crystalline solution models used are: garnet solutions (Berman 1990); jadeite-diopside-hedenbergite solutions (Holland 1990); clinozoisite-pistacite solutions ($1-3X_{Fe}$) where X_{Fe} is atoms of Fe/atoms of (Fe+Al) (Jenkins and others, 1985); and paragonite-muscovite solutions (Chatterjee and Froese 1975).

Because the eclogites do not contain albite stable with clinopyroxene and quartz, minimum metamorphic pressures were estimated using the equilibrium (1), albite = jadeite + quartz. For samples containing epidote, we used the equilibrium (2), 15 diopside + 12 clinozoisite = 13 grossular + 5 pyrope + 12 quartz + 6 H₂O. Assuming an activity of H₂O, (a_{H_2O}) of 1.0, this provides a second equilibrium which intersects the P-T line calculated from the garnet-clinopyroxene Fe-Mg exchange geothermometer and yields a unique P and T. Minimum temperatures can be calculated from the equilibrium (3), lawsonite + 2 titanite = grossular + 2 rutile + quartz + 2 H₂O because the rocks lack lawsonite, which usually crystallizes with a composition near that of the pure phase component. Again, we assumed $a_{H_2O} = 1.0$.

Maximum pressures can be calculated from (4), paragonite = jadeite + kyanite + H₂O, but this usually yields only a broad constraint on the upper limit of pressure. In addition, paragonite is not present in many samples. Because the assemblage garnet-epidote-clinopyroxene-quartz is widespread in eclogite and lawsonite is absent, a more useful limit on maximum pressure can be estimated from the equilibrium, (5), 12 diopside + 12 clinozoisite = 3 lawsonite + 11 grossular + 4 pyrope + 9 quartz. This is a vapour-absent equilibrium and can be applied to epidote-bearing eclogites, which are a relatively common type.

NEW AGE DETERMINATIONS

⁴⁰Ar/³⁹Ar incremental-release heating techniques were used to date eight representative samples from six eclogites and one blueschist, chosen to test the validity of previous results on which much weight has been placed and to date new occurrences. The samples included seven multi-grain white mica concentrates (six eclogites and one blueschist) and one large crystal from one of the eclogites. Sample locations are shown in Figure 1. The ⁴⁰Ar/³⁹Ar analytical data are portrayed as apparent age spectra in Figure 3.

DISCUSSION

From the pressure and temperature

constraints and minimum estimates obtained, we infer that all the eclogites were metamorphosed at depths ≥ 40 km, consistent with the conclusions drawn from the smaller data set of earlier studies. Near Faro, the new data suggest a specific depth range of 40 to 50 km, which is characteristic of Type C eclogites (e.g., Ghent and Stout 1994). As the Faro eclogites originated as upper crustal rocks because garnets have helicitic inclusion trails recording the synkinematic overgrowth of a low-grade metamorphic cleavage and the rocks are of basaltic or gabbroic bulk chemistry, i.e., not mantle derived (see Erdmer and Helmstaedt 1983), the petrologic and P-T data confirm that the Faro rocks underwent subduction followed by rapid unroofing through the blueschist facies. From similarities in field setting and petrography, we infer that a similar depth of burial and return path through the blueschist facies characterize the Ross River rocks, with the additional inference that both the eclogites and host rocks described the entire P-T loop together. P-T paths for the Last Peak and St. Cyr klippe eclogites are less well constrained but each displays a separate P-T peak. Near Last Peak, the separate temperature ranges (at comparable pressure) for the two samples analyzed show that the rocks followed separate burial trajectories. If they were derived from the same rather than different subduction zones as their present physical proximity may indicate, the $\sim 100^\circ\text{C}$ difference between them is the minimum temperature range of eclogite metamorphism within that subduction zone. If not, the temperature discrepancy is evidence of tectonic interleaving of rocks from two subduction zones on the scale of a single outcrop within the Teslin tectonic zone (TTZ), the complex belt of ductilely deformed rocks forming the southern extension of the Yukon-Tanana terrane (see Stevens and Erdmer 1996).

The coincidence of high precision concordant zircon ages for the Last Peak and St. Cyr eclogites (see previous work above) is taken as evidence supporting a genetic link. The common age establishes a strong correlation between allochthonous accreted rocks thrust above parautochthonous North American strata of the Cassiar terrane, and their inferred root, the Teslin tectonic zone. In addition, if the St. Cyr klippe is part of the Slide Mountain terrane, the eclogites in the TTZ also form part of the SMT. If not, the lithologic definition of the Yukon-Tanana terrane may require broadening to include metabasic and ultramafic rocks in various states of strain. Eclogites at Faro and Ross River are in pre-metamorphic contact with their YTT

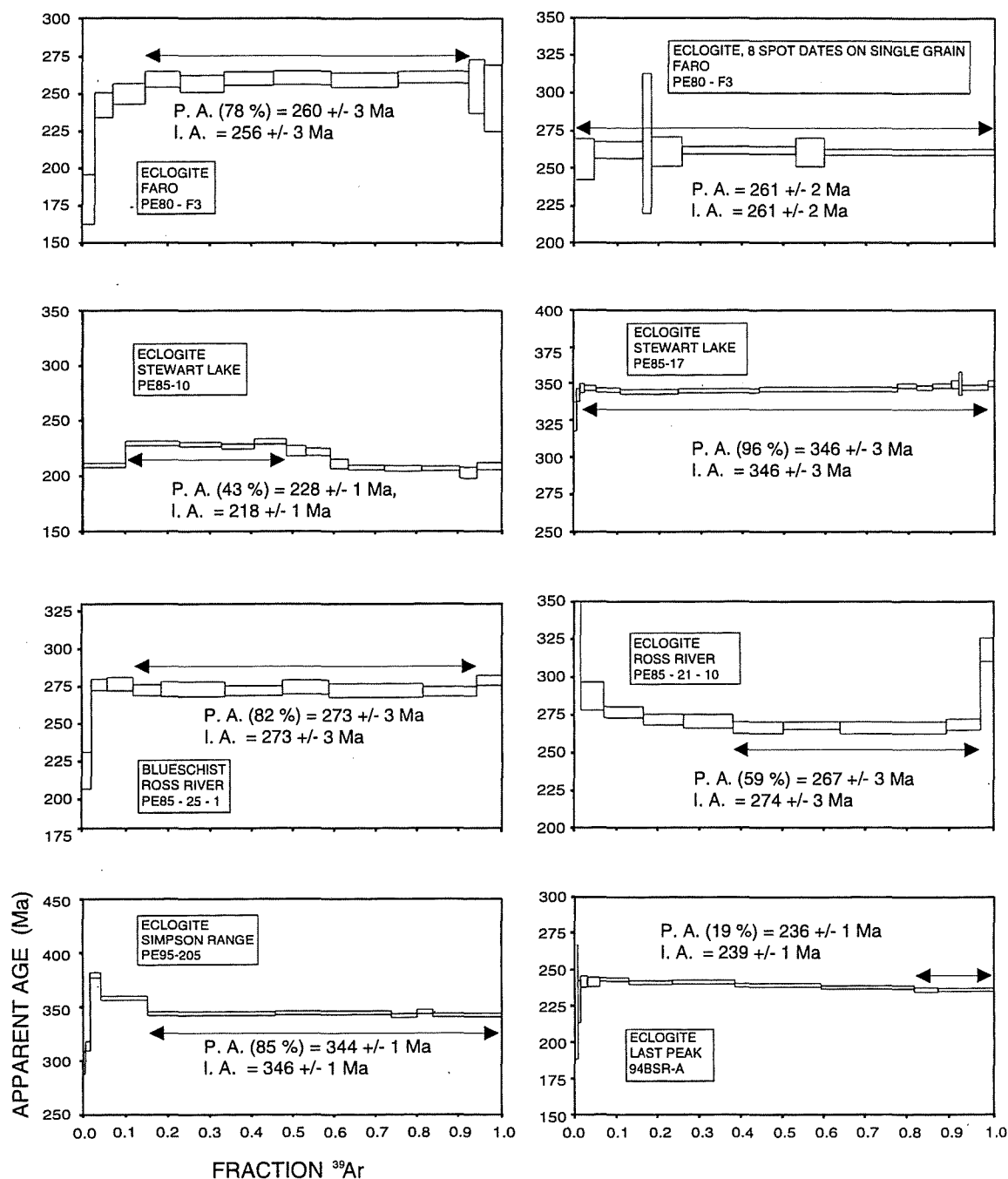


Figure 3. $^{40}\text{Ar}/^{39}\text{Ar}$ Age spectra for white mica separates from six eclogites and one blueschist, and for a single grain of white mica in eclogite from the Yukon-Tanana terrane. Errors indicated are at the 2σ level. Double-ended arrow line indicates the range of steps included in the plateau age. The Faro PE80 - F3 sample locality is within a few metres of sample Faro 5-1 shown on Figure 3.

host protolith; eclogites near Stewart Lake and in the Simpson Range occur with SMT-like rocks and presently have tectonic contacts; eclogites near Last Peak and in the St. Cyr klippe are ambiguous occurrences where rock bodies at a range of scales typical of the YTT are adjacent but contacts are not

exposed, and rock units typical of the SMT also occur (see setting above).

In many localities, the spatial proximity of serpentinite and eclogite cannot be considered diagnostic of either the SMT or YTT, as foliated serpentinite occurs near the Faro, Ross River, Last

Peak, and Stewart Lake eclogites and is everywhere in tectonic contact. It is the occurrence of greenstone, other metabasic rocks, chert, and metachert, together with serpentinite, and the lack of muscovite-quartz rich rocks, that are characteristic of klippen presently assigned to the Slide Mountain terrane. A strong case for SMT affinity is provided by the host rocks of eclogites both near Stewart Lake and in the Simpson Range.

Near Last Peak, the nature of contacts between eclogite and host rocks is addressed by the new age constraints. The concordant 269 ± 2 Ma zircon age (Creaser and others, 1997) records a peak of high-pressure metamorphism which can be taken either as a minimum age for the initiation of subduction or an age between initiation and cessation of subduction. The cessation of subduction and subsequent uplift is indicated by the 236 ± 1 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ age for the same rock. Because the Middle Triassic cooling age is significantly different from mid-Jurassic cooling ages obtained by Hansen and others (1989, 1991) for nearby rocks of the Teslin tectonic zone, the inference of a tectonic contact between the eclogites and at least some rocks of the Teslin tectonic zone is difficult to avoid. If the eclogites are part of the SMT as discussed above, the contact is a terrane-bounding fault with large displacement. If not, the contact is the locus of strain of uncertain magnitude.

The new data from Last Peak do not shed light on the related question of how much of the TTZ experienced subduction-zone metamorphism. On the basis of host rock pressure estimates overlapping those yielded by eclogite, Hansen (1992) proposed that the entire TTZ is an ancient subduction complex. In contrast, stratigraphic relations reported by Stevens and others (1996) show that most of the TTZ was not formed in a subduction complex. Stevens and Erdmer (1996) showed on the basis of structural data that the TTZ could be interpreted as a transpressive wedge over a low-angle crustal detachment, rather than as a subduction mélangé. Thus, the proportion of subducted material presently exposed remains unclear.

The existing K-Ar and Rb-Sr ages and the new Ar-Ar ages are consistent. The new ages indicate cooling of fabric-defining white mica below about 350°C (e.g., Ghent and others, 1988) in Early Carboniferous time at Stewart Lake (346 ± 3 Ma) and in the Simpson Range (344 ± 1 Ma), in Early to Middle Permian time at Ross River ($267 - 273$ Ma) and Faro (260 ± 3 Ma), and in Triassic time near Last Peak (236 ± 1 Ma) and Stewart Lake (228 ± 1 Ma).

We outline three implications of these data. One is that the assumption of continued subduction through Late Triassic or Early Jurassic time proposed or implicit in a number of evolutionary models (e.g., Tempelman-Kluit 1979, Hansen 1992, Dusel-Bacon and others, 1995) requires revision. Subduction had ceased and cooling had taken place by Middle Triassic time in all high-pressure rocks. A second is that the synkinematic metamorphism dates high-pressure ductile fabrics to be older than final emplacement of the rocks as brittle allochthons above strata of the former North American continental margin. For rocks in the Teslin tectonic zone, this is consistent with structural data from other tectonites which constrain the latest ductile deformation to a minimum age of Late Triassic - Early Jurassic (see Stevens and Erdmer 1996); the genetic link between the TTZ and the St. Cyr klippe extends this constraint to the penetrative fabrics in the allochthons. A third is that separate subduction events and (or) subduction zones are represented in the Yukon. This is a significant departure from the assumption of a single colliding arc which has guided investigations of regional tectonics for nearly twenty years (see Tempelman-Kluit 1979). At least two distinct periods of peak metamorphism are recorded, one early Carboniferous or earlier and one early Permian; a Triassic event may also be preserved.

The zircon (U-Pb) and muscovite ($^{40}\text{Ar}/^{39}\text{Ar}$) dates can be used to set limits on the cooling history of the Last Peak rocks. We assume that the peak temperature for the Last Peak rocks, $605 \pm 20^\circ\text{C}$, was attained at the time given by the zircon age (269 ± 2 Ma, Creaser and others, 1997). The $^{40}\text{Ar}/^{39}\text{Ar}$ age of 236 ± 1 Ma dates a closure temperature of 350°C . These data suggest cooling rates of 7 to 10°C my^{-1} . This is not an unusually fast cooling rate (e.g., Spear, 1993, p. 730) and the preservation of eclogite mineral assemblages suggest that the rocks cooled in a relatively dry state. The occurrence of oligoclase, biotite, and brown hornblende in these rocks suggests that at least some of the unroofing proceeded at elevated temperatures. The occurrence of blueschist assemblages in both country rocks and eclogite near Faro and Ross River suggests a different cooling history, with higher cooling rates. This is confirmed by the difference in cooling ages. In addition, independently of petrographic evidence, when peak temperatures are considered with the cooling ages, all eclogites have separate temperature-time trajectories (Fig. 4).

There are no matches between the ages of Yukon high-pressure rocks and those of other

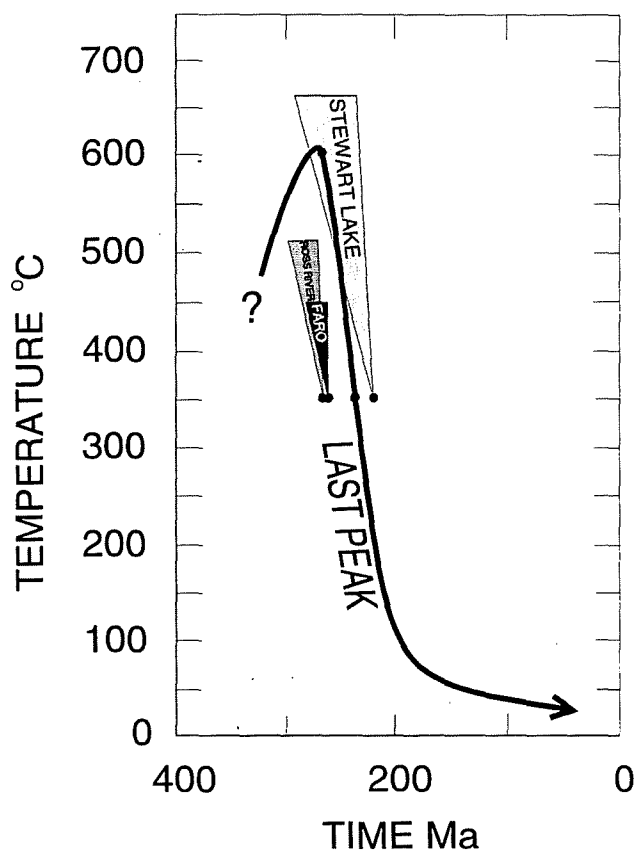


Figure 4. Temperature-time plot of four eclogites for which cooling ages are shown in Fig. 3. For the Last Peak eclogite, peak and closure temperatures are shown (dots), with a possible trajectory. For the other eclogites, closure temperature is plotted (dot) and a range of possible peak temperature is back-calculated using limiting cooling rates of 5 and 50 $^{\circ}\text{C my}^{-1}$. All eclogites had different cooling rates since they have different peak temperatures, cooled through different metamorphic facies, and have different cooling ages.

occurrences in North America, which is significant because it highlights a mechanism of crustal growth characteristic of Cordilleran tectonics. The North American Cordillera is unique among orogens in the number and range of ages of preserved high-pressure metamorphic rocks. The notion that the history of Cordilleran convergence is one of a succession of short, perhaps intense subduction episodes rather than of continuous subduction was proposed by Armstrong and others (1986). The Cordillera records events from Late- or Middle Paleozoic to Cretaceous, with a general outward (westward) younging of ages (see Fig. 1). The widely varying petrologic, structural, and

age characteristics of known subduction-zone rocks including those from this study are compatible with episodic accretion of short-lived separate arcs, and incompatible with protracted convergence at a single subduction zone. In the Yukon, because high-pressure rocks with Middle Paleozoic cooling ages occur near others with Mesozoic cooling ages (near Stewart Lake), successive subduction zones may have developed in close spatial proximity. This suggests the closure of small ocean basins rather than large ones and the telescoping of regional facies belts and structural boundaries, rather than of highly exotic lithotectonic assemblages and major plate boundaries. Irrespective of their degree of allochthoneity, all high-pressure rocks in the Yukon were accreted to the ancestral North American continental margin and are exotic with respect to its miogeocline.

All of the high-pressure rocks in the Yukon predate the oldest magnetic stripe record of Jurassic age in Pacific oceanic crust. The subducted rocks physically record the fact that North America was moving westward with respect to adjacent plates well before Jurassic time. Whether the convergence resulted from the closing of a large proto-Pacific ocean or the collapse of several smaller basins still needs to be clarified, but all available data for the high-pressure rocks of the Cordillera show that the duration of convergence since the Early or Middle Paleozoic was long enough to support multiple subduction zones. The linear amount of subducted Paleozoic lithosphere is inferred to at least match the amount since Jurassic time, whether the subduction zones were the locus of orthogonal or only oblique plate convergence.

The inferred P-T history of the Franciscan blueschists, some of the best studied high-pressure rocks in the Cordillera, is one of unroofing coincident with continued subduction (e.g., Ernst 1988). Multiple events recording separate subduction cycles have been proposed for the Franciscan complex (Mattinson 1988). Alternatively, Cloos (1985) proposed that the entire range of Franciscan metamorphic ages result from the thermal evolution of a single, prolonged subduction episode. The Yukon rocks constitute evidence of multi-episodic subduction within a single terrane whether or not both the Yukon-Tanana and Slide Mountain terranes host eclogite. If the Last Peak, Simpson Range, Stewart Lake, and St. Cyr eclogites are part of the Slide Mountain terrane, a hypothesis for which available evidence is reviewed above, evidence of multiple subduction zones in a single terrane is provided by the age data from Stewart Lake, essentially a single

locality. If all high-pressure rocks in this study are part of the Yukon-Tanana terrane, then they are the products of separate subduction zones now exposed in a single extensive terrane of the northern Cordillera. The Yukon eclogites had different unroofing paths, some of which did not require the refrigeration due to continued subduction which has been suggested for the Franciscan complex. While our data for the Yukon rocks cannot support an inference that all high-pressure Cordilleran terranes were multi-episodic, they are consistent with the conclusion that multi-episodic high-pressure metamorphism is an orogenic characteristic of the Cordillera.

CONCLUSIONS

Eclogite and blueschist from Yukon to Alaska which occur as primary units in or are tectonically interleaved with the Yukon-Tanana terrane and the Slide Mountain terrane preserve a partial record of Middle Paleozoic, Late Paleozoic, and Early Mesozoic subduction and subsequent unroofing. From mineral paragenesis, petrologic relations, pressure and temperature constraints, and minimum pressure and temperature estimates obtained, eclogites near Faro, Ross River, Last Peak, Stewart Lake, and in the St. Cyr klippe were metamorphosed at depths ≥ 40 km, confirming the initial data from earlier studies. The data for eclogites at Faro suggest a specific depth range of 40 to 50 km, characteristic of Type C eclogites. The coincidence of distinctive high precision concordant zircon ages of ~ 269 Ma from the Last Peak and St. Cyr klippe eclogites is taken as evidence supporting a direct correlation and is the strongest physical link to date between allochthonous accreted rocks above North American rocks of the Cassiar terrane and their inferred root, the Teslin tectonic zone. If the St. Cyr klippe is part of the Slide Mountain terrane, the correlation implies that the eclogites in the Teslin tectonic zone also form part of the Slide Mountain terrane. Notwithstanding this, rocks of the Slide Mountain terrane in the Stewart Lake klippe and in the Simpson Range underwent subduction-zone metamorphism similar to parts of the Yukon-Tanana terrane.

Previously available K-Ar and Rb-Sr ages are consistent with new Ar-Ar ages which indicate cooling of fabric-defining white mica below about 350 °C in early Carboniferous time at Stewart Lake and in the Campbell Range, in Early to Middle Permian time at Ross River and Faro, and in Triassic time near Last Peak and Stewart Lake. The data imply

that (1) subduction ceased and cooling took place by Middle Triassic time in all rocks; (2) the synkinematic metamorphism dates high-pressure ductile fabrics as being older than final emplacement; and (3) separate subduction events and (or) zones are represented in the Yukon. At least two distinct periods of peak metamorphism are recorded, one early Carboniferous or earlier, and one early Permian. A Triassic event may also be preserved. This is a significant departure from the assumption of a single collided arc which has guided investigations of regional tectonics until now.

There are no matching ages of Yukon high-pressure rocks in other occurrences in North America. The North American Cordillera is unique among Phanerozoic orogens in the number and ranges of ages of preserved high-pressure metamorphism. The Cordillera records events from Early Paleozoic to Cretaceous. There is a general outward (from the interior of the plate toward the margin) younging of ages in California but this is not the case in the Yukon. Episodic accretion of short-lived separate arcs rather than protracted convergence at a single subduction zone was a characteristic mechanism of crustal growth in the Cordillera.

REFERENCES

- Armstrong, R.L., Harakal, J.E., Brown, E.H., Bernardi, M.L., and Rady, P.M., 1983, Late Paleozoic high-pressure metamorphic rocks in northwestern Washington and southwestern British Columbia - The Vender Complex: Geological Society of America Bulletin, v. 94, p. 451-458.
- Berman, R.G., 1988, Internally consistent thermodynamic data for minerals in the system $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{CaO}-\text{MgO}-\text{FeO}-\text{Fe}_2\text{O}_3-\text{Al}_2\text{O}_3-\text{SiO}_2-\text{TiO}_2-\text{H}_2\text{O}-\text{CO}_2$: Journal of Petrology, v. 29, p. 445-522.
- Berman, R.G., 1990, Mixing properties of Ca-Mg-Fe-Mn garnets: American Mineralogist, v. 75, p. 328-344.
- Berman, R.G., 1991, Thermobarometry using multi equilibrium calculations: a new technique with petrological applications: Canadian Mineralogist, v. 29, p. 833-855.
- Berman, R.G., Aranovich, L.Y., and Pattison, D.R.M., 1995, Reassessment of the garnet-clinopyroxene Fe-Mg exchange thermometer: II. Thermodynamic analysis: Contributions to Mineralogy and Petrology, v. 119, p. 30-42.
- Brown, E.H., and Forbes, R.B., 1986, Phase petrology of eclogitic rocks in the Fairbanks district, Alaska, in B.W. Evans and E.H. Brown, eds., Blueschists and eclogites: Geological Society of America Memoir 164, p. 155-168.
- Brown, T.H., Berman, R.G., and Perkins, E.H., 1988, Ge0-Calcd: a software package for calculation and display of pressure-temperature-composition phase diagrams using an IBM or compatible personal computer: Computers and Geosciences, v. 14, p. 279-289.
- Cloos, M., 1985, Thermal evolution of convergent plate margins - Thermal modelling and reevaluation of isotopic Ar-ages for blueschists in the Franciscan complex of California: Tectonics, v. 4, p. 421-433.

- Cloos, M., 1986, Blueschists in the Franciscan Complex of California: Petrotectonic constraints on uplift mechanisms: *in* B.W. Evans and E.H. Brown, eds., *Blueschists and eclogites*: Geological Society of America Memoir 164, p. 77-94.
- Creaser, R.A., Heaman, L., and Erdmer, P., 1997, Timing of high-pressure metamorphism in the Yukon-Tanana terrane, Canadian Cordillera: Constraints from U-Pb zircon dating of eclogite from the Teslin tectonic zone: *Canadian Journal of Earth Sciences*, in press.
- Chatterjee, N.D. and Froese, E., 1975, A thermodynamic study of the pseudo binary join muscovite-paragonite in the system $\text{KAlSi}_3\text{O}_8\text{-NaAlSi}_3\text{O}_8\text{-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$: *American Mineralogist*, v. 60, p. 985-993.
- Coleman, R.G., Lee, D.E., Beatty, L.B. and Brannock, W.W., 1965, Eclogites and eclogites: their differences and similarities: *Geological Society of America Bulletin*, v. 76, p. 483-508.
- Dusel-Bacon, C., Hansen, V.L. and Scala, J.A., 1995, High-pressure amphibolite-facies dynamic metamorphism and the Mesozoic tectonic evolution of an ancient continental margin, east-central Alaska: *Journal of Metamorphic Geology*, v. 13, p. 9-24.
- Ellis, D.J., and Green, D.H., 1979, An experimental study of the effect of Ca upon garnet-clinopyroxene Fe-Mg exchange equilibria: *Contributions to Mineralogy and Petrology*, v. 71, p. 13-22.
- Ernst, W. G., 1988, Tectonic history of subduction zones inferred from retrograde blueschist P-T paths. *Geology*, v. 16, p. 1081-1084.
- Erdmer, P., 1987, Blueschist and eclogite in mylonitic allochthons, Ross River and Watson Lake area, southeastern Yukon: *Canadian Journal of Earth Sciences*, v. 24, p. 1439-1449.
- Erdmer, P., 1992, Eclogitic rocks in the St. Cyr klippe, and their tectonic significance: *Canadian Journal of Earth Sciences*, v. 29, p. 1296-1304.
- Erdmer, P. and Armstrong, R.L., 1989, Permo-Triassic isotopic dates for blueschist, Ross River area, Yukon, *in* *Yukon Geology*, v. 2, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 33-36.
- Erdmer, P. and Helmstaedt, H., 1983, Eclogite from central Yukon: a record of subduction at the western margin of ancient North America." *Canadian Journal of Earth Sciences*, v. 20, p. 1389-1408.
- Ghent, E. D. and Stout, M. Z., 1994, Geobarometry of low-temperature eclogites: applications of isothermal pressure-activity calculations. *Contributions to Mineralogy and Petrology*, v. 116, p. 500-507.
- Ghent, E. D., Stout, M. Z., and Erdmer, P., 1993, Pressure-temperature evolution of lawsonite-bearing eclogites, Pinchi Lake, British Columbia. *Journal of Metamorphic Geology*, v. 11, p. 279-290.
- Ghent, E.D., Stout, M.Z., and Parrish, R.R., 1988, Determination of metamorphic pressure-temperature-time (P-T-t) paths, *in* *Short Course on Heat, Metamorphism, and Tectonics*, eds Nisbet, E.G. & Fowler, C.M.R., Mineralogical Association of Canada Short Course v. 14, p. 155-188.
- Hansen, V.L., 1992, P-T evolution of the Teslin suture zone and Cassiar tectonites, Yukon, Canada: evidence for A- and B-type subduction: *Journal of Metamorphic Geology*, v. 10, p. 239-263.
- Hansen, V.L., Heizler, M.T., and Harrison, T.M., 1991, Mesozoic thermal evolution of the Yukon-Tanana composite terrane: new evidence from $^{40}\text{Ar}/^{39}\text{Ar}$ data: *Tectonics*, v. 10, p. 51-76.
- Hansen, V.L., Mortensen, J.K., and Armstrong, R.L., 1989, U-Pb, Rb-Sr, and K-Ar isotopic constraints for ductile deformation and related metamorphism in the Teslin suture zone, Yukon-Tanana terrane, south-central Yukon: *Canadian Journal of Earth Sciences*, v. 26, p. 2224-2235.
- Holland, T.J.B., 1990, Activities of components in omphacitic solid solutions: an application of Landau theory to mixtures: *Contributions to Mineralogy and Petrology*, v. 105, p. 446-453.
- Hunt, P.A., and Roddick, J.C., 1993, A compilation of K-Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ ages: Report 23. *In* *Radiogenic age and isotopic studies: report 7*. Geological Survey of Canada Paper 93-2, p. 145.
- Jenkins, D.M., Newton, R.C., and Goldsmith, J.R., 1985, Relative stability of Fe-free zoisite and clinozoisite: *Journal of Geology*, v. 93, p. 663-672.
- Mattinson, J.M., 1988, Constraints on the timing of Franciscan metamorphism: geochronological approaches and their limitations: *in* Ernst, W.G., ed., *Metamorphism and crustal evolution of the western United States*, Rubey volume 7: Englewood Cliffs, New Jersey, Prentice-Hall, p. 1023-1034.
- Spear, F. S., 1993, *Metamorphic phase equilibrium and pressure-temperature-time paths*: Mineralogical Society of America Monograph, 789 p.
- Stevens, R.A., Erdmer, P., Grant, S. and Creaser, R.A., 1996, Mississippian continental crust in the Yukon-Tanana terrane: evidence from the Teslin tectonic zone, south-central Yukon Territory: *Canadian Journal of Earth Sciences*, v. 33, p. 103-116.
- Stevens, R.A. and Erdmer, P., 1996, Structural divergence and transpression in the Teslin tectonic zone, southern Yukon Territory: *Tectonics*, v. 15, in press.
- Tempelman-Kluit, D.J., 1970, An occurrence of eclogite near Tintina Trench, Yukon, *in* *Report of activities, Part B*, Geological Survey of Canada Paper 70-1B, p. 19-22.
- Tempelman-Kluit, D.J., 1979, Transported cataclasite, ophiolite and granodiorite in Yukon: evidence of arc-continent collision. *Geological Survey of Canada Paper 79-14*, 28 p.
- Wanless, R.K., Stevens, R.D., Lachance, G.R., and Delabio, R.N., 1978, Age determinations and geological studies: K-Ar isotopic ages, report 13: Geological Survey of Canada Paper 77-2, 60 p.
- Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W. and Woodsworth, G.J., compilers, 1991, *Terrane map of the Canadian Cordillera*: Geological Survey of Canada Map 1713A, scale 1:2 000 000, 2 sheets.

Mantle Xenolith and Alkaline Basalt Mapping of the Lithospheric Mantle Beneath Northwestern Canada

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Mantle xenoliths, and their recent alkaline basalt hosts, provide a sampling of the lithospheric mantle both along and across the northern Canadian Cordillera. The majority of mantle xenolith suites from the Washington - B.C. border in the South to eastern Alaska in the North are characterized by unimodal populations dominated by relatively fertile spinel lherzolites that are interpreted to represent the prevalent lithospheric mantle beneath the Intermontane Belt. Two types of bimodal xenolith suites, however, exist. Three mantle xenolith suites near the B.C. - Yukon border exhibit bimodal populations comprised of fertile lherzolites and refractory harzburgites, separated by a distinct population minimum. These three bimodal xenolith suites are geographically correlated with a newly discovered low-velocity anomaly in the upper mantle extending to depths of 500 km (Frederiksen & Bostock, 1996). A strong correlation between major element depletion and trace element enrichment in the bimodal suite mantle xenoliths suggest that the harzburgite xenoliths reflect the residue of melting of the lower lherzolite lithosphere, induced by the influx of both heat and volatiles from an underlying region of anomalous hot mantle. A second type of bimodal mantle xenolith suite occurs at the two most easterly volcanic centres in central B.C. These suites consist of bimodal populations of fertile lherzolites, similar to those found throughout the Cordillera, and clinopyroxene-rich wehrlites, which may become an important component of the lithospheric mantle moving towards the Archean craton.

Regional variations in the compositions of recent alkaline basalts also provide evidence for discontinuous changes in the character of the lithospheric mantle across major terrane boundaries of the northern Cordillera. Overall, there is a striking correspondence between the Sr-isotopic variations in basalts and that documented in Mesozoic to Tertiary granitoids by Armstrong. For example, alkaline basalts within the Coast Plutonic Belt display significantly higher trace element and isotopic ratios (Nb/Zr, Rb/Zr, $^{87}\text{Sr}/^{86}\text{Sr}$) compared to those within the Intermontane Belt to the East. Further east, across the Cassiar fault, recent alkaline basalts of the Omineca Belt again show trace element and isotopic enrichments similar to those in the Coast Plutonic Belt. The most striking evidence for a discontinuous change occurs across the Tintina Fault, a major transcurrent fault separating the assembled terranes of the Cordillera from the North American Craton. Lavas of the east side of the fault are characterized by significant higher Ca, Zr, but lower heavy rare-earth elements and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios than their equivalents on the west side of the fault. These results indicate that the Tintina Fault penetrates the crust and separates distinct lithospheric mantles juxtaposed at the edge of ancestral North American.

A comparison of these results to those recently acquired on mantle xenoliths from the Nikos kimberlite pipe, Somerset Island, indicates that the lithospheric mantle beneath the Canadian craton is significantly more refractory than the lherzolite beneath much of the Cordillera, but similar in composition to the refractory harzburgite xenoliths of the Cordilleran bimodal suites. The orthopyroxene-rich harzburgites that characterize the mantle root beneath the Kaapvaal Craton of South Africa are not present in the Somerset suite.

Petrology of the Lithosphere beneath the Northern Cordillera

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Overview

This report is an update to our study of xenolith distributions in Neogene to Quaternary volcanic centres of the Northern Cordillera Volcanic Province (NCVP). We present preliminary temperature estimates for felsic granulite-facies xenoliths from Prindle volcano and a preliminary petrological cross-section of the subsurface continental lithosphere beneath the Northern Cordillera. The schematic cross-section incorporates data collected and compiled for xenoliths found within the NCVP. This preliminary cross-section and subsequent revisions to the cross-section constrain the petrology of the underlying lithosphere along and across Corridors 2 and 3 of the SNORCLE Transects (Figure 1).

The Northern Cordillera Volcanic Province, parts of which have been referred to as the "Stikine Volcanic Belt", comprises over one hundred Neogene to Recent volcanic centres: all of the volcanoes are situated in a region bounded by the Denali fault system to the west and the Tintina fault system to the east (Edwards & Russell 1997; Figure 1). At least 39 of the centres contain crustal and/or mantle xenoliths (Table 1). Xenolith-bearing centres in the NCVP occur in five different lithostratigraphic terranes including: Yukon-Tanana, Stikine, Cache Creek, Cassiar, and the Coast Plutonic Complex. They also cross several major structural features (e.g., King Salmon arch, Nahlin and Teslin faults; Souther, 1992).

Distribution of Xenoliths within the NCVP

During the 1995 and 1996 field seasons we (BRE, JKR, T.S. Hamilton) visited 19 volcanic centres within the NCVP (Figure 2a). We collected xenoliths (> 500), representing a broad range of compositions (peridotite to granite). We sampled xenolith-bearing volcanoes situated within 5 of the different lithostratigraphic terranes underlying the NCVP including: Yukon-Tanana (Prindle, west Dawson), Stikinia (Hoodoo Mtn.), Cache Creek (Atlin), Cassiar

(Ash Mountain, South tuya) and the Coast Plutonic Complex (western Iskut-Unuk rivers) (Figure 2b). We also compiled data from the literature for other centres in the NCVP reported to contain xenoliths (Table 1). The distribution of feldspathic and peridotitic xenoliths within the NCVP is shown in Figure 2a. The widespread distribution of xenoliths has two implications. Firstly, the xenoliths are samples of the column of continental lithosphere directly beneath the volcanic centres and, as such, elucidate the composition and evolution of the northern Cordillera lithosphere. Secondly, the abundance of xenoliths indicates that the geochemical evolution of NCVP magmas was potentially complicated by reactions between the xenoliths and their host magmas.

Peridotitic xenoliths have been documented from 15 different centres covering over two-thirds of the length of the Stikine Volcanic Belt (Figure 2a; Table 1). Their distribution is skewed towards the northern half of the NCVP and to the Yukon-Tanana and Cache Creek terranes (Figure 2b). Ultramafic xenoliths are found in the majority of centres located in Yukon-Tanana, in approximately one-half of the centres in Cache Creek, and in some of the centres within the Stikine terrane. No ultramafic xenoliths are known from NCVP centres within the Cassiar terrane or east of the Tintina Fault (D. Francis, per. comm., 1996). Peridotitic xenoliths from the NCVP include dunite, lherzolite, harzburgite, websterite, wehrlite and garnet pyroxenite (Foster et al. 1967; Littlejohn & Greenwood 1974; Sinclair et al. 1978; Hamilton 1981; Nicholls et al. 1982; Prescott 1983; Ross 1983; Higgins & Allen 1985; Francis 1987). Both tectonized and non-tectonized mineral fabrics have been documented in the peridotite xenoliths (Prescott 1983; Ross 1983).

The feldspathic xenoliths, including sedimentary, plutonic and metamorphic rocks, are extremely common throughout the NCVP (Figure 2a). The most frequent types are granitic rocks that commonly derive from intrusions exposed as bedrock (e.g., Eiché et al. 1987). In contrast, samples of high-grade, granulite-facies metamorphic rocks are found only at Prindle (Foster et al., 1967; Prescott 1983), Fort Selkirk (Prescott 1983), Castle Rock (Prescott 1983) and Iskut River (Nicholls et al., 1982). Granulite facies basement rocks are not exposed adjacent to any of these volcanic centres.

Many of the feldspathic xenoliths exhibit reaction textures with the surrounding magma and some are partly melted and now contain glass. Partly reacted xenoliths have been noted at Alligator Lake (Eiché et al. 1987; Carignan et al. 1994), Ruby Mountain (Edwards et al. 1996), Volcanic Creek (Edwards et al. 1996), Cracker Creek (Edwards et al. 1996), Chikoida

Mountain (Edwards et al. 1996), Level Mountain (Hamilton 1981), Ash Mountain (De P. Watson & Mathews, 1948), South Tuya, Mathew's Tuya (Simpson 1996), Mount Edziza (Souther 1992), Hoodoo Mountain (Edwards & Russell 1994a; Edwards et al. 1995), and the Iskut-Unuk rivers centres (Stasiuk & Russell 1989; Hauksdóttir 1994; Hauksdóttir et al. 1994; Hauksdóttir & Russell 1994). Feldspar and quartz xenocrysts are also found in many volcanic centres including Ft. Selkirk (Francis & Ludden 1991), Mount Edziza (Souther 1992), the Stikine River area (Read & Psutka 1985), and the Iskut-Unuk rivers centres (Hauksdóttir 1994). Hauksdóttir (1994) showed conclusively that lavas from individual centres in the Iskut River volcanic field could not be related by closed system differentiation. In addition, she found partly melted xenoliths at several of the centres and documented texturally and compositionally distinct plagioclase populations. The evidence from Hauksdóttir (1994) overwhelmingly supports the hypothesis that crustal contamination played an important role in the differentiation history of this volcanic field. Subsequent work by Cousens and Bevier (1995) also found isotopic and trace element evidence consistent with crustal or lithospheric contamination in the Iskut-Unuk volcanic field.

Prindle volcano as an example

One of the most important xenolith locations in the NCVF is Prindle volcano (Figs. 1, 2a & b). Prindle is important because it contains a wide range of xenoliths including Qtz-Pl-Opx-Cpx granulites, Cpx-Scapolite granulites, Spl lherzolites, Spl harzburgites, and websterites (Foster et al. 1966; Prescott 1983; this study). Xenoliths from Prindle volcano are direct samples of the continental lithosphere under the Yukon-Tanana terrane. We (in collaboration with other workers) are in the process of completing a number of petrological and geochronological studies of the granulite xenolith suite, including geothermometry and U-Pb dating (Jim Mortensen, U.B.C.). Potential also exists for measuring physical properties of both the granulite and the peridotite the xenoliths from Prindle (T. Hamilton, P.G.C.).

We have analyzed minerals from two Qtz-bearing granulite xenoliths (95PV02 and 95PV43). 95PV02 contains the assemblage Opx, Cpx, Pl, Qtz, Ilm, Mt, and Rt. Sample 95PV43 contains the assemblage Opx, Cpx, Pig, Pl, Qtz, and Ilm. Based on the compositions of coexisting Opx and Cpx from each of the two samples, we have calculated temperatures of 920-930 ° C (95PV02) and of 945-981 ° C (95PV43). Temperatures were calculated using the Wells (1977) two-pyroxene thermometer (Figure 3). These

temperatures are similar to those calculated for spinel lherzolite xenoliths from Prindle by Prescott (1983). Included in Figure 3 are two reference lines: the spinel lherzolite - garnet lherzolite transition (from O'Neill (1981) for Fe_{90} and corrected for Cr content of spinel) and an estimated geothermal gradient for alkaline basalt provinces (90 mWm^{-2} ; Pollack & Chapman 1977, Jones et al. 1983). These reference lines place broad constraints on the depths of origin of the xenoliths. Since none of the lherzolite xenoliths contain garnet, they probably derive from depths of not greater than 55 km. If the granulites equilibrated along the same geothermal gradient as the lherzolites, they could have been derived from 40-55 km. The similarity of temperatures for both granulites and lherzolites could be interpreted to suggest that the ultramafic rocks are stratigraphically close to the granulites (e.g., Griffin & O'Reilly 1987; O'Reilly & Griffin 1994, 1996). Although this work is very preliminary, it shows that we gain important new information about the stratigraphy of the lithosphere from the xenoliths.

Preliminary lithospheric cross-section

Our objectives are to provide constraints on the physical, thermal and chemical structure of continental lithosphere in the northwestern Canadian Cordillera along SNORCLE transects 2 and 3. The petrological characteristics of the xenoliths provide a record of the lithospheric stratigraphy extant when the host magmas erupted. Figure 4a is a schematic cross-section showing the location of several xenolith-bearing NCVP volcanic centres and SNORCLE transects 2 and 3. The line of section is given in Figure 3a & b as a dotted line. Obviously, many questions exist about the nature of the subsurface continental lithosphere, the orientation of major structures that define separate terranes, and the lower lithosphere-asthenosphere boundary. Currently we do not know if the asthenosphere under the terranes is allochthonous or autochthonous to North America.

Figure 4b is a preliminary attempt at synthesizing our current observations and data into a single cross-section. The figure shows schematically the types of xenoliths found at several NCVP centres. The depths of origin of xenoliths will improve as our work progresses. At the base of Figure 4b is a summary of geothermometry based on mineral compositions reported in this work, in the literature, and in unpublished theses (e.g. Prescott 1983). Figure 4b also includes approximate boundaries for the P-wave anomaly recently reported by Frederickson (1996).

Temperatures recorded by spinel lherzolite xenoliths appear to increase to the south, where the highest temperatures are from Castle Rock (Prescott 1983; Ross 1983). The increase in temperatures from Prindle volcano to Alligator Lake and Atlin generally corresponds to the P-wave velocity anomaly found by Frederickson (1996). In addition, the increase in temperatures from the spinel lherzolites may indicate that the petrological Moho deepens to the south.

Conclusions

Clearly, this lithospheric cross-section is not complete; however, it represents a first attempt to provide a petrological picture with which to constrain interpretations of geophysical data collected on SNORCLE transects. In the future we intend to complete our synthesis of "petrological stratigraphy" for the Northern Cordillera.

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References

- BC-Hydro 1985. Stikine-Iskut development, Iskut Canyon and More Creek Projects, 1982-1984. Geotechnical Investigations, Main Report, Volume 1, Report No. H1614. BC-Hydro Information Centre.
- Bultman, T.R. 1979. Geology and tectonic history of the Whitehorse trough west of Atlin, British Columbia; Ph.D. thesis, Yale University, New Haven, Connecticut.
- Carignan, J., Ludden, J. & Francis, D. 1994. Isotopic characteristics of mantle sources for Quaternary continental alkaline magmas in the northern Canadian Cordillera. *Earth Planet. Sci. Lett.*, v. 128, 271-286.
- Carignan, J., Ludden, J. & Francis, D. 1995. Asthenosphere-lithosphere interaction during the formation of continental alkaline basalts in the northern Canadian Cordillera. *EOS, Transactions*, Fall 1995, F587.
- Casey, J. J. 1980. Geology of the Heart Peaks Volcanic Centre, Northwestern British Columbia. unpub. M.S. thesis, The University of Alberta, Edmonton, 116 p.
- Cousens, B.L. & Bevier, M.L. 1995. Discerning asthenospheric, lithospheric and crustal influences on the geochemistry of Quaternary basalts from the Iskut-Unuk rivers area, northwestern British Columbia. *Can. J. Earth Sci.*
- Edwards, B.R. & Russell, J.K. 1994a. Preliminary Stratigraphy of Hoodoo Mountain volcano, northwestern B.C. *in* Current Research Part A; Geological Survey of Canada, Paper 94-1A.
- Edwards, B.R. & Russell, J.K. 1996. An overview of the nature, distribution and tectonic significance of xenoliths from the Stikine Volcanic Belt, northern Cordillera. *in* Cook, F. & Erdmer, P. (compilers), 1996 Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary, Lithoprobe Report No. 50, 96-107.

- Edwards, B.R. & Russell, J.K. 1997. Definition of a New Volcanic Province in Northwestern Canada: The Northern Cordilleran Volcanic Province, Geological Association of Canada-Mineralogical Association of Canada 1997 Annual Meeting Program with Abstracts, Ottawa.
- Edwards, B.R. & Russell, J.K. 1997. Implications of assimilation for mineral growth and zoning. *Canadian Mineralogist*, 34. Lithoprobe Pub. #763.
- Edwards, B.R., Edwards, G. & Russell, J.K. 1995. Revised stratigraphy for the Hoodoo Mountain volcanic centre, northwestern British Columbia; in *Current Research, Part A*; Geological Survey of Canada, Paper 95-1A.
- Edwards, B.R., Hamilton, T.S., Nicholls, J., Stout, M.Z., Russell, J.K. & Simpson, K. 1996. Late Tertiary to Quaternary volcanism in the Atlin area, northwestern British Columbia. in *Current Research Part A*; Geological Survey of Canada, Paper 96-1A, 29-36.
- Eiché, G.E. 1986. Petrogenesis of the basalts of the Alligator Lake alkaline complex, Yukon Territory. unpub. M.Sc., McGill University.
- Eiché, G.E., Francis, D.M., & Ludden, J.N. 1985a. Geochemistry and petrogenesis of Quaternary alkaline basalts from the Alligator Lake volcanic complex, Yukon Territory. Program with Abstracts, Geological Association of Canada-Mineralogical Association of Canada Joint Annual Meeting, Fredericton, N.B., p. A16.
- Eiché, G.E., Francis, D.M., & Ludden, J.N. 1985b. Temporal evolution of alkaline magmatism in the northern Canadian Cordillera. Abstracts with Programs - Geological Society of America v. 17, p. 157.
- Eiché, G.E., Francis, D.M., & Ludden, J.N. 1987. Primary alkaline magmas associated with the Quaternary Alligator lake volcanic complex, Yukon Territory, Canada. *Contributions to Mineralogy and Petrology*, v.95. 191-201.
- Evenchick, C.A. & Thorkelson, D.J. 1993. Geology, Spatzizi River, British Columbia (104H). Geological Survey of Canada, Open File 2719, scale 1:250 000.
- Foster, H.L., Forbes, R.B., & Ragan, D.L. 1966. Granulite and peridotite inclusions from Prindle Volcano, Yukon-Tanana Upland, Alaska. U.S.G.S. Prof. Paper 550-B, B115-B119.
- Francis, D. 1987. Mantle-melt interaction recorded in spinel lherzolite xenoliths from the Alligator Lake volcanic complex, Yukon, Canada; *Journal of Petrology*, v. 28, p. 569-597.
- Francis, D. 1991a. Volcano Mountain. in *Volcanoes of North America*, C.A. Wood & J. Kienle (eds.). Cambridge University Press: New York. 118-119.
- Francis, D. & Ludden, J. 1990. The mantle source for olivine nephelinite, basanite and alkaline olivine basalts at Fort Selkirk, Yukon, Canada; *Journal of Petrology*, v. 31, p.
- Francis, D. & Ludden, J. 1995. The signature of amphibole in mafic alkaline lavas, a study in the northern Canadian Cordillera. *J. Petrology*, v.36, 1171-1191.
- Francis, D., Abraham, A.C., Rowins, S., Shi, L., Carignan, J. & Ludden, J. 1996. A chemo-isotopic transect of the lithospheric upper mantle across the northern Canadian Cordillera. in Cook, F. & Erdmer, P. (compilers), 1996 Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary, Lithoprobe Report No. 50, p. 108.
- Frederickson, A.W. 1996. A teleseismic study of the Northern Cordilleran upper mantle beneath the SNORCLE Transect. unpub. M.Sc., University of British Columbia, 85p.
- Gabrielse, H. 1963. McDame map-area, Cassiar District, British Columbia. Geological Survey of Canada Memoir 319.
- Gabrielse, H. 1968. Geology of the Jennings River map-area, British Columbia (104-O). Geological Survey of Canada Paper 68-55.
- Gabrielse, H. 1978. Cry Lake, British Columbia. Geological Survey of Canada Open File 610.
- Gabrielse, H. & Souther, J.G. 1962. Dease Lake map-area, British Columbia. Geological Survey of Canada Map 21-1962.
- Griffin, W.L. & O'Reilly, S.Y. 1987. The composition of the lower crust and the nature of the continental Moho - xenolith evidence. in *Mantle Xenoliths*, P.H. Nixon (ed.), John Wiley & Sons, 413-431.
- Hamilton, T.S. 1981. Late Cenozoic Alkaline Volcanics of the Level Mountain Range, Northwestern British Columbia: Geology, Petrology, and Paleomagnetism. unpub. Ph.D. dissertation., The University of Alberta, Edmonton, 490 p.
- Hamilton, T.S. 1991. Level Mountain. in *Volcanoes of North America*, C.A. Wood & J. Kienle (eds.). Cambridge University Press: New York. 121-123.
- Hamilton, T.S. & Scarfe, C.M. 1976. Cenozoic alkaline lavas from the Level Mountain volcanic centre. Abstracts of the Geological Association of Canada / Mineralogical Association of Canada Annual Meeting, v.1, p.47.

- Hamilton, T.S. & Scarfe, C.M. 1977. Preliminary report on the Petrology of the Level Mountain volcanic centre, northwestern British Columbia. Geological Survey of Canada Report of Activities, Paper 77-1A, p429-434.
- Hamilton, T.S., Baadsgaard, H. & Scarfe, C.M. 1978. Petrogenesis of the late Cenozoic volcanics, Level Mountain, northern British Columbia. GAC/MAC/GSA annual meeting programme with abstracts v.10, p.414-415.
- Hasik, V., Francis, D. & Ludden, J. 1993. Volcanic evidence for a compositional contrast in the lithospheric upper mantle across the Tintina Trench, SE Yukon. GAC-MAC Abstracts with Program, v.18, A-41.
- Hauksdottir, S. 1994. Petrography, geochemistry and petrogenesis of the Iskut-Unuk rivers volcanic centres, northwestern British Columbia, unpub. M.Sc. thesis, University of British Columbia, 253p.
- Hauksdottir, S. & Russell, J.K. 1994. Assimilation-crystallization reactions in recent basalts of the Iskut-Unuk rivers area, northwestern British Columbia. 1994 GAC-MAC abstract.
- Hauksdottir, S., Enegren, E.G. & Russell, J.K. 1994. Recent basaltic volcanism in the Iskut-Unuk rivers area, northwestern B.C. *in* Current Research Part A; Geological Survey of Canada, Paper 94-1A.
- Hickson, C.J. 1991. Volcano vent map and table. *in* Volcanoes of North America, C.A. Wood & J. Kienle (eds.). Cambridge University Press: New York. 116-118.
- Higgins, M.D. & Allen, J.M. 1984. A new locality for primary xenolith-bearing nephelinites in northwestern British Columbia. Can. J. Earth Sci., v.22, 1556-1559.
- Jackson, L.E., Jr. 1989. Pleistocene subglacial volcanism near Fort Selkirk, Yukon Territory. *in* Current Research, Part E., Geological Survey of Canada, Paper 89-1E, p. 251-256.
- Jackson, L.E., Jr., & Stevens, W. 1992. A recent eruptive history of Volcano Mountain, Yukon Territory. *in* Current Research, Part E., Geological Survey of Canada, Paper 92-1A, p. 33-39.
- Jones, A.P., Smith, J.V., Dawson, J.B. and Hansen, E.C. 1983. Metamorphism, partial melting, and K metasomatism of garnet-scapolite-kyanite granulite xenoliths from Lashaine, Tanzania. Journal of Geology v. 91, 143-165.
- Kerr, F.A. 1926. Dease Lake area, Cassiar District, B.C. in Geological Survey of Canada Summary Report, 1925, Part A, p. 75 - 99.
- Littlejohn, A.L. & Greenwood, H.J. 1974. Lherzolite nodules in basalts from British Columbia, Canada. Canadian Journal of Earth Sciences, v.11, 1288-1308.
- Mathews, W.H. 1947. "Tuyas", flat-topped volcanoes in northern British Columbia; American Journal of Science, v. 245, 560-570.
- Moore, J.G., Hickson, C.J. and Calk, L. 1995. Tholeiitic-alkalic transition at subglacial volcanoes, Tuya region, British Columbia; Journal of Geophysical Research, Solid Earth. (in press)
- Mortensen, J.K. & Roddick, J.C. 1989. Miocene ^{40}Ar - ^{39}Ar and K-Ar ages for basaltic volcanic rocks in southwestern Dawson map area, western Yukon Territory. in Radiogenic Age and Isotopic Studies: Report 3, Geological Survey of Canada, Paper 89-2, 17-22.
- Nicholls, J. & Stout, M.Z. 1996. Basaltic lava flows and enclosed xenoliths as samples of the lithosphere and low velocity zone beneath northern British Columbia, a progress report. in Cook, F. & Erdmer, P. (compilers), 1996 Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary, Lithoprobe Report No. 50, 109-115.
- Nicholls, J., Stout, M.Z., and Fiesinger, D.W. 1982. Petrologic variations in Quaternary volcanic rocks, British Columbia, and the nature of the underlying upper mantle; Contributions to Mineralogy and Petrology, v. 79, 201-218.
- O'Neill, H.St.C. 1981. The transition between spinel lherzolite and garnet lherzolite and its use as a geobarometer. Contributions to Mineralogy and Petrology, v.77, 185-194.
- O'Reilly, S.Y. & Griffin, W.L. 1994. Moho and crust-mantle boundary coincide under southeastern Australia: comment, Geology, v.22, 666-667.
- O'Reilly, S.Y. & Griffin, W.L. 1996. 4-D Lithosphere mapping: methodology and examples, Tectonophysics, v. 262, 3-18.
- Pollack, H.N. & Chapman, D.S. 1977. On the regional variation of the heat flow, geotherms and lithospheric thickness. Tectonophysics v.38, 279-296.
- Prescott, J. 1983. Petrogenesis of ultramafic xenoliths from the Canadian Cordillera and Alaska. unpublished M.Sc., McGill University, 185p.
- Read, P.B. & Psutka, J.F. 1985. Quaternary and Late Tertiary volcanism, Stikine River project area, British Columbia. unpublished BCHydro report. 62p.
- Ross, J.V. 1983. The nature and rheology of the Cordilleran upper mantle of British Columbia: inferences from peridotite xenoliths. Tectonophysics, v. 100, 321-357.
- Simpson, K. 1996. The geology, geochemistry and geomorphology of Mathews Tuya: a subglacial volcano in northwestern British Columbia. unpub. B.Sc. thesis, University of British Columbia. 97 p.

- Sinclair, P.D., Templeman-Kluit, D.J. & Medaris, L.G. Jr. 1978. Lherzolite nodules from a Pleistocene cinder cone in central Yukon. *Canadian Journal of Earth Sciences*, v. 15, 220-226.
- Souther, J.G. 1971. Telegraph Creek map-area, British Columbia. *Geological Survey of Canada Paper* 71-44, 38p.
- Souther, J.G. 1977. Volcanism and tectonic environments in the Canadian Cordillera - a second look. in *Volcanic Regimes in Canada*, W.R.A. Baragar, L.C. Coleman and J.M. Hall (eds.). *Geological Association of Canada, Special Paper* 16, 3-24.
- Souther, J.G. 1991e. Maitland. in *Volcanoes of North America*, C.A. Wood & J. Kienle (eds.). *Cambridge University Press: New York*. 126-127.
- Souther, J.G. 1992. The late Cenozoic Mount Edziza Volcanic Complex, British Columbia; *Geological Survey of Canada, Memoir* 420, 320 p.
- Souther, J.G., and Yorath, C.J. 1991. Neogene assemblages. Chapter 10 in *Geology of the Cordilleran Orogen in Canada*. H. Gabrielse and C.J. Yorath (ed.); *Geological Survey of Canada. Geology of Canada*. no. 4. 373-401.
- Stasiuk, M. & Russell, J.K. 1989. Quaternary volcanic rocks of the Iskut River region, northwestern British Columbia. in *Current Research, Geological Survey of Canada Paper* 90-1E, p. 153-157.
- Thorkelson, D. J. 1992. Volcanic and tectonic evolution of the Hazelton Group in the Spatzizi River (104H) map-area, north-central British Columbia. unpub. Ph.D. thesis, Carleton University, Ottawa, 281p.
- Trupia, S. 1992. Petrology of nephelinites and associated ultramafic nodules of Volcano Mountain, Yukon Territory. M.Sc. thesis, University of Calgary, 123p.
- Trupia, S. and Nicholls, J. 1996. Petrology of Recent lava flows, Volcano Mountain, Yukon Territory, Canada. *Lithos* v. 37, 61-78.
- Watson, K. De P. & Mathews, W.H. 1944. The Tuya-Teslin area, northern British Columbia. *British Columbia Department of Mines Bulletin* No. 19.
- Watson, K. De P. & Mathews, W.H. 1948. Partly vitrified xenoliths in pillow basalt; *American Journal of Science*, v. 244, p. 601-614.
- Wirth, K.R. 1991. Processes of lithosphere evolution: geochemistry and tectonics of mafic rocks in the Brooks Range and Yukon-Tanana region, Alaskan. Ph. D. thesis, Cornell University.

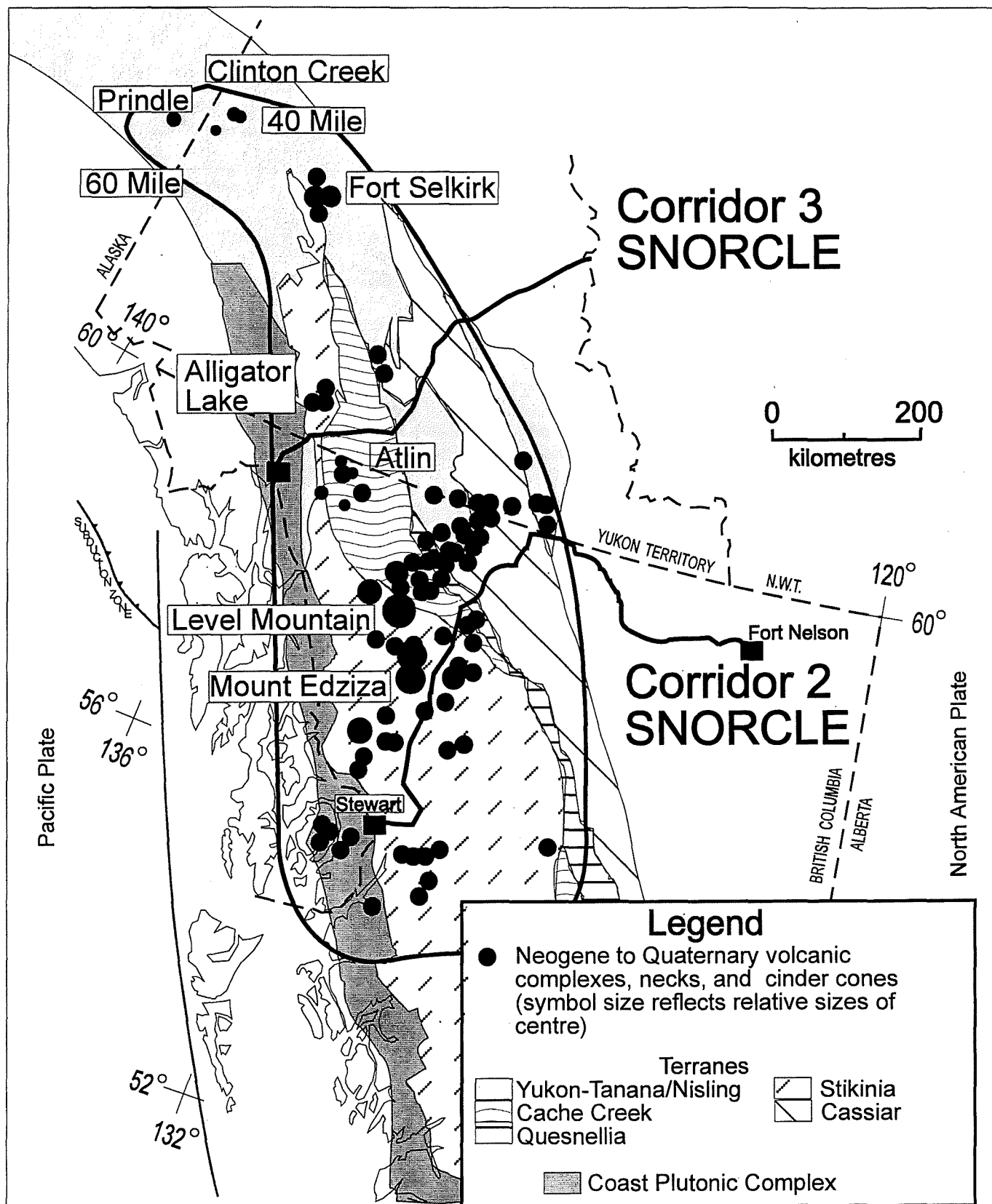


Figure 1. Location of Quaternary volcanic centres within the Northern Cordillera Volcanic Province (Edwards & Russell 1997). Corridors 2 and 3 for the SNORCLE Transect are shown in bold lines.

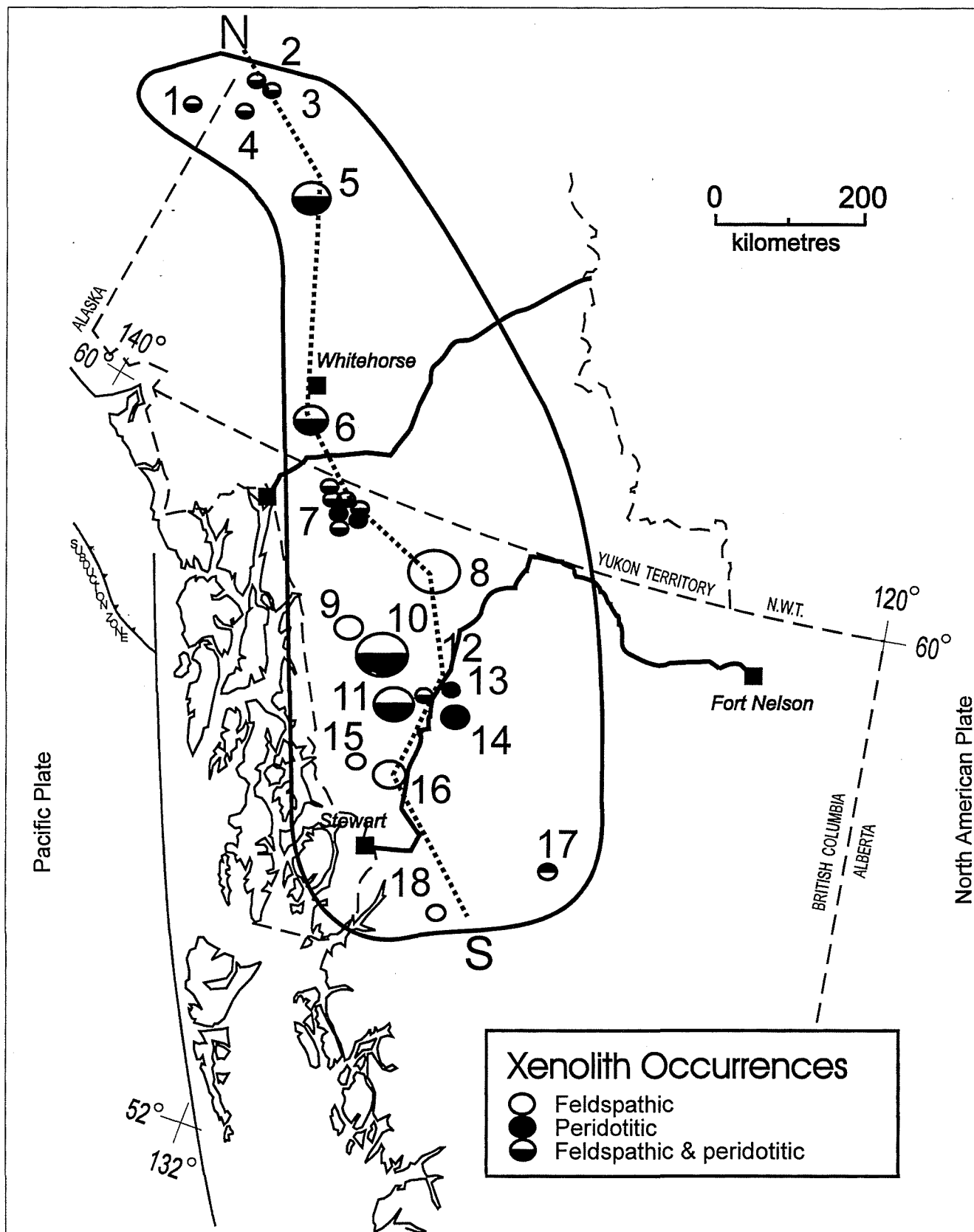


Figure 2a. Distribution of xenoliths in the NCVP. Heavy lines are SNORCLE Transects 2 and 3. Dotted line is line of section used in Figure 4a and b. Numbers of centres are given in Table 1.

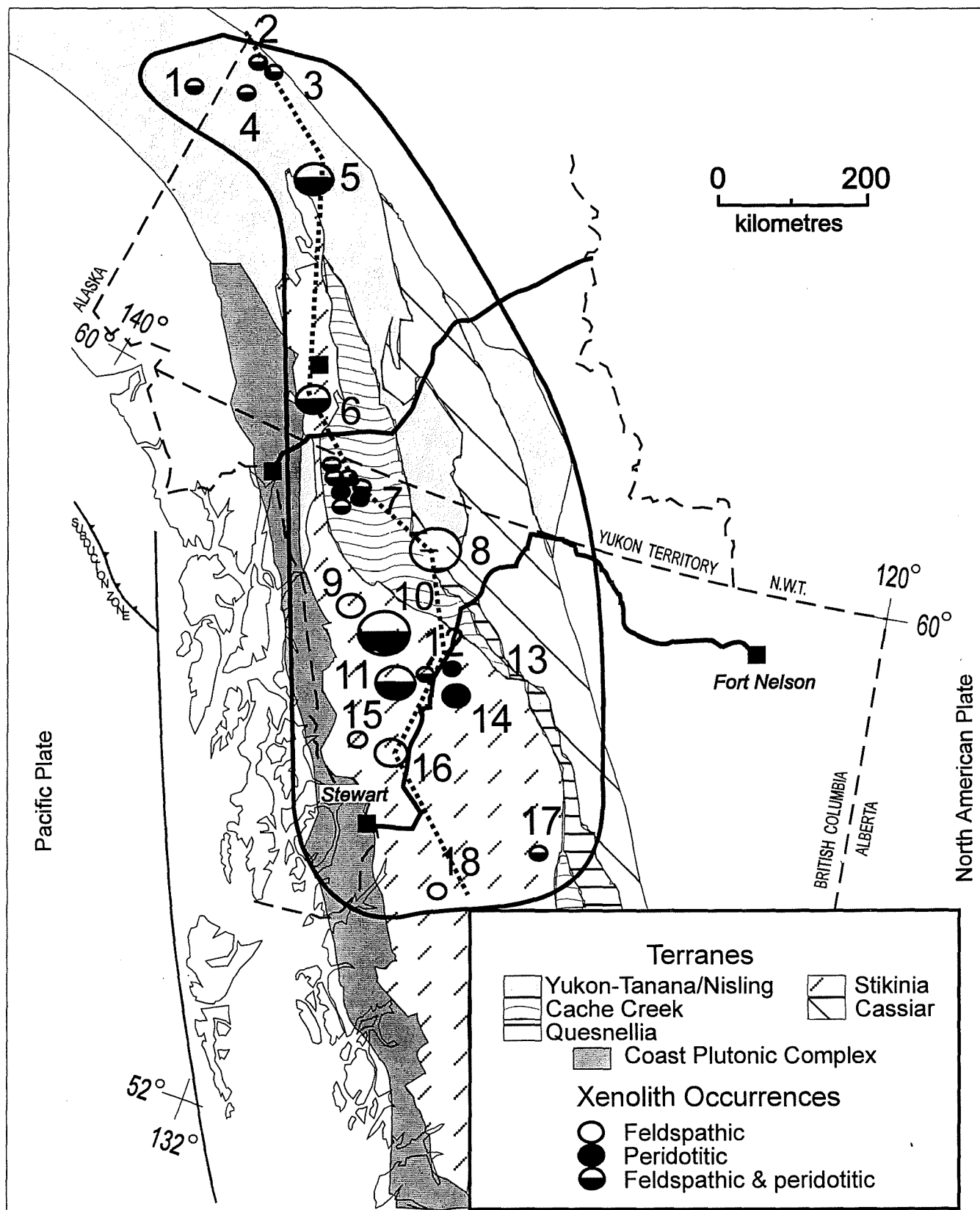


Figure 2b. Distribution of xenoliths in the NCVP with respect to major terrane boundaries (refer to Table 1 for key to numbered locations). Simplified terrane boundaries from Mortensen (Per. Comm., 1996).

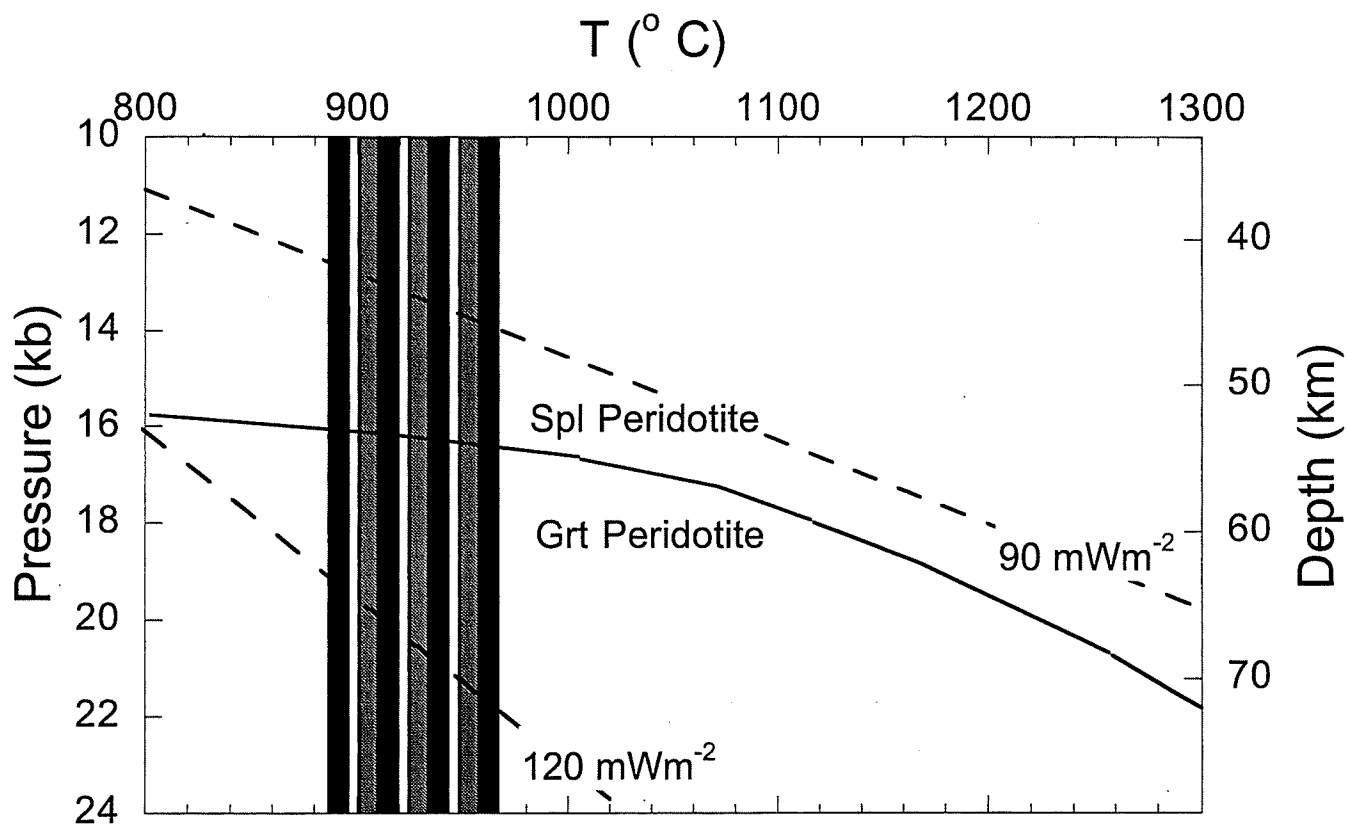


Figure 3. Temperature estimates using Wells (1977) two pyroxene geothermometer for felsic granulites (grey; this study) and spinel lherzolites (black; Prescott 1983). Dashed lines are representative geothermal gradients.

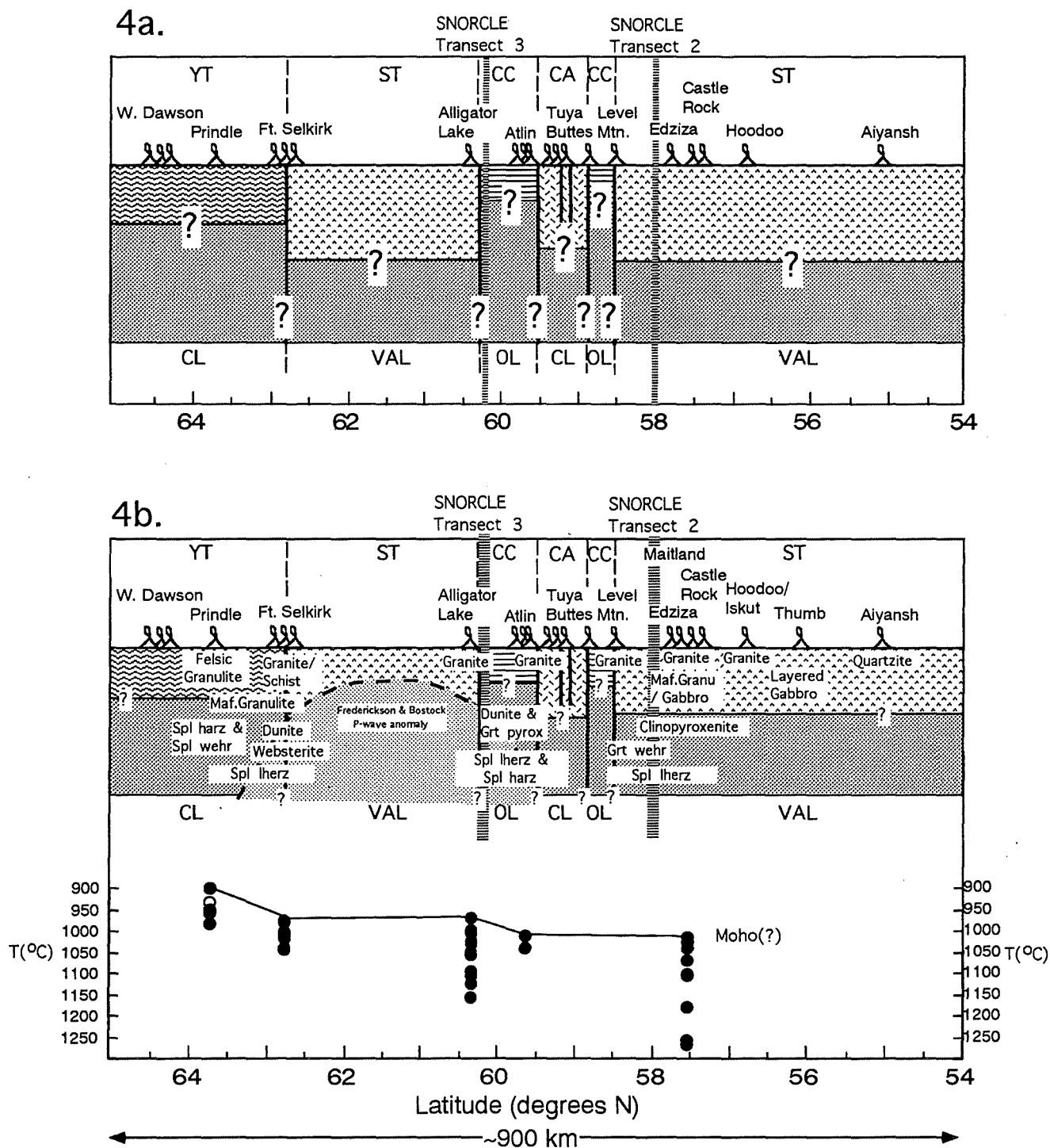


Table 1. Summary of xenolith-bearing magmatic centres in the Northern Cordilleran Volcanic Province based on this work and the literature. Numbers correspond to labels in Figures 2a and 2b.

Volcanic centre	Terrane	Types of xenoliths/inclusions	References
Prindle (1)	Yukon-Tanana	spinel lherzolite, spinel harzburgite, spinel wehrlite, mafic granulite, felsic granulite, clinopyroxene xenocrysts	23, 63, 64, 93
West Dawson volcanic field (including 60 Mile(4), Clinton Creek (2), 40 Mile (3))	Yukon-Tanana	peridotite, sedimentary rocks, granite	62
Fort Selkirk Volcanic Complex (5) (including Volcano Mountain, Wootton's Cone/Ne Che Dhwaha, Fork Selkirk, Pelly Formation, Wolverine Formation)	Yukon-Tanana / northern Stikinia	spinel lherzolite, websterite, dunite, granitoids, schist, xenocrysts (quartz, feldspar, olivine, spinel, Cr-diopside, enstatite)	25, 26, 28, 49, 50, 67, 68, 85, 86
Alligator Lake Volcanic Complex (6)	northern Coast Plutonic Complex / Stikinia	spinel lherzolite, spinel harzburgite, granite	17, 18, 19, 20
Atlin volcanic field (7) (Ruby Mountain, Cracker Creek, Volcano Creek, Chikoida Mountain, Hirschfeld Creek/Line Lake, Llangorse Mountain)	northern Cache Creek	dunite, spinel lherzolite, spinel harzburgite, websterite, garnet pyroxenite, gabbro, granite, granodiorite, clinopyroxene/olivine/ spinel xenocrysts	8, 9, 16, 29, 48
Tanzilla volcanic field (8) (Ash Mountain, 3 Caribou tuya, Mathew's tuya, South tuya, Kawdy Mountain)	Cache Creek/Cassiar	granite, granodiorite, troctolite	47, 60, 87, 88
Heart Peaks volcanic complex (9)	northern Stikinia	possible xenocrysts	10, 11
Level Mountain volcanic complex (10)	northern Stikinia	spinel lherzolite, garnet wehrlite, gabbro, granitic gneiss, sedimentary rocks, clinopyroxene xenocrysts	30, 35, 36, 37, 38, 39, 40, 41
Stikine River (19)	northern Stikinia	granite, peridotite; Cr-diop, opx, ol, spl, pl, qtz, & alkali fsp xenocrysts,	92
Castle Rock volcanic field (12)	northern Stikinia	spinel lherzolite, granite, gneiss, gabbro, dunite, mafic granulite	56, 67, 71
Mount Edziza volcanic complex (11)	northern Stikinia	hornblende biotite granite, gabbro, peridotite(?)	77
Thatue Mountain (13)	northern Stikinia	peridotite, clinopyroxenite	92
Maitland volcanic field (14) (Maitland Creek, Kunigus Creek, Tumeka Lake and Griffith Creek)	northern Stikinia	peridotite, feldspathic xenoliths	21, 22, 76, 84, 92
Hoodoo Mountain volcanic complex (15) (Little Bear mountain)	northwestern Stikinia	granite and syenite; clinopyroxene xenocrysts	13, 14, 15
Iskut-Unuk rivers volcanic field (16) (Lava Fork, Iskut River, Snippaker Creek, King Creek, Cone Glacier)	northwestern Stikinia	gabbro, granulite, granitic gneiss and schist; plagioclase & clinopyroxene xenocrysts	4, 12, 43, 44, 45, 53, 81
Aiyansh (18)	western Stikinia	quartzite(?)	(this work)
The Thumb (17)	central Stikinia	layered gabbro	65

^a - Key to numbered references is as follows: 4 - BC Hydro (1985); 8 - Carignan et al. (1994); 9 - Carignan et al. (1995); 10 - Casey (1980); 11 - Casey & Scarfe (1980); 12 - Cousens & Bevier (1995); 13 - Edwards & Russell (1994a); 14 - Edwards & Russell (1994b); 15 - Edwards et al. (1995); 16 - Edwards et al. (1996); 17 - Eiché (1986); 18 - Eiché et al. (1985a); 19 - Eiché et al. (1985b); 20 - Eiché et al. (1987); 21 - Evenchick (per. comm., 1995); 22 - Evenchick & Thorkelson (1993); 23 - Foster et al. (1966); 24 - Francis et al. (1996); 25 - Francis (1987); 26 - Francis (1991a); 27 - Francis (1991b); 28 - Francis & Ludden (1990); 29 - Francis & Ludden (1995); 30 - Gabrielse (1968); 31 - Gabrielse (1969); 32 - Gabrielse (1978); 33 - Gabrielse & Tipper (1984); 35 - Hamilton (1981); 36 - Hamilton (1991); 39 - Hamilton & Scarfe (1976); 40 - Hamilton & Scarfe (1977); 41 - Hamilton et al. (1978); 42 - Hasik et al. (1993); 43 - Hauksdóttir (1994); 44 - Hauksdóttir et al. (1994); 45 - Hauksdóttir & Russell (1994); 47 - Hickson (per. comm., 1995); 48 - Higgins & Allen (1984); 49 - Jackson (1989); 50 - Jackson & Stevens (1992); 56 - Littlejohn & Greenwood (1974); 60 - Moore et al. (1995); 61 - Mortensen (1992); 62 - Mortensen & Roddick (1989); 65 - Nicholls & Stout (1996); 66 - Nicholls et al. (1982); 67 - Prescott (1983); 68 - Ross (1983); 69 - Simpson (1996); 70 - Sinclair et al. (1978); 76 - Souther (1991e); 77 - Souther (1992); 81 - Stasiuk & Russell (1989); 84 - Thorkelson (1992); 85 - Trupia (1992); 86 - Trupia & Nicholls (1996); 87 - Watson & Mathews (1944); 88 - Watson & Mathews (1948); 91 - Wuorinen (1978); 92 - Read & Psutka (1985); 93 - Wirth (1991)

Deformation Processes Along the Denali Fault System

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The objectives of this project are three-fold: (1) evaluation of the of kinematic and displacement records along the Denali fault system, particularly in SW Yukon; (2) examination of fault rock textures and fabrics to establish mechanical and chemical processes characteristic of upper crustal deformation; (3) comparison of deformation processes and P/T constraints with geophysical data, particularly seismic records, in the context of the rocks being records exhumed from a still-active seismogenic zone.

The initial field season of the study (1996) encompassed a regional survey of rocks along the Denali fault system from White River, Yukon ($140^{\circ} 35'W$, $62^{\circ}00'N$) to Mansfield Creek, B.C. ($136^{\circ} 40'W$, $59^{\circ}52'N$). The first-order exercise was to examine bedrock exposures as close to the fault trace as possible, given that, as is typical of the northern Cordilleran transcurrent fault zones, the Denali Fault trace is buried beneath Quaternary sediments or Alpine tundra for much of its strike-length. Such exposures are largely within Pennsylvanian through Cretaceous rocks of the Wrangell terrane (Campbell & Dodds 1982a,b,c, 1983). Initial emphasis was placed on identifying the youngest deformation possible within these rocks in order to avoid Jura-Cretaceous deformation (Eisbacher 1976) that may not relate directly to the current behaviour of the Denali fault system.

The intensity of deformation within Wrangell rocks between the Denali (Shakwak and Dalton faults) and Duke River faults is both variable, and in general, more intense than anticipated from existing descriptions of the rocks. Foliation is typically penetrative, producing a transposed compositional layering to which the lithostratigraphic contacts form enveloping surfaces. These regional fabrics vary from steep and northwest-striking near the south end of Kluane Lake to more south to southwest-dipping, northwest of the Duke River ($139^{\circ}05'W$, $61^{\circ}25'N$). The steep fabrics have asymmetry in their synoptic patterns that is consistent with dextral displacement along the Denali Fault. As one approaches the fault trace, the foliation patterns become symmetrical with respect to it, suggesting more intense transposition by higher strains near the fault. The fabrics north of Duke River show no obvious relationship with inferred transcurrent movement, but rather could be related to north or northeast thrusting, for which there is evidence in the Quill Creek area (T. Bremner, pers. comm.). Lineations that might relate to transport are not routinely observed. A few good stretching lineations are observed north of Duke River sub-parallel to the Denali Fault trend, but the relationship of these to local geometries could not be ascertained (i.e. the relationship to the fault orientation may be fortuitous).

The regional foliation is cut by both normal and reverse faults, though in general, normal faulting is youngest. Thrust faults have not been identified as showing consistent patterns of orientation or sense of displacement. The most obvious normal faults trend sub-parallel to the Denali Fault trace. These can vary from discrete brittle features with fine calcite veining through to metre-thick gouge zones i.e. there is a complete range from young to mature faults. The early foliation can be overprinted by a cleavage parallel to the Denali Fault trace e.g. a steep, northwest -trending cleavage. This is observed in the field, but is most clearly seen in thin section. In intensely deformed zones, quartz mylonites defining the earlier foliation (often derived from syntectonic quartz veining) are commonly overprinted by younger cataclastic deformation, indicative of protracted deformation relevant to the fault zone. The most intense deformation, particularly discrete faults, are associated with extensive carbonate veining and/or are localized within carbonate horizons. Cataclasites and unindurated gouges equally show evidence of repeated carbonate injection and subsequent deformation. The extremely high twin densities observed

in calcite reflect high differential stress typical of upper crustal deformation. Samples closest to the Denali Fault trace show excellent twin boundary migration and recrystallization; the latter is somewhat paradoxical, as the low greenschist metamorphic grade is not anticipated to favour such features. Calcite mylonites were found at the base of Sheep Mountain (138° 32'W, 61°02'N) along Kluane Lake near Denali-parallel faults.

The best exposed sections of distinct fault rocks occur along the Duke River Fault. Along the eroded cliffs of Bullion Creek (138° 40'W, 60°59'N), a zone of gouge and cataclasite 100m wide is exposed. This is of particular interest given the high seismicity in this area (Horner 1983, Canadian National Earthquake Database 1980-96), including a M5.2 earthquake in June 1995 sited at 138°24'W, 60°59'N. The fault zone comprises metre-scale compositional layer typical of large, mature fault zones. These layers are themselves cut by vertically emplaced carbonate veins, now in various degrees of dismemberment. Phyllite-like gouge on the northwest edge of the fault zone consists of 1- 10 μ m grain size quartz, calcite and minor sericite. The fault rocks grade into progressively more carbonate-rich material to the southeast until what has been mapped as a massive limestone (Campbell & Dodds 1982a) is reached. In thin section, the limestone is a highly strained mylonitic rock, itself cut by carbonate veins.

The Duke River Fault serves as the boundary between the Alexander terrane and Wrangellia and is interpreted as a east verging thrust contact (Wheeler and McFeely 1991), but its current geometry indicates it to be either a strike-slip or normal fault given the formation of vertical hydraulic fractures (carbonate veins) that define the σ_1 - σ_2 plane. Where examined, these rocks showed no lineation in the field. Further study of hand specimens suggests a weak sub-horizontal lineation, but it has not yet been ascertained whether it relates to tectonic transport direction.

The abundant evidence for suprahydrostatic fluid paleopressures in the form of vein arrays is of note because it may mirror the current hydrologic environment in the seismogenic zone.. An optimally oriented fault can be estimated to have a strength defined by $\sigma_1 = 4 \cdot \sigma_3$ (e.g. Sibson 1990). Assuming vertical stress equals σ_2 and $\sigma_2 = \sigma_3$ for strike-slip then the differential stress at failure, $\sigma_1 - \sigma_3 = 3 \cdot$ vertical stress. At 5 km depth, typical of the June 1985 earthquake, overburden pressure corresponds to approximately 250 MPa, giving a strength of 750 MPa. This is unrealistic given that even a differential stress of 100 MPa would correspond to the high range of observed stress drops in earthquakes. Using 100 MPa as an upper limit of differential stress, a $\lambda \equiv$ fluid pressure/overburden pressure = 0.87 can be back-calculated. Lower strength would require larger λ . Hence, these exhumed faults may prove to be excellent analogues to the active faults at depth to which we have no direct access. Comparison can be made through examination of the earthquake catalogue which shows a distinct cutoff indicative of the brittle-ductile transition at about 18 km. Calculations of required stress states for either thrusting or transcurrent displacements likewise requires $\lambda \approx 0.9$

Samples retrieved from exactly along the mapped trace of the Denali Fault in Dalton Creek (137°16'W, 60°20'N) from Triassic volcanic rocks (Nicolai Fm.) at the contact with Jura-Cretaceous arc-related sedimentary rocks (Dezdeash Fm.) exhibit minimal deformation with preservation of primary ophitic texture. This would require either extreme localization of the estimated 300 km of dextral displacement or accommodation of the displacement through distributed deformation within Jura-Cretaceous rocks. Previous mapping (Eisbacher 1976, Campbell & Dodds 1982c) indicates an apparent truncation of large-scale fold structures in the Dezdeash Fm. This appears to be an up to 5 km wide zone of transposition adjacent to the Denali Fault, with preferential accommodation in the sedimentary as opposed to igneous units. Re-evaluation of fold and cleavage data (Campbell & Dodds 1982c) shows re-orientation of folded bedding, as well as folding of cleavage about a sub-horizontal northeast axis that is consistent with dextral transpression. This apparent transition from sinistral to dextral asymmetry has been discussed by Eisbacher (1976), with recent extension of the ideas by Evenchick (1996).

Gouge zones that are oriented NNE to NE, parallel to the local topography and at high angles to the NW Denali Fault trend provide possible evidence of neotectonic to recent displacements. These gouge zones occur within normal faults that effectively define the faces of major topographic lineaments e.g. Slims River. Because they occur sub-parallel to active slope faces, their probability of survival in the record after exhumation is deemed to be low.

Earthquake records for 1980-1996 (Canadian National Earthquake Database) have been examined in conjunction with faults as mapped in the original regional mapping of the St. Elias area. The seismic records have been sampled by magnitude, depth and time to determine what relationships might exist with the surface geology. The most striking feature is the close relationship between mapped structure and seismic activity irrespective of the age of the rocks. The abrupt cessation of seismicity at about 18 km is bracketed by deeper events beneath the St. Elias Mt. thrusts and at the Denali/Duke River faults, indicating a major crustal break at this points, consistent with a 2000 km long lineament. Fault displacement transfers are evident between the Duke River and Denali faults,, with seismicity concentrated at their intersections. The Slims River seismicity concentration correlates with the abrupt transfer of seismicity away from the main northwesterly Denali trend to the more westerly Duke River system, combined with events parallel to the NNE-trending Slims River topographic lineament along which gouges occur. The westerly seismic concentration in the Cement Ck. area shows distinctly dipping rupture planes suggestive of thrusts, comparable to those of Power (1988). Thrusting would be kinematically anticipated given the strong bend in the Totschunda-Duke River fault system away from the main predicted transcurrent displacement direction. What is surprising is that the mapped deformation fabrics independently suggest N-NE trending thrusts, arguing for a close relationship between the surface geology and the current tectonic framework. Similarly, the distribution of deformation along the Denali fault within the weaker Dezdeash Fm. rocks corresponds to an existing disseminated seismicity. A feature that repeatedly appears in reviewing the earthquake records is a SE trending lineament extending from the junction of the Totschunda-Duke River faults to the Fairweather Fault. Various arguments have been made for and against an extension of the Totschunda Fault through the Icefield Ranges (e.g. Lanphere 1978; Lahr & Plafker 1980; Power 1988), but the observed correlations of faults with seismicity in other areas would argue strongly for the existence of an Icefield Ranges seismic zone that could be interpreted as a young propagating transfer zone representing the continued outboard migration of displacement in the northern Cordillera.

REFERENCES

- Campbell, R.D. & Dodds, C.J. 1982a. Geol. Surv. Can Open File 829.
Campbell, R.D. & Dodds, C.J. 1982b. Geol. Surv. Can Open File 830.
Campbell, R.D. & Dodds, C.J. 1982c. Geol. Surv. Can Open File 831.
Campbell, R.D. & Dodds, C.J. 1983. Geol. Surv. Can Open File 926.
Eisbacher, G.H. 1976. Can. J. Earth Sci. 13, 1459-1513.
Evenchick, C.A. 1996. In Lithoprobe Report No. 50, 190.
Horner, R.B. 1983. Bull. Seismol. Soc. Am. 73, 1117-1137.
Lahr, J.C. & Plafker, G. 1980. Geology 8, 483-486.
Lanphere, M.A. 1978. Can. J. Earth Sci. 15, 817-822.
Power, M.A. 1988. Unpub. M.Sc. Thesis, Dept. of Physics, U. Alberta, 125 pp.
Sibson, R.H. 1990. Min. Assoc. Can. Short Course vol. 18., 93-132.
Wheeler, J.O. & McFeely, P. (comp.) 1991. Tectonic Assemblage Map of the Canadian Cordillera. Geol. Surv. Can. Map 1712A, Scale 1:2 000 000.

Metamorphic evolution of the northwestern Coast Belt of the North American Cordillera: constraints from petrographic and geothermobarometric studies of the Kluane metamorphic assemblage in the southwest Yukon

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Abstract

The Kluane metamorphic assemblage (KMA) is situated at the northwestern margin of the Coast Belt of the North American Cordillera, between pericratonic terranes to the east, and the Insular superterrane to the west. Two major metamorphic events can be distinguished in aluminous schists of the KMA. A high P-low T event M_1 is preserved in grossular-rich garnets with spiral-shaped graphitic inclusion trails, implying synkinematic growth. Absence of synkinematic staurolite restricts maximum T during M_1 to less than 525°C. A low P-high T event M_2 is related to the Ruby Range Batholith (RRB), part of the Coast Plutonic Complex. A 5 km thick contact aureole has developed in the KMA, ranging from lower amphibolite (staurolite) away from the contact to lower granulite grade (garnet-cordierite-K-feldspar-sillimanite) near the contact. Thermal recrystallization overprinted existing fabrics in the schist and resulted in grain size coarsening towards the intrusive contact. No major deformation is associated with M_2 . Geothermobarometry and garnet core composition imply minimum P of at least 5-6 kbar during M_1 , corresponding to a depth of 15-18 km. P-T during M_2 are 3.5-4.5 kbar and 640-680°C, indicating emplacement of the RRB at depth of 12 km.

Timing of M_1 is poorly constrained. Coeval metamorphism and deformation suggest accretion of the KMA onto the North American continental margin occurred during sinistral transpression in Late Jurassic to Late Cretaceous. Peak metamorphism of M_2 is contemporaneous with the Early Eocene crystallization of the RRB.

This study shows that the metamorphic evolution of the KMA differs from similar assemblages west of the Denali fault in eastern Alaska. Proposed post-Eocene right lateral offset of 400 km along the Denali fault, based on correlation of metamorphic assemblages in the Yukon and eastern Alaska, has to be reconsidered.

Introduction

The Kluane metamorphic assemblage (KMA) consists of aluminous and calcic mica-quartz schists with interlayered olivine serpentinite lenses. It is situated at the northwestern margin of the Coast Belt of the North American Cordillera, between pericratonic metamorphic assemblages of North American affinity to the east and volcanic rocks and volcanoclastic sediments of the Insular Superterrane to the west (Figure 1). Contact relationships are obscured by faults to the west and the Ruby Range Batholith (RRB) to the east.

Regional mapping by McConnell (1905), Kindle (1952) and Muller (1967) assigned the KMA, previously known as the "Kluane Schist", to the Precambrian "Yukon Group". Eisebacher (1976) interpreted the KMA as the metamorphosed equivalent of the Dezadeash Formation (DF), part of the Late Jurassic - Early Cretaceous Gambier overlap assemblage.

More recent studies by Tempelman-Kluit (1974) and Erdmer (1990, 1991) recognized the homogeneity of

the mica-quartz schist of the KMA, distinguishing it from the more heterogeneous metamorphic assemblages of the Nisling terrane (Aishihik Metamorphic Suite, Nisling assemblage). Marble and quartzite, which occur in these assemblages and imply continental proximity, are not present in the KMA. Tempelman-Kluit (1974) observed regionally metamorphosed schist in the southern Aishihik Lake map sheet was thermally overprinted by the RRB. Erdmer (1991) reported a single period of deformation and sillimanite grade metamorphism of the eastern KMA. Geochronological dating of mica-quartz schists of the KMA yield ages of 40-57 Ma, interpreted as cooling ages related to the Paleocene - Eocene intrusion of the RRB and subsequent uplift (Stevens et al., 1982; Farrar et al., 1988; Mortensen & Erdmer, 1992).

Recent microtectonic and neodymium analyses have shown that the protolith of the KMA is not of North American affinity, but originated in a backarc basin, and was accreted to the North American continental margin during sinistral transpression (Mezger, 1996; Mezger & Creaser, 1996).

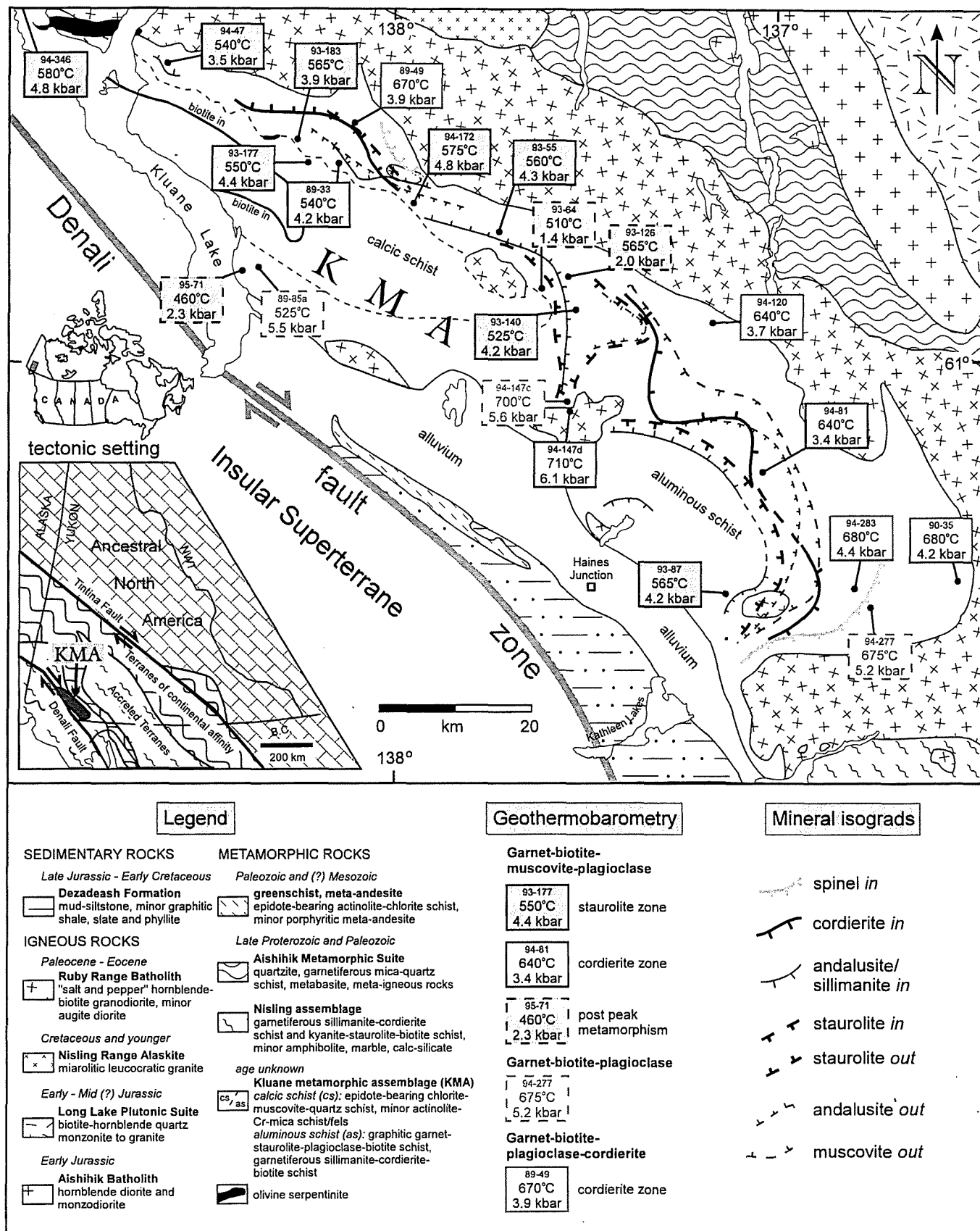


Figure 1: Mineral isograds and geothermobarometry of the Kluge metamorphic assemblage, SW Yukon. Geothermobarometry samples are plotted on a petrogenetic grid on figure 2. The geology is partly modified after Kindler (1952), Muller (1967), Wheeler & McFeely (1991), Dodds & Campbell (1992) and Johnston & Timmerman (1993). The geology west of the Denali fault is not shown.

This paper presents new constraints on the metamorphic evolution of the northwestern Coast Belt, based on detailed petrographic and geothermobarometric studies of the KMA.

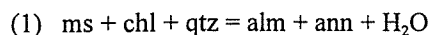
Metamorphic mineral zones of the KMA

The distinct feature of the KMA mica-quartz schists is the presence of up to 1 cm large plagioclase (An_{23-36}) porphyroblasts. Minute graphitic inclusions in plagioclase are interpreted as traces of original bedding and give the porphyroblasts a grey appearance. The mica schists can be subdivided into *calcic* schist, with epidote and clinozoisite, and an *aluminous* pelitic schist, with garnet, staurolite, andalusite/sillimanite and cordierite. The sheet silicates that define foliation in the calcic schist are chlorite and muscovite, while biotite is the dominant mica in the aluminous schist. Orientation of schistosity is similar in both schist types, suggesting an original stratigraphic contact or a faulted contact prior to the development of the major foliation.

Mineral assemblages described below were obtained by petrographic studies and electron microprobe analyses of over 150 thin sections. The first or last observance, in a prograde sense, of a mineral is shown as "in" or "out" isograds on Figure 1.

The metamorphic character of the KMA is best described in the northwestern part, where schistosity homogeneously dips to the NNE, and its strike parallels the contact with the RRB.

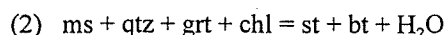
The area east of Kluane Lake is underlain by the calcic epidote-bearing chlorite-muscovite schist. Biotite is absent along the lake shore. The first appearance of biotite, overgrowing foliation, thus indicating postkinematic growth, can be traced as a biotite isograd, 15-20 km away from the exposed contact with the RRB. The appearance of garnet indicates a change in bulk rock composition from the calcic to the aluminous sequence. Chloritoid, which would form at lower T than garnet in pelitic rocks, is absent. The change in bulk rock composition also coincides with an increase of biotite abundance, caused by increasing metamorphic temperatures. Presence of garnet indicates T of 500°C according to reaction¹ (Figure 2):



Spiral-shaped graphitic inclusion trails preserved

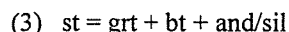
in garnets near the calcic/aluminous contact yield a sense of shear consistent with C/S fabrics in the same samples. This indicates synkinematic growth of garnet.

Staurolite is the first true prograde mineral that can be identified in the aluminous sequence, 9 km away from the intrusive contact. It marks the beginning of the amphibolite facies (~525°C). As a result of the staurolite-forming reaction:



chlorite is completely consumed and muscovite reduced to an accessory phase, while biotite is being produced. The consumption of garnet implies that the rims of garnets are not in chemical equilibria with other minerals. This has to be considered when interpreting geothermobarometry calculations of staurolite zone samples (see below). Euhedral staurolite occurs in a 2 km wide zone.

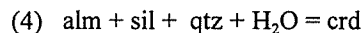
Andalusite and sillimanite appear simultaneously as poikilitic porphyroblast and as small acicular fibrolite, respectively. Staurolite decreases in abundance (10 to <1 vol.%) and commonly occurs as anhedral small relics (< 250µm) mantled by andalusite. Aluminosilicates are produced by the consumption of staurolite:



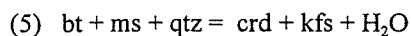
Fibrolite growing at the rim of andalusite indicates replacement of andalusite, thus implying prograde metamorphism. The staurolite-out reaction coinciding with the replacement of andalusite by fibrolitic sillimanite indicates P-T of 2.5 kbar and 580°C (Figure 2). Coexisting fibrolite and andalusite are common in the KMA.

Cordierite, which forms porphyroblasts up to 3 mm in length, changes the appearance of the KMA rocks from well foliated schist to more gneissic rock.

Cordierite-formation involves the consumption of almandine and sillimanite:



and biotite and muscovite:



However, reaction (5) did not contribute to the bulk of cordierite, as K-feldspar, a by-product of that reaction has only been observed in a few cordierite-bearing samples.

Muscovite, which is a reactant in reaction (2), is completely consumed by reaction (5). As a result most cordierite schist samples do not contain any primary muscovite. Muscovite observed in these samples is the result of retrograde alteration of garnet or cordierite.

Within 1-2 km of the contact with the RRB,

1: Note that reactions are not balanced. alm: almandine, and: andalusite, ann: annite, bt: biotite, chl: chlorite, crd: cordierite, hc: hercynite, kfs: K-feldspar, ms: muscovite, qtz: quartz, sil: sillimanite

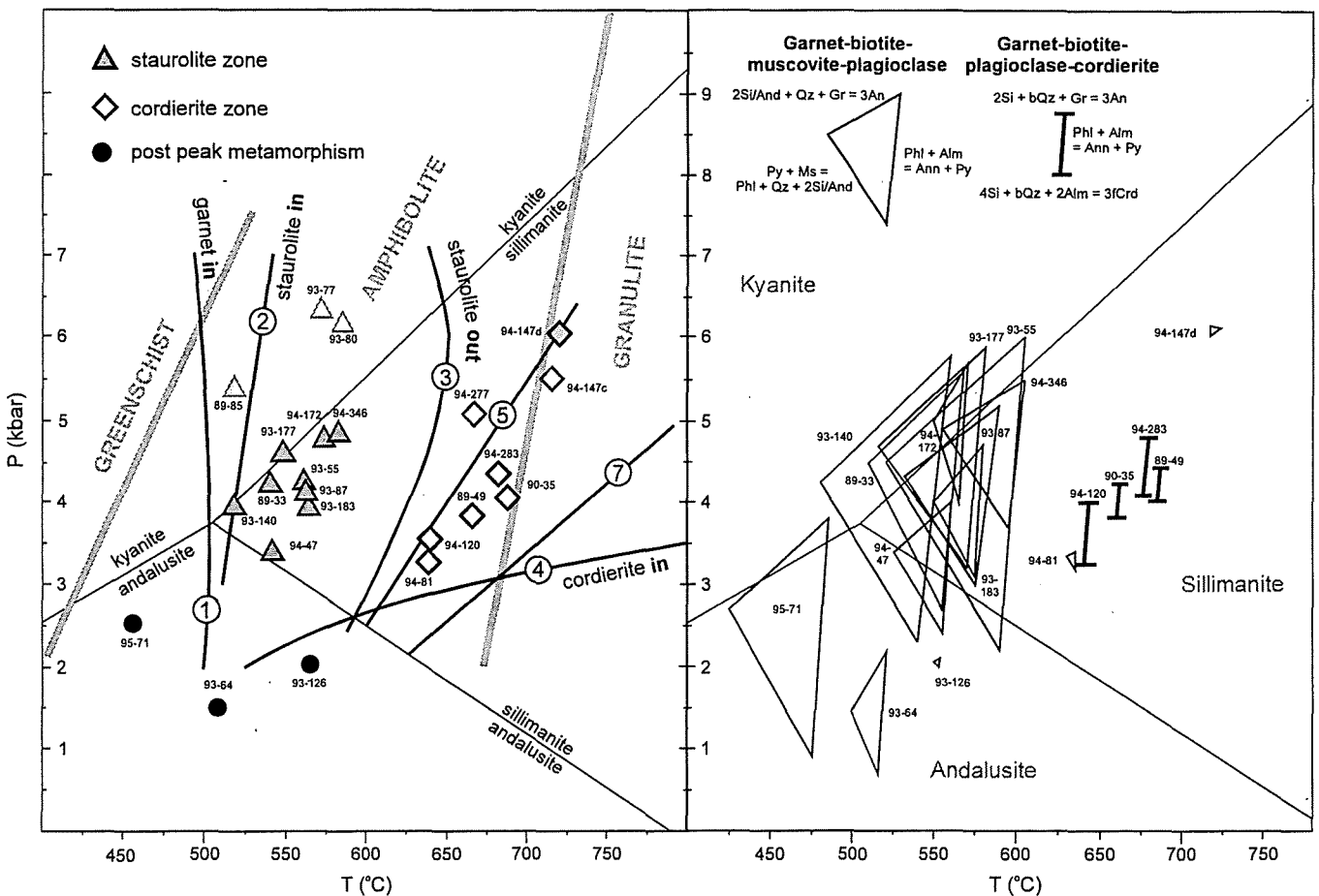


Figure 2: P-T estimates of mica-quartz schist of the Kluane metamorphic assemblage. Staurolite-bearing samples are plotted as triangles. Their P-T is estimated from an intersection triangle of reaction equilibria calculated by the program TWQ (2.02), using the garnet-biotite-muscovite-plagioclase assemblage, and shown on the right grid. P-T of the cordierite-bearing samples (diamonds) were obtained from the garnet-biotite-plagioclase-Fe-cordierite assemblage, since primary muscovite is generally absent. The intersections of the reaction equilibria do not result in a triangle, but form a bar. Samples shown in grey only have two reactions intersecting at one point, which is a good pressure constrain. Estimates from those samples are less reliable. The location of important mineral reactions discussed in the text are plotted on the left grid. Reactions 1, 3-5 and 7 are after Bucher & Frey (1994). Reaction 2 is after Spear and Cheney (1989). The aluminosilicate triple point is from Holdaway & Mukhopadhyay (1993). Facies division is after Bucher & Frey (1994).

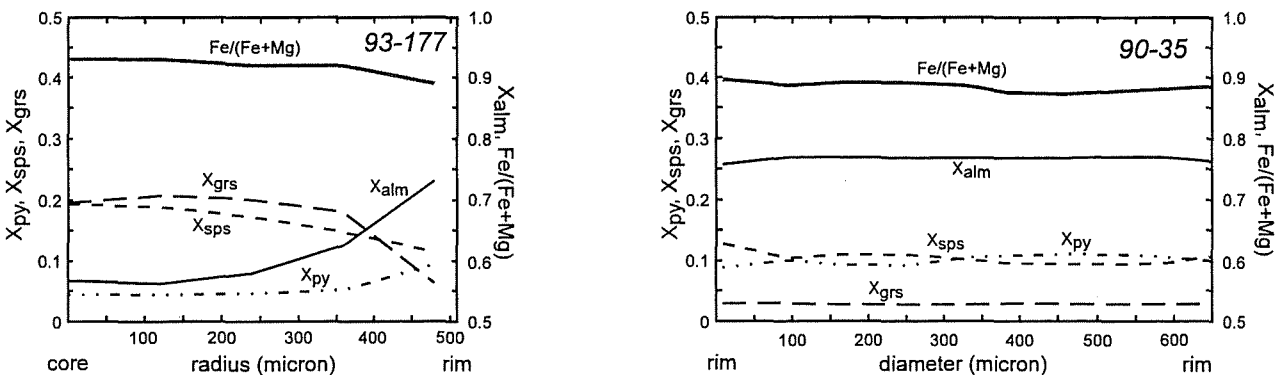
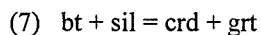


Figure 3: Compositional cross-sections of garnets. **Left:** Growth zonation in a garnet from the staurolite zone. The decrease in Mg (grs=grossular end member) and increase in Fe (alm= almandine) from core to rim indicates decompression and heating during growth of the crystal. **Right:** A garnet of the cordierite zone displays no obvious zoning, indicating temperatures in excess of 600°C, at which diffusion homogenizes the garnet crystal. Sps and py stand for spessartine and pyrope, respectively.

hercynite, a Fe-rich spinel, nucleates in core of cordierite, and is commonly surrounded by sillimanite. A possible hercynite-forming reaction is (Chacko, pers.com., 1997):



The highest grade metamorphic mineral assemblage in the KMA is realized in the easternmost area of the KMA (90-35, Figure 1). It consists of cordierite-sillimanite-K-feldspar-garnet. New euhedral garnet can be observed, formed according to reaction:



This assemblage is indicative of the lowermost granulite facies, 670°C at 3 kbar.

The shape of the mineral isograds in the KMA parallels the contact with the RRB. Towards the eastern portion of the KMA, the isograds are deflected by several intrusive granodiorite plugs that are part of the RRB and are widened (Figure 1).

Post-peak deformational thermal overprinting is indicated by: 1) coarsening of the grain size in the schist, 2) overprinting of foliation and lineation near the contact with the RRB and 3) fibrolite and cordierite overgrowing undeformed crosscutting quartz veins in the schist.

Geothermobarometry

P-T estimates were obtained from 23 samples of the aluminous schist of the KMA. Samples of the calcic schist are not suitable, since they lack the essential garnet. Mineral compositions of garnet, biotite and plagioclase, plus muscovite for staurolite zone samples and cordierite for cordierite zone samples were obtained by electron microprobe analyses.

P and T of each sample were estimated from intersections of mineral equilibria calculated and plotted by the computer program TWQ 2.02 (Berman, 1996). TWQ 2.02 is a DOS-based program that calculates the position of equilibria reactions using an internally consistent set of thermodynamic data. The convergence of all possible reaction curves in a single point is P-T space is regarded as the equilibration point of all minerals involved (Berman, 1991). The tightness of the intersection can be regarded as an indicator of the quality of the state of equilibrium in the specific sample. It is not to be confused with uncertainty. The composition of garnet rims, which are most likely in chemical equilibrium with other minerals, was chosen for the P-T calculations.

Reactions calculated for staurolite zone samples form an intersection triangle, while reactions calculated for cordierite zone samples form a bar. P and T for each

sample is then graphically estimated from the center of the intersection triangle or the bar (Figure 2).

The P-T results obtained by TWQ reactions generally agree with petrographic observations. All staurolite zone samples plot in the staurolite stability field, while cordierite-bearing samples plot at higher T. Reliable results of staurolite samples yield P between 3.5 and 5 kbar, with T around 550°C. Higher P (>6 kbar) are obtained from several samples. However, the spread of the reaction intersections is wide ($\pm 3-4$ kbar, not shown on Figure 2), suggesting that the garnet rim is not in equilibria with the other minerals in the matrix. This is the result of consumption of garnet during the formation of staurolite (see previous section). In thin sections, garnets appear embayed and their rims corroded.

Most of the analyzed staurolite zone samples contain andalusite, which is being formed at higher temperatures (>600°C), as the result of staurolite breakdown reaction (3). In general, T obtained from staurolite zone garnet rims underestimate the peak metamorphic T, since garnets stopped growing.

Compositional cross-sections of staurolite zone garnets show distinct growth zonation (Figure 3). Mg abundance decreases from $X_{\text{grs}}20$ to $X_{\text{grs}}5$, while Fe increases from $X_{\text{alm}}57$ to $X_{\text{alm}}74$, from core to rim. This zoning is indicative of heating and decompression during growth of the garnet (Spear, 1993). P conditions during the formation of the garnet core were likely higher than those obtained for rim composition. However, it is not possible to calculate garnet core P-T, since other minerals involved in the calculation have re-equilibrated during later low P-high T event, and the calculated reaction equilibria are therefore meaningless.

Cordierite zone samples cluster between 3.5 to 4.5 kbar and 640-680°C. P is slightly higher than to be expected from the major cordierite-forming reaction (5). However, high Mg content of cordierite can shift the reaction to higher P.

Compositional cross-sections of cordierite zone garnets show no obvious zoning, indicating diffusional homogenization, which is effective at T above 600°C. The high Fe-content ($X_{\text{alm}} > 75$) and low Ca-content ($X_{\text{grs}}3$) are indicative of low P-high T conditions. In thin sections these garnets generally do not have graphitic inclusions and their rims are less corroded than staurolite zone garnets.

Low P (<2.5 kbar) and low T (<575°C) obtained from three samples can not be related to any major metamorphic event, and are may represent late local thermal events during uplift. This is supported by their euhedral shape and small size (<250µm).

The highest P (6.1 kbar) and T (710°C) is recorded in a garnetiferous granodiorite of a RRB plug, located immediately at the contact with the KMA (Figures

1 and 2, 94-147d). It indicates equilibration of that sample at depths greater than the other samples of the KMA.

P-T-t paths

Petrography and geothermobarometry of the KMA can be summarized in a P-T-t path (Figure 4). The first event M_1 is a high P-low T metamorphism coeval with the major deformation. M_1 is preserved in synkinematic garnets and grossular-rich garnet cores, that were not overprinted by later thermal events. Peak P conditions during M_1 can not be calculated, but Ca-rich garnet cores imply that P was greater (>6 kbar, 18 km depth) than the estimates obtained from garnet rim composition (4-5 kbar). Maximum T did not exceed 525°C, at which staurolite is being produced by reaction (2), restricting M_1 to the upper greenschist facies. The

timing of M_1 is not well constrained. Direct dating by geochronology is not possible, since all ages are reset by M_2 . Regional constraints suggest that it occurred between Late Jurassic and Late Cretaceous (see below).

High P-low T metamorphism was followed by decompression and isobaric heating, as indicated by the mineral zones described above. Geothermobarometry and petrographic analyses show that this low P-high T event M_2 occurred at 3-4.5 kbar, corresponding to depth of 9-13 km. M_2 is related to the intrusion of the RRB, as obvious in the large contact aureole in the KMA. U-Pb monazite and xenotime ages of 55-57 Ma for KMA schist, date the time at which these rocks cooled below 700 and 650°C, the respective closure temperatures (T_c) for U (Mortensen & Erdmer, 1992). T_c of monazite and xenotime are similar to thermometry results reported above, suggesting that the U-Pb ages date peak metamorphism. These ages are similar to the crystallization age of the RRB (50-58 Ma,

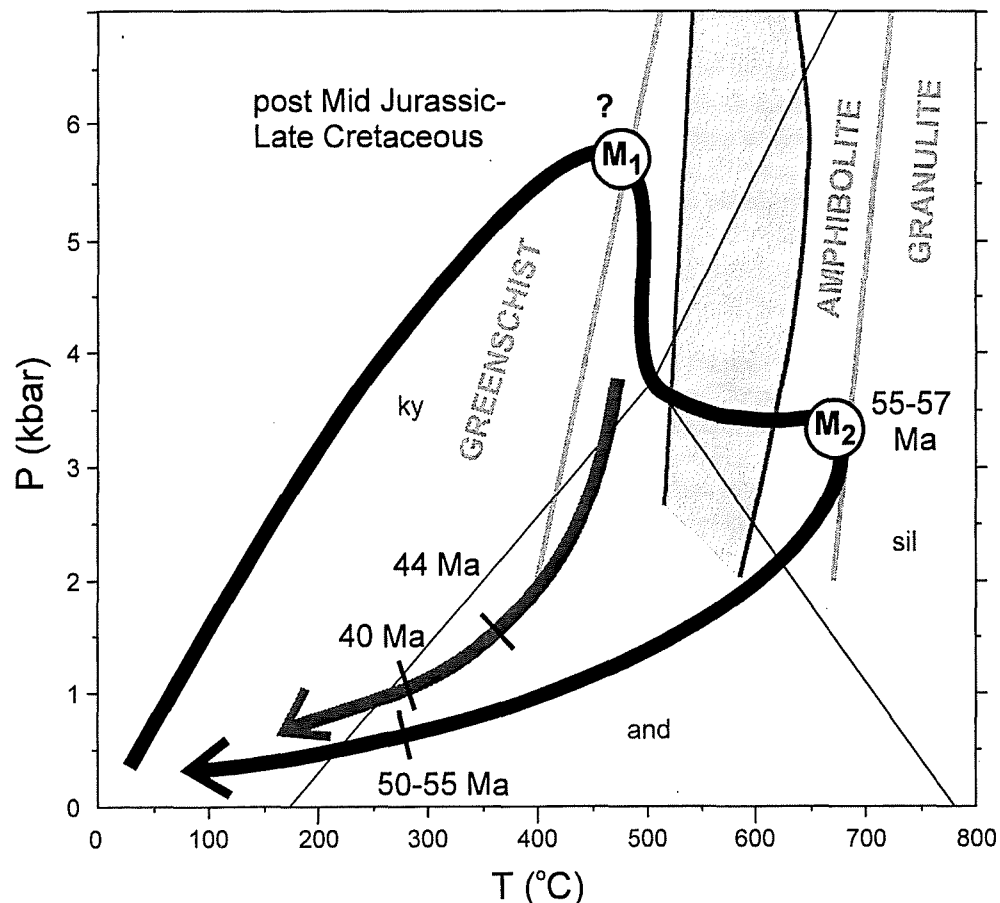


Figure 4: P-T-t paths with observed metamorphic events for the KMA. Black line outlines P-T-t path of high grade rocks close to the contact with the Ruby Range Batholith. Grey line describes path of low grade rocks from Kluane Lake shore. Staurolite stability field is shaded grey. Age constraints of M_2 are from U-Pb dating of monzonite and xenotime in biotite-quartz schist of the KMA (Mortensen & Erdmer, 1992) and date peak metamorphic conditions. Cooling ages are determined by $Ar^{40}-Ar^{39}$ in muscovite (350°C) and K-Ar in biotite (280°C) (Stevens et al., 1982; Mortensen & Erdmer, 1992).

Mortensen & Erdmer, 1992). K-Ar biotite (T_c 280°C) ages of 50-55 Ma in the same schist samples indicate rapid cooling and uplift of higher grade rocks (Mortensen & Erdmer, 1992).

The P-T-t path for lower grade KMA rocks in the southwest is slightly different (grey line in Figure 4). The effect of the M_2 is not reflected in the mineral assemblage. Ar^{40} - Ar^{39} muscovite and biotite ages of 44 and 40 Ma indicate slower cooling and uplift of the lower grade rocks in the southwest, compared to the high grade assemblages to the northeast and east (Mortensen & Erdmer, 1992). This can also explain the absence of biotite in those rocks, where time was sufficient for retrograde chlorite to replace biotite.

The clockwise P-T-t path described above and shown on Figure 4 is typical for burial of relatively cool rocks (Platt, 1986). The relatively cool rocks deflect the geotherm, thus experiencing high P- low T. Longer duration at great depth (tens of Ma ?) relaxes the geotherm and isobaric heating will commence (Spear, 1993). However, no high P-high T mineral assemblages are observed in the KMA, suggesting that uplift to depths of 9-13 km followed quickly after burial.

Metamorphic evolution of the Coast Belt in the southwestern Yukon

High P-high T mineral assemblage (kyanite-staurolite) are preserved in the pericratonic metamorphic assemblages northeast and southeast of the KMA, the Aishihik Metamorphic Suite (AMS) and the Nisling assemblage. The minimum age of metamorphism is given by Aishihik Batholith, which intruded the AMS at depth of 30 km in the Early Jurassic (186 Ma, Johnston et al., 1996). The AMS experienced immediate rapid uplift to 6 km and repeated burial in the Middle Jurassic (165 Ma, Johnston et al., 1996). The absence of high P-high T mineral assemblages and mid-Mesozoic intrusions in the KMA, suggest that accretion and subsequent M_1 -metamorphism of the KMA occurred after the Middle Jurassic.

Contact aureoles in the KMA, AMS and NS ascribed to the RRB indicate that the KMA was already attached to the North American continental margin by Late Paleocene. Underplating of the KMA underneath the AMS is suggested by: 1) a thicker contact aureole in the KMA (5 km) than in the AMS (~1 km, Johnston, pers.com., 1996), and 2) northward-dipping schistosity of the KMA and the AMS, and the exposed margins of the RRB.

The RRB was emplaced as a southward-verging sill along the contact between the KMA and AMS. A major post-emplacement tilt is unlikely, since no significant P-gradient can be observed (Figure 1). Higher P (6 kbar) recorded at a RRB plug in the southwest (94-

147d) suggest a second sill-like body, partly covered by the KMA, that intruded the KMA at greater depth (18 km).

Some geological observations allow to constrain the time of accretion, deformation and M_1 -metamorphism in the KMA:

1) Late Cretaceous (68 Ma) ages of phyllites of the Dezadeash Formation (DF) and granodiorites of the Coast Plutonic Complex (CPC) are interpreted as the time of intrusion of the CPC into the DF (LeCouteur & Tempelman-Kluit, 1975; Farrar et al., 1988, Lowey, pers. comm., 1995). This suggests that the DF was already attached to North America by the Late Cretaceous. Since the DF is situated southwest or outboard of the KMA, the KMA had to be attached to the continental margin prior to the Late Cretaceous.

2) Evidence of sinistral motion along a proto-Denali fault is found in the consistent sense of shear of C/S fabrics in the lower grade KMA schists (Mezger & Creaser, 1996). NNE-trending contractional structures in the DF are interpreted by Evenchick (1995) as results of a NW-trending sinistral shear zone. The minimum age of the DF (135 Ma) and structural crosscutting plutons (106 Ma) constrain the time of motion. A sinistral Late Jurassic accretion of the Insular Superterrane onto North America and subsequent sinistral faulting in the Early Cretaceous is proposed by Monger et al. (1994). This is in agreement with relative southeast convergence of the Kula plate with North America between 95 and 150 Ma (Engelbreton et al., 1995).

The accretion of the KMA onto North America could have occurred as early as Late Jurassic (165 Ma). The development of sinistral shear sense indicators is constrained by the duration of sinistral motion in the latest Jurassic to Early Cretaceous. M_1 -metamorphism, which at least partly overlaps with deformation, probably occurred at the youngest possible time (90-100 Ma). Earlier burial would have resulted in high P-high T mineral assemblages in the KMA by the time the RRB intruded in the Eocene.

Conclusions

The protolith of the KMA was deposited in a backarc basin setting, distal to a continental margin (Mezger & Creaser, 1996). Accretion onto the North America occurred as early as Late Jurassic as a result of the accretion of the Insular superterrane. Shear sense indicators in the KMA show that accretion and/or subsequent deformation occurred in a sinistral transpressional regime, along a proto-Denali fault. Burial to a minimum depth of 18-20 km is recorded in garnet core composition. Spiral-shaped inclusions show that M_1 -metamorphism and deformation were coeval. Static thermal overprinting of the KMA, caused by the sill-like

south-verging emplacement of the RRB along the contact between the KMA and the AMS, occurred during or after uplift in Late Paleocene, at a depth of 12 km.

The interpretation of the KMA as a metamorphosed equivalent of the DF, as proposed by Eisbacher (1976) does not hold in the light of geochemical and isotope data (Mezger, 1996). The metamorphic grade of the KMA does not decrease towards the contact with the DF, contrary to Eisbacher. Upper amphibolite grade KMA schist are juxtaposed to subgreenschist grade DF slate.

The KMA has been correlated with the MacLaren Glacier Metamorphic Belt (MGMB), west of the Denali fault in the eastern Alaska Range, on the base of similar structural and metamorphic evolution. This correlation has been called upon to propose a 400 km dextral offset along the Denali fault in post-Eocene time (Forbes et al., 1973; Nokleberg et al., 1985). However, early Eocene penetrative deformation of the MGMB and Late Cretaceous intrusions clearly post-dates peak deformation in the KMA (Nokleberg et al., 1985). Together with different stratigraphy, it is suggested that the KMA and the MGMB can not be correlated. Consequently, calculations of dextral displacement along the Denali fault have to be reconsidered.

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References

- Berman, R.G. (1991): Thermobarometry using multiequilibrium calculations: a new technique, with petrologic applications.- *Can.Mineral.* **29**, pp. 833-855.
- Berman, R.G. (1996): TWQ (version 2.02).
- Bucher, K & Frey, M. (1994): Petrogenesis of Metamorphic Rocks.- 318 p., Springer-Verlag.
- Dodds, C.J. & Campbell, R.B. (1992): Geology of NE Yakutat (114O) and Tatshenshini River (114P) map areas, British Columbia.- *Geol.Sur.Can.Open File* **2191**.
- Eisbacher, G.H. (1976): Sedimentology of the Dezadeash flysch and its implications for strike-slip faulting along the Denali Fault, Yukon Territory and Alaska.- *Can.J.Earth Sci.* **13**, pp. 1495-1513.
- Engelbreton, D.C., Kelley, K.P., Burmester, R.F., Russell, R. & Blake, M.C. (1995): North American Plate Interactions Re-revisited.-*Geol.Assoc.Can.Min.Assoc.Can.Abstr. Programs* **20**, p. A 28.
- Erdmer, P. (1990): Studies of the Kluane and Nisling assemblages in Kluane and Dezadeash map areas, Yukon.- *Current Research, Part E, Geological Survey of Canada, Paper* **90-1E**, pp. 107-111.
- Erdmer, P. (1991): Metamorphic terrane east of Denali fault between Kluane Lake and Kusawa Lake, Yukon Territory.- *Current Research, Part A, Geological Survey of Canada, Paper* **91-1A**, pp. 37-42.
- Evenchick, C.A. (1995): Structural evidence of Early Cretaceous sinistral displacement in the Northern Canadian Cordillera.-*Geol.Assoc.Can.Min.Assoc.Can.Abstr. Programs* **20**, p A 30.
- Farrar, E., Clark, A.H., Archibald, D.A. & Way, D.C. (1988): Potassium-Argon age of granitoid plutonic rocks, southwest Yukon Territory, Canada. *Isochron/West* **51**, pp. 19-23.
- Forbes, R.B., Smith, T.E. & Turner, D.L. (1973): Comparative petrology and structure of the MacLaren, Ruby Range and Coast Range belts: Implications for offset along the Denali fault system.-*Geol.Soc.Am.Abstr.Programs* **6**, p. 177.
- Holdaway, M.J. & Mukhopadhyay, B. (1993): A reevaluation of the stability relations of andalusite: thermochemical data and phase diagram for the aluminium silicates.- *Am.Mineral* **78**, pp. 298-315.
- Johnston, S.T. & Timmerman, J.R. (1993): Geology of the Aishihik Lake and Hopkins Lake Map areas (115 H6/7), southwestern Yukon.- *Yukon Exploration & Geology* **1993**, pp. 93-110.
- Johnston, S.T., Mortensen, J.K. & Erdmer, P. (1996): Igneous and metaigneous age constraints for the Aishihik metamorphic suite, southwest Yukon.- *Can.J.EarthSci.* **33**, pp. 1543-1555.
- Kindle, E.D. (1952): Dezadeash map-area, Yukon Territory.- *Geological Survey of Canada Memoir* **268**, 68 p.

- Le Couteur, P.C. & Tempelman-Kluit, D.J. (1976): Rb/Sr Ages and a profile of initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios for plutonic rocks across the Yukon Crystalline Terrane.- *Can.J.EarthSci.* **13**, 319-330.
- McConnell, R.G. (1905): The Kluane Mining District.- *Geol.Surv.Can. Annual Report* **16**, pp. 1A-18A.
- Mezger, J.E. (1996): The Kluane Metamorphic Assemblage, SW Yukon - an accretionary wedge of backarc basin affinity.- *Geol.Assoc.Can.Min.Assoc.Can.Abst.Programs* **21**, p. A 65.
- Mezger, J.E. & Creaser, R.A. (1996): Backarc basin setting of the Kluane Metamorphic Assemblage and sinistral strike-slip along a proto-Denali fault: Evidence from isotope and microtectonic studies in the SW Yukon.- *Geol.Soc.Amer. Abstr.Programs.* **28** (7). p. A 312.
- Monger, J.W.H., van der Heyden, P., Journeay, J.M., Evenchick, C.A. & Mahoney, J.B. (1994): Jurassic-Cretaceous basins along the Canadian Coast Belt: Their bearing on pre-mid-Cretaceous sinistral displacements.- *Geology* **22**, pp. 175-178.
- Mortensen, J.K. & Erdmer, P. (1992): U-Pb, Ar-Ar and K-Ar Ages for Metamorphism of the Kluane and Aishihik Assemblages in Southwestern Yukon.- *Radiogenic Age and Isotopic Studies; Report 6; Geological Survey of Canada, Paper* **92-2**, pp. 135-139.
- Muller, J.E. (1967): Kluane lake map-area, Yukon Territory (115G, 115F E1/2). *Geological Survey of Canada Memoir* **340**, 137 p.
- Nokleberg, W.J., Jones, D.L. & Silberling, N.J. (1985): Origin and tectonic evolution of the Maclaren and Wrangellia terranes, eastern Alaska, Alaska.- *Bull.Geol.Soc.Am.* **96**, pp. 1251-1270.
- Platt, J.P. (1986): Dynamics of orogenic wedges and uplift of high-pressure metamorphic rocks.- *Geol.Soc.Amer.Bull.* **97**, pp. 1037-1053.
- Spear, F.S. (1993): Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths.- *Mineral.Soc.Amer.Monograph*, 799 p.
- Spear, F.S. & Cheney, J.T. (1989): A petrogenitic grid for pelitic schists in the system SiO_2 - Al_2O_3 - FeO - MgO - K_2O - H_2O .- *Contrib.Mineral.Petrol.* **101**, pp. 149-164.
- Stevens, R.A, Delabio, R.N. & Lachance, G.R. (1982): Age determinations and geological studies - K-Ar Isotopic Ages, Report 16.- *Geological Survey of Canada, Paper* **82-2**, pp. 15-26.

Geological data cannot rule out large scale (>1000 km) transcurrent motion across the Coast orogen.

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The Coast shear zone (Fig. 1) forms a crustal-scale boundary between segments of the Coast Ranges that record different structural, metamorphic, and intrusive histories. It is a candidate deep crustal structure for large scale (>1000 km) transcurrent strike-slip motion at the time of postulated northwards translation of the Insular superterrane between 85 and 60 Ma. The range of published U/Pb pluton dates (83-48 ma) within the central gneiss complex (CGC), which is located between the Coast shear zone and the Stikine terrane (Fig. 2a), overlaps the time of the postulated transcurrent motion. We therefore include the entire CGC as a region where the transcurrent motion could occur, on horizontal as well as vertical structures.

Postulated plate motions between 85 and 60 Ma were transpressive. Because the rocks of the CGC were at mid to lower crustal depths during the late Cretaceous and early Tertiary, and were being intruded by plutons during that interval, this region deformed ductily during the transpression. The interplay of transpression and ductile flow, and periodic intrusion of plutons, will produce a complex strain field, with strain partitioned in space and time. Hence, recognizing large scale orogen parallel displacement across such a gooey mess is difficult.

One goal of ACCRETE (<http://geo.princeton.edu/accrete/accrete.html>) is to focus the collective expertise of metamorphic and structural geologists to this problem. Its resolution is extremely important: if we can identify how the lower crust behaves during transpressive deformation, we will better understand how crustal scale strike-slip faults work.

Our work to date suggests the following:

- 1) Near vertical, high-strain zones occur along the Coast shear zone for >800 km. Two phases of deformation are recognized within it; the earliest deforms 65 Ma plutons and involved dominantly coaxial shear strains with northeast-southwest directed flattening. The second deformation, with a date of about 55 Ma, produced steep to sub-vertical fabrics and a kilometer-scale dextral deflection of older fabrics along the west side of the CGC. The east-side-down component of the oblique-dextral shear couple model is probably due to crustal relaxation following cessation of compressive deformation. The minimum dextral component, which is indicated by deformation in the wall rock of the shear zone only, is on the order of 10s of km.

2) Further east, within the CGC, pre 58 Ma (a date of the Quottoon pluton, Fig. 2a) deformation involved generally top to the south thrusting (Fig. 2b). This thrusting appears to have occurred from at least 83 Ma until perhaps 58 Ma. Fabrics formed by this thrusting predate the coaxial strain mentioned above, which may be manifest in folds of the thrust fabric with upright axial planes. A high T/P metamorphic overprint on moderate pressure rocks occurred late in the thrusting history and was probably related to exhumation of the hot, thick thrust pile.

A 3 km thick dextral transcurrent ductile shear zone with a dip-slip component has been identified at the eastern margin of the Quottoon pluton (Fig. 2a). The north-south extent of the shear zone is currently unknown; it has a minimum length of 25 km. It trends to the north-northeast, and mainly predates intrusion of the Quottoon pluton, although it probably overlapped final crystallization. Transport direction inferred for the shear zone from c/s intersections plunges 2° to 022° . In contrast, the mean stretching lineation plunges 31° to 340° . This apparent contrast in transport directions is likely to be due to partitioning of transpressive strain, and/or rotation of mineral lineations. In the southeastern mapped portion of the shear zone, lineations plunge about 40° NNW and fabrics dip steeply to the east and west. Dextral shearing was synchronous with the formation of sheath folds with fold axes parallel to the mineral stretching lineations in this area. Refolded folds within this zone suggest that movement on this shear zone largely post-dates thrusting, although formation of sheath folds appears to have been contemporaneous with a portion of the thrusting. Thus, transcurrent motions were partitioned both horizontally and vertically within the shear zone and adjacent areas. The 3 km width of the shear zone and the intensity of fabrics developed within the shear zone suggest a minimum strike-slip displacement on the order of tens of kilometers.

3) Along the east side of the CGC is the Shames mylonite zone mapped by Heah (1991); it is over 4 km thick (Fig. 2b) and may be traceable north to northeasterly along the east side of the Coast Mountains up to Portland Inlet. Kinematic indicators show down-dip motion, and we interpret the shear zone as a major extensional fault. It is mainly cut by, or underlies, a belt of 50 Ma plutons. The lower contact of the detachment zone dips moderately east and cuts the top to the south thrust fabric at a low angle. Although mostly ductile, this shear zone formed at lower temperature than the earlier thrust deformation, based on microstructures. Its activity is constrained to be before 48 Ma and after 65 Ma. This overlaps the time interval of rapid cooling of the CGC.

This paper is a progress report on the geologic component of a coordinated attempt to place limits on estimates of where, when, and how much orogen parallel motion occurred within the Coast orogen. At present, the geologic data are highly suggestive that a large amount of strike-slip displacement could have occurred across the CGC during the time interval postulated for such displacement by paleomagnetic arguments. We emphasize (1) the low angle ductile thrusting which may represent lower crustal transfer of strike-slip motion across the orogen, (2) the plutons that intruded during deformation which must have produced a heterogeneous stress field leading to complex strain fields and reorientations of structures including lineations, and (3) the Shames detachment that obliterated earlier kinematic indicators of strike-slip or thrust displacements.

The dramatic contrast in pluton and cooling ages across its western boundary and the contrast of structural history between the CGC and adjacent blocks require major faulting along its margins and emphasize the importance of the CGC in the late Cretaceous to early Tertiary history of western North America.

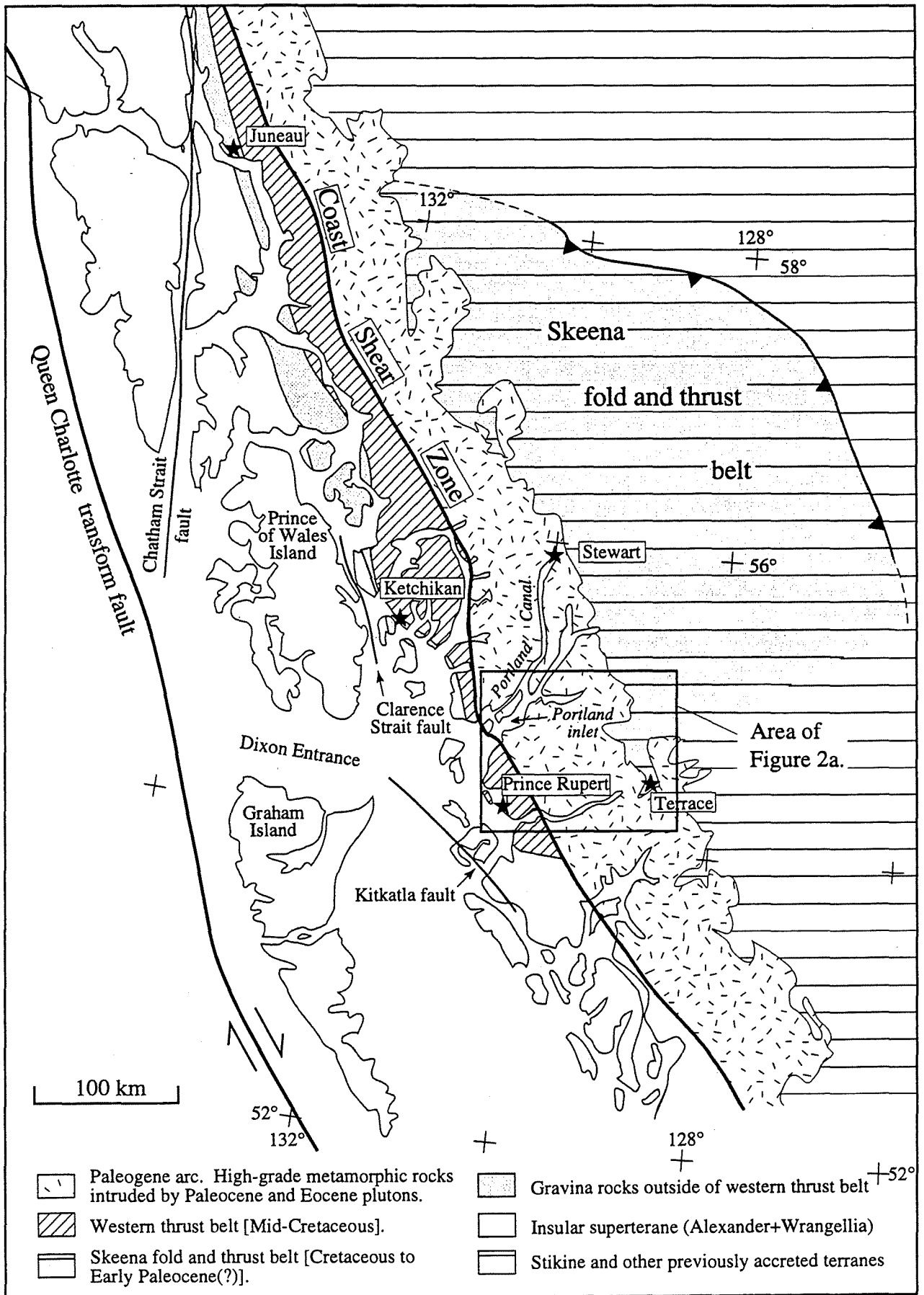


Figure 1.

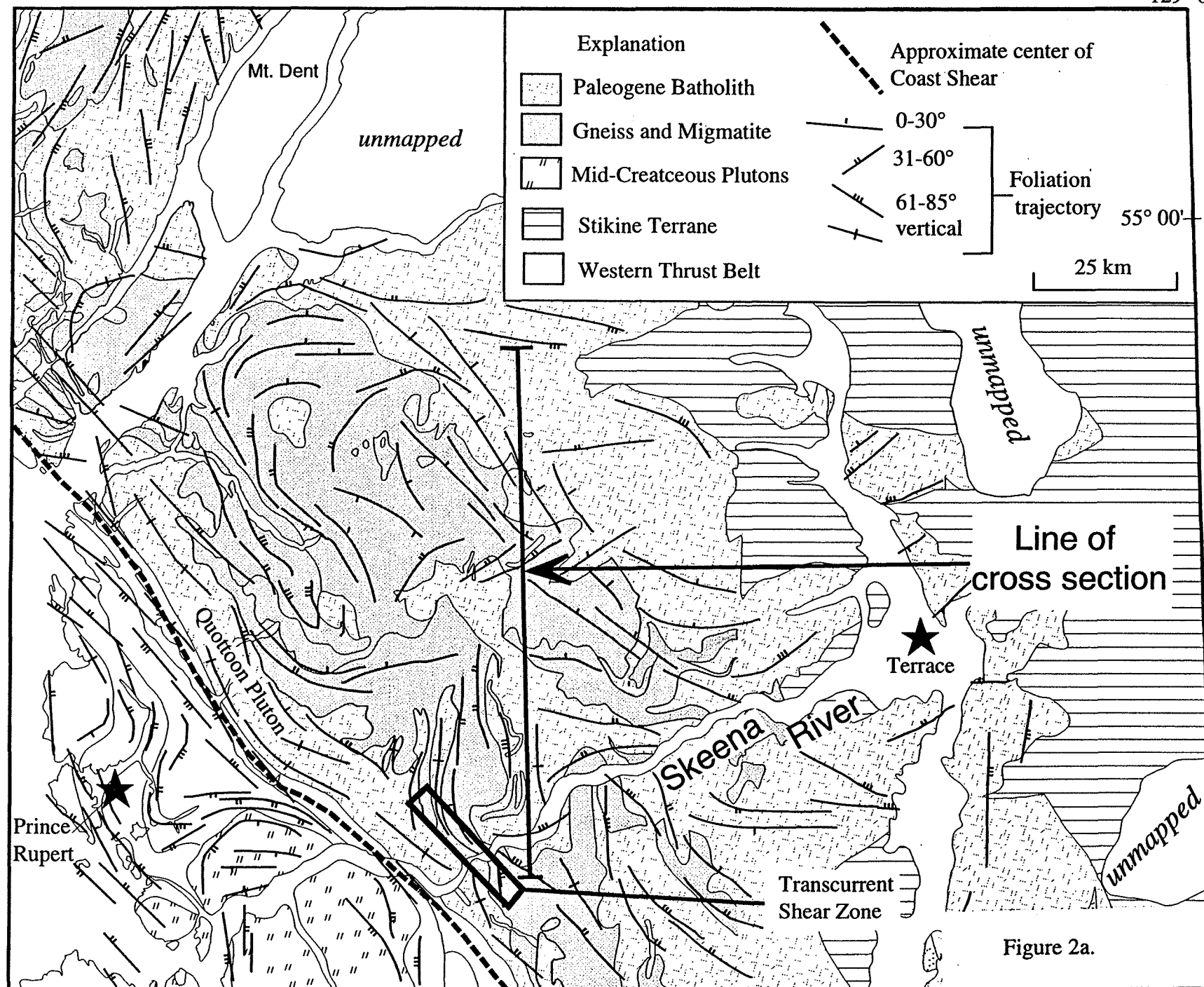
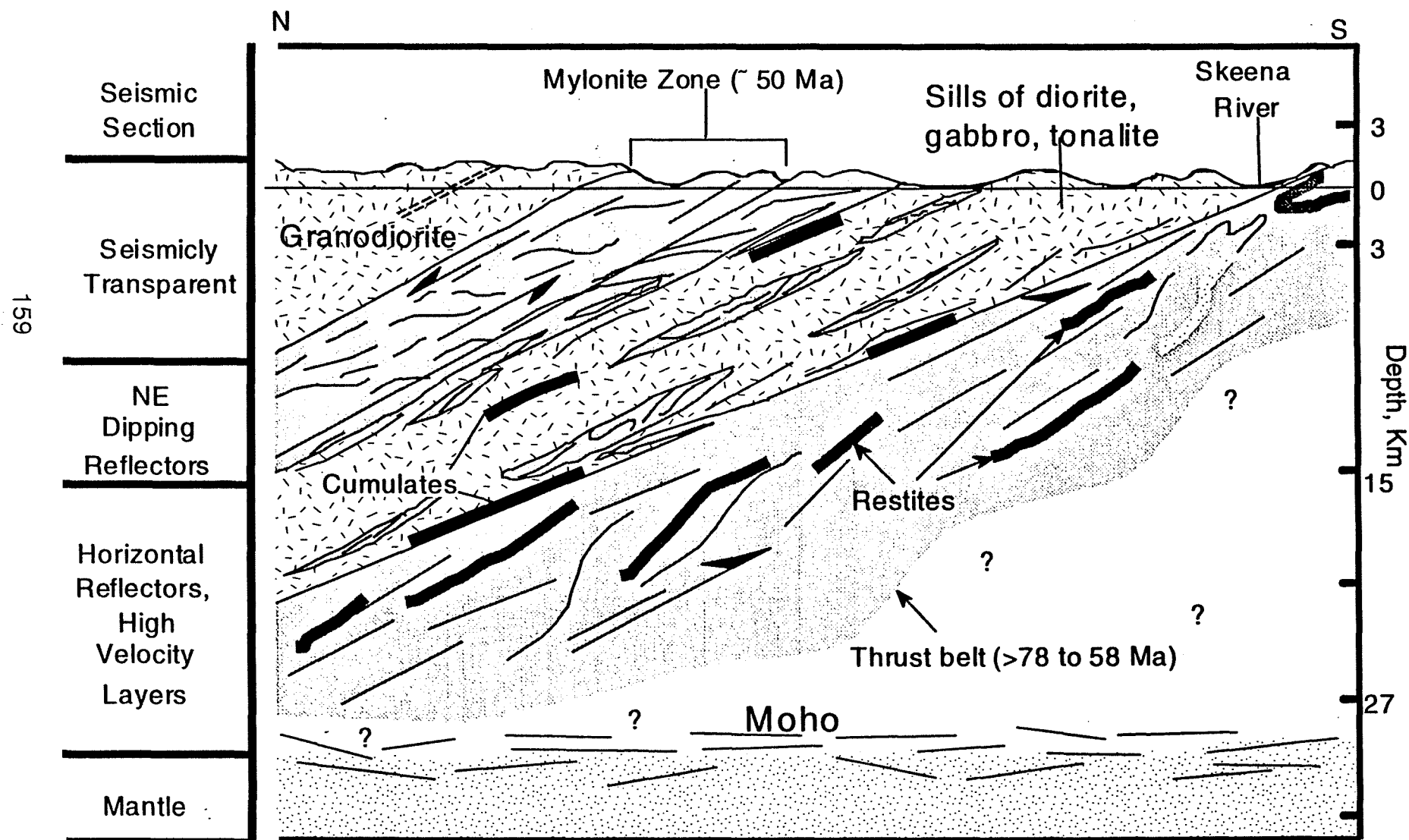


Figure 2a.

Figure 2b. The location of this crosssection is shown on Figure 2a. The seismic section description is based on preliminary interpretation of the MCS data for Portland Canal. No vertical exaggeration.



ACCRETE Crustal Velocity Structure Across the Transition Between the Coast Plutonic Complex and Stikinia

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ABSTRACT

The Coast orogen of British Columbia and SE Alaska contains the suture resulting from the mid-Cretaceous collision between the exotic Insular superterrane and the previously accreted Intermontane superterrane [Fig. 1]. This geotectonic environment has been targeted by ACCRETE to determine how continents grow by magmatic and terrane accretion. One focus of the project is the Coast Plutonic Complex and its eastern transition to the Skeena Fold Belt of the Stikinia terrane. The 1994 ACCRETE seismic experiment crosses this transition and provides a direct link to the planned seismic studies along SNORCLE Corridor 2.

The ACCRETE refraction/reflection experiment was conducted along Portland Canal, a 200 km long fjord that penetrates deeply into the Coast orogen. The seismic source was a 132 l airgun array towed by the R/V Maurice Ewing. In addition to near-vertical incidence data collected by the Ewing hydrophone streamer, wide-angle data were acquired with a land-based array of 60 IRIS/PASSCAL Reftek

3-component seismographs. Seventeen of these instruments were deployed inline with the shiptrack, extending 105 km northeast from the head of the fjord through the Coast Plutonic Complex and into Stikinia. The resulting wide-angle dataset provides a densely sampled, inline profile across the transition zone. Data quality is excellent; numerous phases (e.g., Pg, PmP, Pn, PmS, Sg and SmS) are identifiable and distinct P-arrivals are observed to ranges greater than 250 km. Derived velocity models require a well-defined transition between the Coast Plutonic Complex and Stikinia. Average crustal P-velocities decrease from 6.55 km/s beneath the Coast Plutonic Complex to 6.35 km/s beneath Stikinia. The slower velocities within Stikinia are not restricted to the thin-skinned Skeena Fold Belt, but extend to the lower crust.

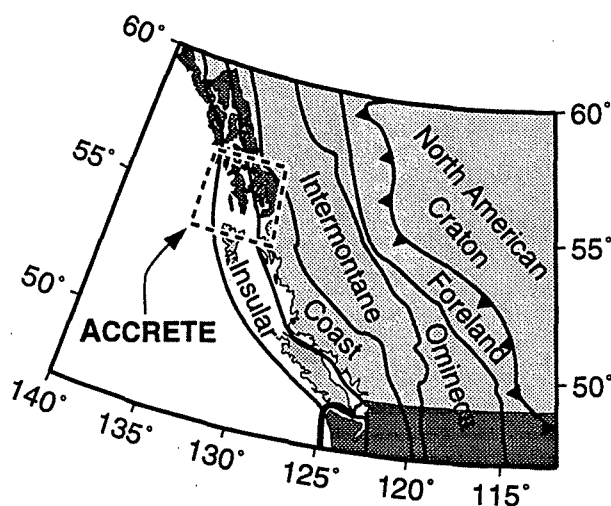


Figure 1. ACCRETE transect region (box) shown in relation to generalized morphogeological belts of the Canadian Cordillera.

GEOTECTONIC SETTING

The Coast Mountains represent the suture between the exotic Insular Superterrane (Alexander and Wrangellia terranes) and the previously accreted Intermontane Superterrane (Stikinia, Taku and Yukon terranes) [Fig. 1]. The high grade metamorphic orogen core is bounded by: a) the east-verging, thin-skinned Skeena Thrust and Fold Belt to the east (Stikinia), and b) the west-verging,

thick-skinned thrust belt to the west [Figs. 2 and 3]. Based on studies of plate motions in the northeast Pacific (*Engebretson et al., 1985*) the orogenic sequence can be described as follows:

- i) Pre - 110 Ma: The Insular Superterrane was juxtaposed with Stikinia as the oceanic plate (Farallon/Kula) moved north relative to North America.
- ii) 110 - 84 Ma: Transition to near-orthogonal convergence. The two thrust belts of opposite vergence formed during this period.
- iii) 84 - 59 Ma: Oblique convergence between the Kula and North American Plates. The subduction-related Coast Plutonic Complex formed during this interval and was rapidly uplifted and exhumed.
- iv) 59 - 42 Ma: Transcurrent motion between the Kula and North American Plates. The majority of deformational and thermal events terminated.
- iv) 40 - 0 Ma: The present transcurrent margin is established and is associated with minor mafic igneous activity. The Queen Charlotte Basin in the southwest of the ACCRETE study region exhibits late-Miocene crustal extension (*Rohr and Dietrick, 1992*).

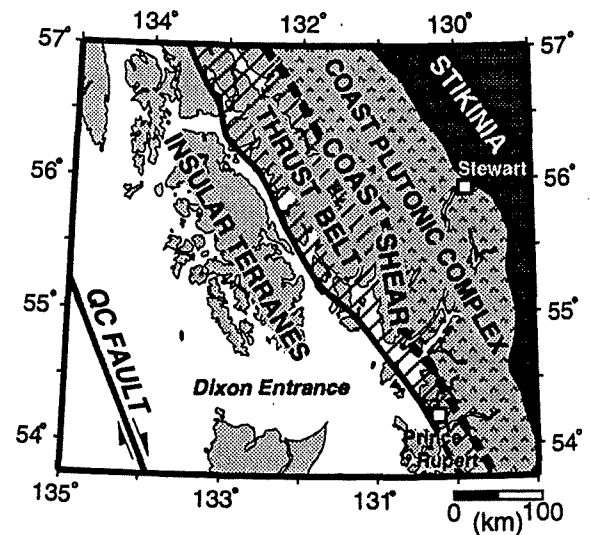


Figure 2. Generalized map of the major geotectonic zones in the study region.

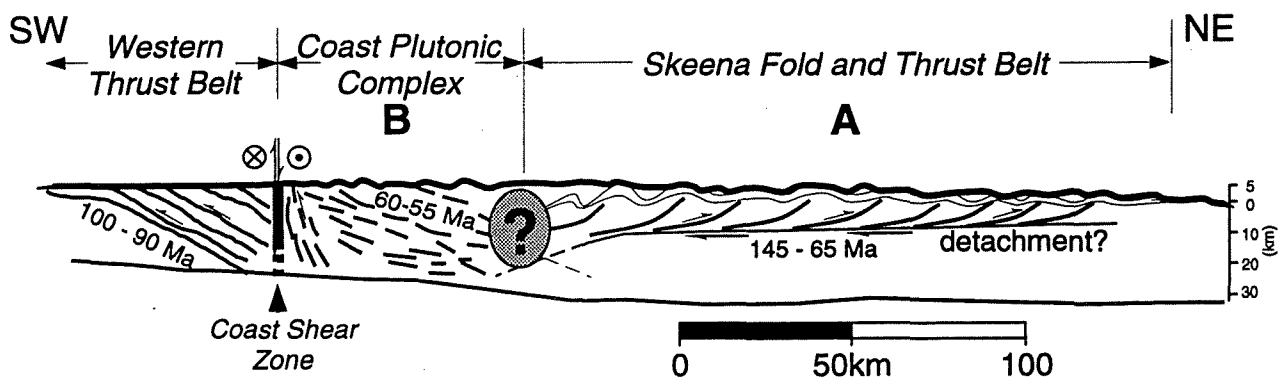


Figure 3. Schematic cross-section across the Coast orogen.

The Skeena Fold and Thrust Belt [A, Fig. 3] developed between 140 and 65 Ma, coeval with the west-vergent thrust belt. However, the latitudes at which the two belts formed remain controversial. Understanding the development of the Skeena belt is a key to unravelling the tectonic history of the region. The belt spans most of the width of the northern Intermontane superterrane and experienced more than 160 km of northeastward shortening through thin-skinned thrusting and folding (*Evanchock, 1991*). This suggests that 160 km of Stikinia in the footwall of the proposed basal detachment(s) must be in or beneath the Coast Plutonic Complex. The ACCRETE seismic dataset may define the transition between Stikinia and the overprinting magmatic arc, and constrains the location of the proposed detachment fault.

The eastern Coast Plutonic Complex [B, Fig. 3] exhibits a northeast-dipping normal detachment zone (*Heah, 1990*). The western margin of the arc is truncated by the enigmatic Coast Shear Zone (CSZ). This 5-10 km wide mylonite zone extends for more than 800 km. At the surface, the CSZ

vertically truncates the western thrust belt (Crawford *et al.*, 1987). However, it is not clear whether the CSZ represents a fossil transform fault and/or a massive normal fault soling into the lower crust. Analyses of the southern component of the ACCRETE dataset address questions related to this structure (Morozov *et al.*, 1996).

EXPERIMENT

The R/V Maurice Ewing (LDEO) was used to acquire 1700 km of marine multichannel reflection, seasurface gravity and magnetics data [Fig. 4]. This coverage included tracks along Portland Canal, Clarence Strait, Dixon Entrance and across the Queen Charlotte Fault. The 20 airgun array (136 l or 8385 in³) towed by the Ewing also served as the seismic source for the refraction/wide-angle reflection seismic survey. The refraction data was collected at shot intervals of both 20 s (~50m at 4.85 kts) and 60 s. The recording array was comprised of 3-component Reftek seismographs set to continuously acquire data at a 0.01 s sampling interval. Timing and position were controlled by GPS. The seismographs were deployed as an inline array parallel to the shiptrack along Portland Canal. Forty instruments (Δ) were deployed along the shores of the fjord and seventeen instruments ($\blacktriangle$) were placed north of Portland Canal in a line extending 105 km north-east through the Coast Mountains. The northern component of the seismograph array provides

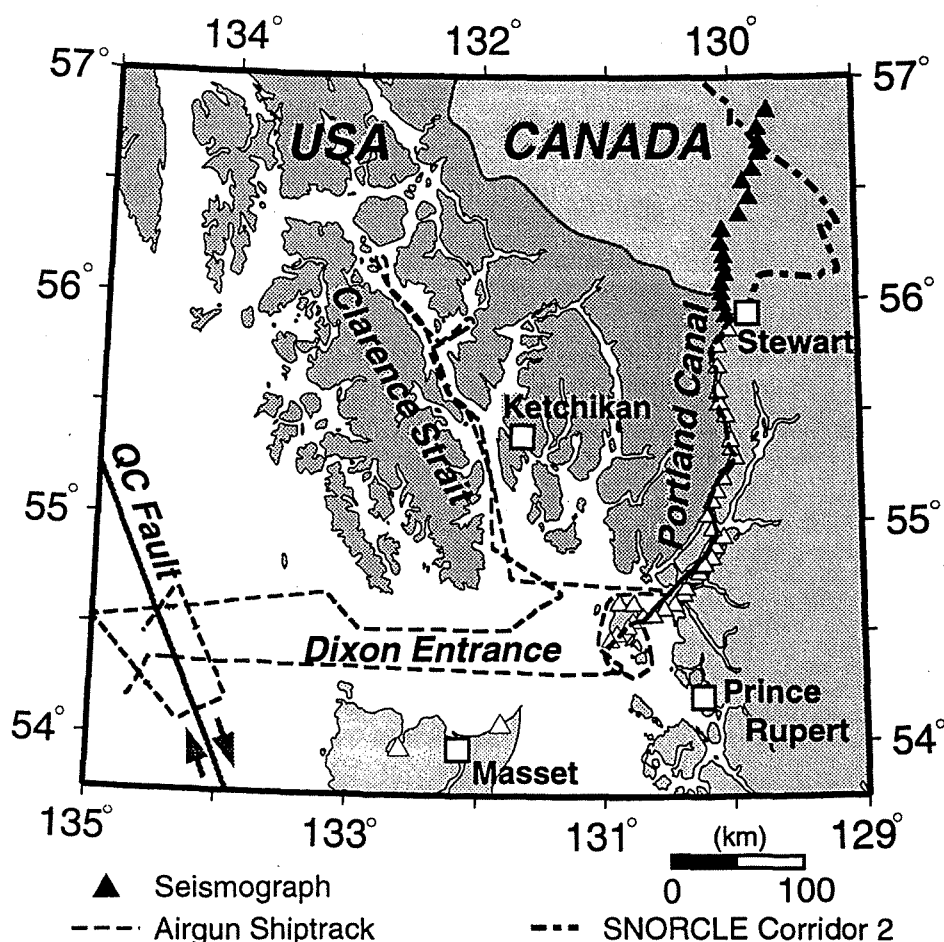


Figure 4. ACCRETE pilot seismic experiment coverage. Seismograph array (triangles) acquired data from airgun shots (dashed line) along Portland Canal and Clarence Strait.

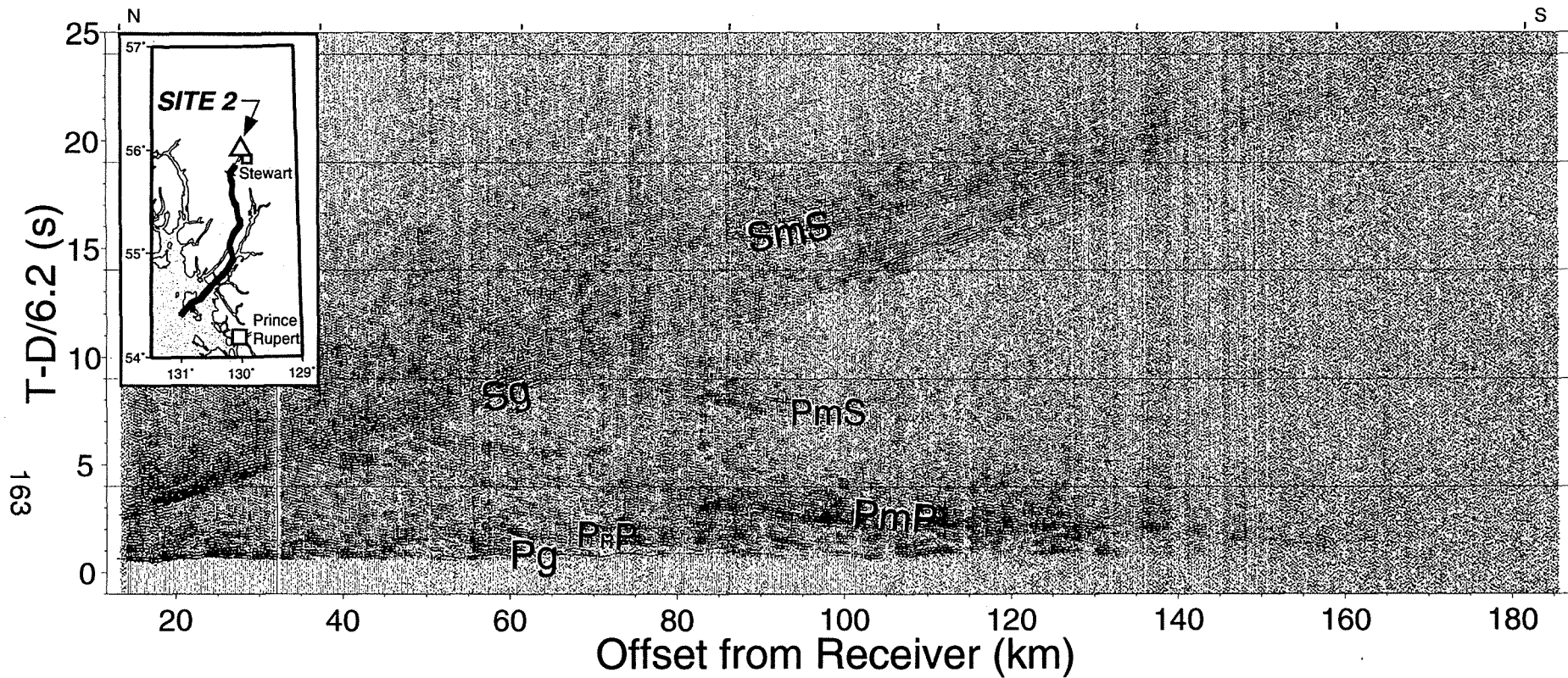


Figure 5. Representative vertical component receiver gather displayed using a 6.2 km/s reducing velocity. The data has been bandpass filtered from 1-12 Hz and the amplitudes are trace normalized. The inset figure locates the receiver (UBC Site 2) relative to the inline airgun shots (60 s spacing) as the seismic ship sailed from north to south along Portland Canal.

unreversed coverage across the transition between the Coast Plutonic Complex and Stikinia. In order to improve velocity constraints in this region, the SNORCLE Corridor 2 refraction experiment will be designed to add reversed, wide-angle data to the northeastern portion of the ACCRETE seismic corridor. The ACCRETE marine reflection data extend to within 5 km of SNORCLE Corridor 2, enabling near-vertical incidence reflection coverage to be virtually continuous between transects.

DATASET

The wide-angle, 3-component dataset provides dense coverage along the Portland Canal line (6000 shots). Although reverberation does slightly contaminate the data, quality is generally excellent and a rich suite of arrivals are observed. A typical receiver gather is presented in Fig. 5. P-wave arrivals include upper crustal refractions (Pg), a number of crustal reflections (PrP), Moho reflections (PmP) and upper mantle refractions (Pn). Arrivals were recorded to offsets of 250 km. Stacking of 20 s and 60 s data (100 m bin increments yielded approximately 10-fold stacks) using *Plotsec* (Amor, UBC) proved useful for picking arrival times from shots at large offsets and for cases of poor signal/noise.

The data also include strong S-wave arrivals (Sg, SmS), indicative of efficient P-to-S conversion along the fjord sediment/basement interface. Wide-angle P-to-S conversion also occurred at the Moho (PmS) with strong arrivals consistently observed at approximately 80 km offset. Surprisingly, this phase appears to have been recorded at near-vertical incidence angles by the R/V Ewing hydrophone streamer (Diebold *et al.*, 1996).

The rugged water/sediment and sediment/basement interfaces [Fig. 6] along the fjord complicate arrivals and significantly influence velocity modeling. Statics corrections were applied using interface picks made from the near-vertical incidence reflection data (data courtesy of T. Das, Princeton/LDEO).

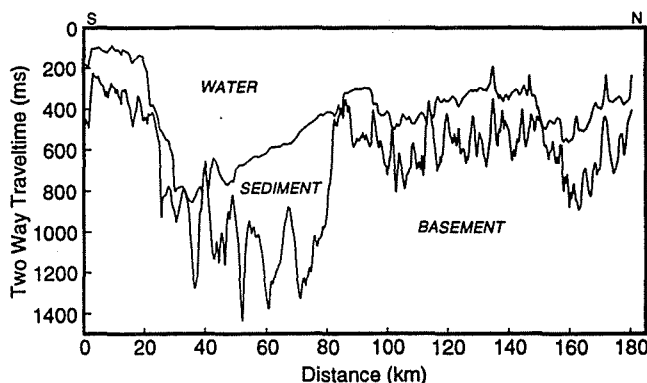


Figure 6. Rugged bathymetry and basement topography along Portland Canal.

VELOCITY STRUCTURE MODELS

Velocity structure along the unreversed in-line profile is modeled using RAYINVR (Zelt and Smith, 1992). 7274 traveltimes picks of Pg, PmP, PrP and Pn phases recorded by the northern seventeen seismographs are incorporated in the inversion. The P-velocity model for the crust and upper mantle is displayed in Fig. 7. A comparison between observed travel time picks and modeled travel times is given in Fig. 8. 2-dimensional (2-d) rays traced for each phase are also illustrated. The displayed model fits the data with a $\chi^2 = 0.98$.

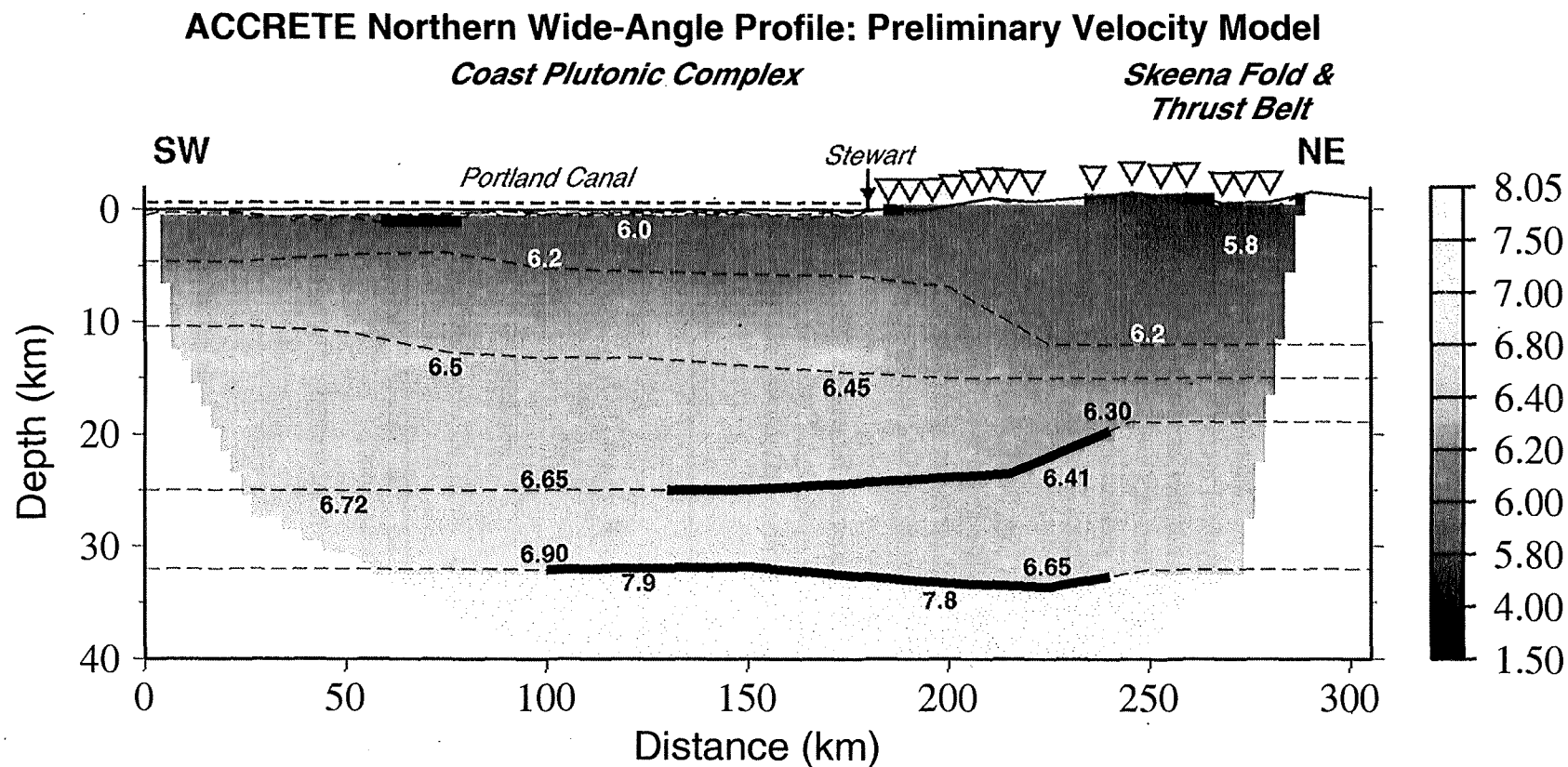


Figure 7. Velocity model for the crust and upper mantle. The triangles (∇) represent the seismographs deployed north of the fjord and the dashed line (-----) represents the airgun shots along Portland Canal [see **Fig. 4**]. Bold black lines indicate the modeled position for reflectors in the mid-lower crust and at the Moho.

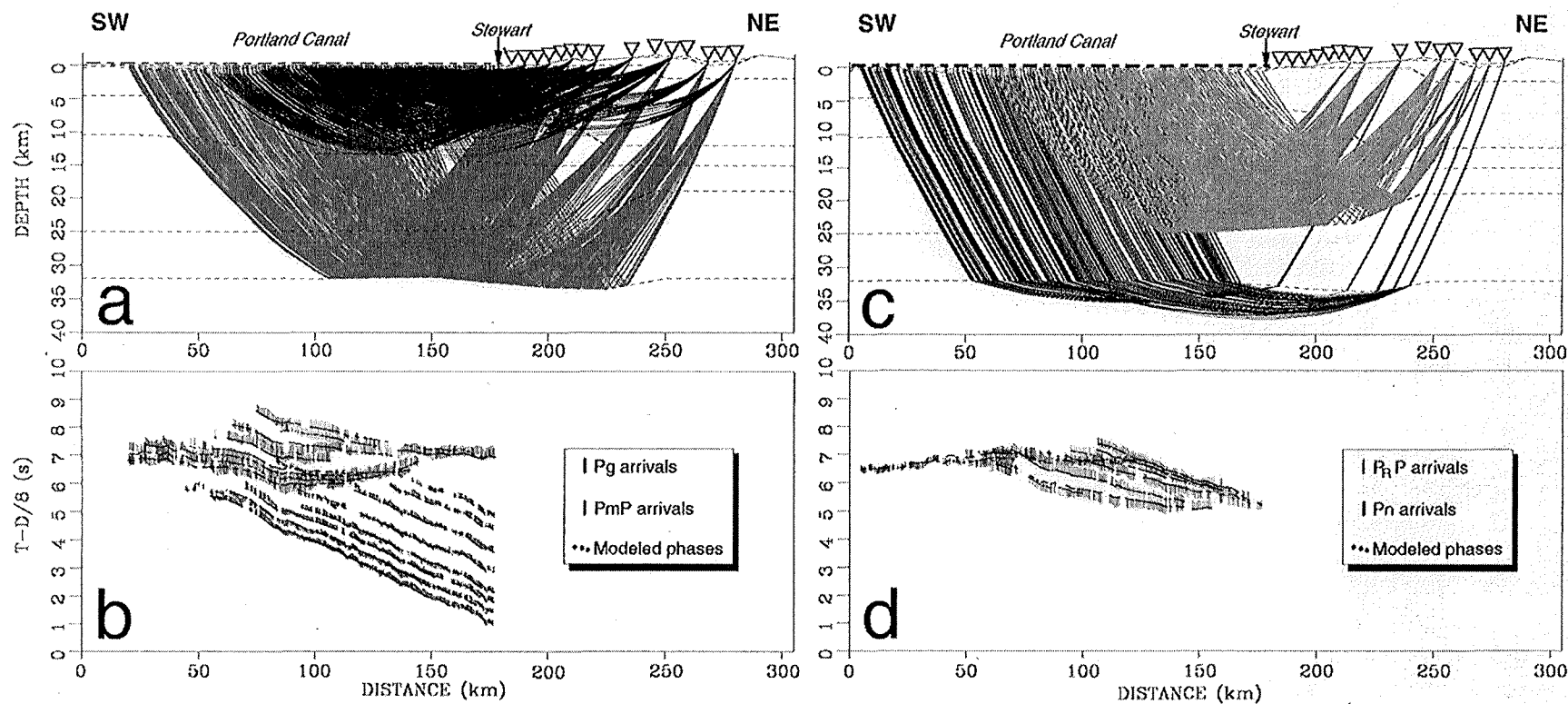


Figure 8. (a) Rays are traced for the Pg and PmP phases. (b) Comparison between travel time picks (bars) and modeled travel times (dots) for Pg and PmP phases. (c) Traced rays for the PrP and Pn phases. (d) Comparison between travel time picks and modeled arrival times for the PrP and Pn phases. For figure clarity, rays have been decimated and data is not shown from all stations. Distance scale represents range from the SW end of Portland Canal.

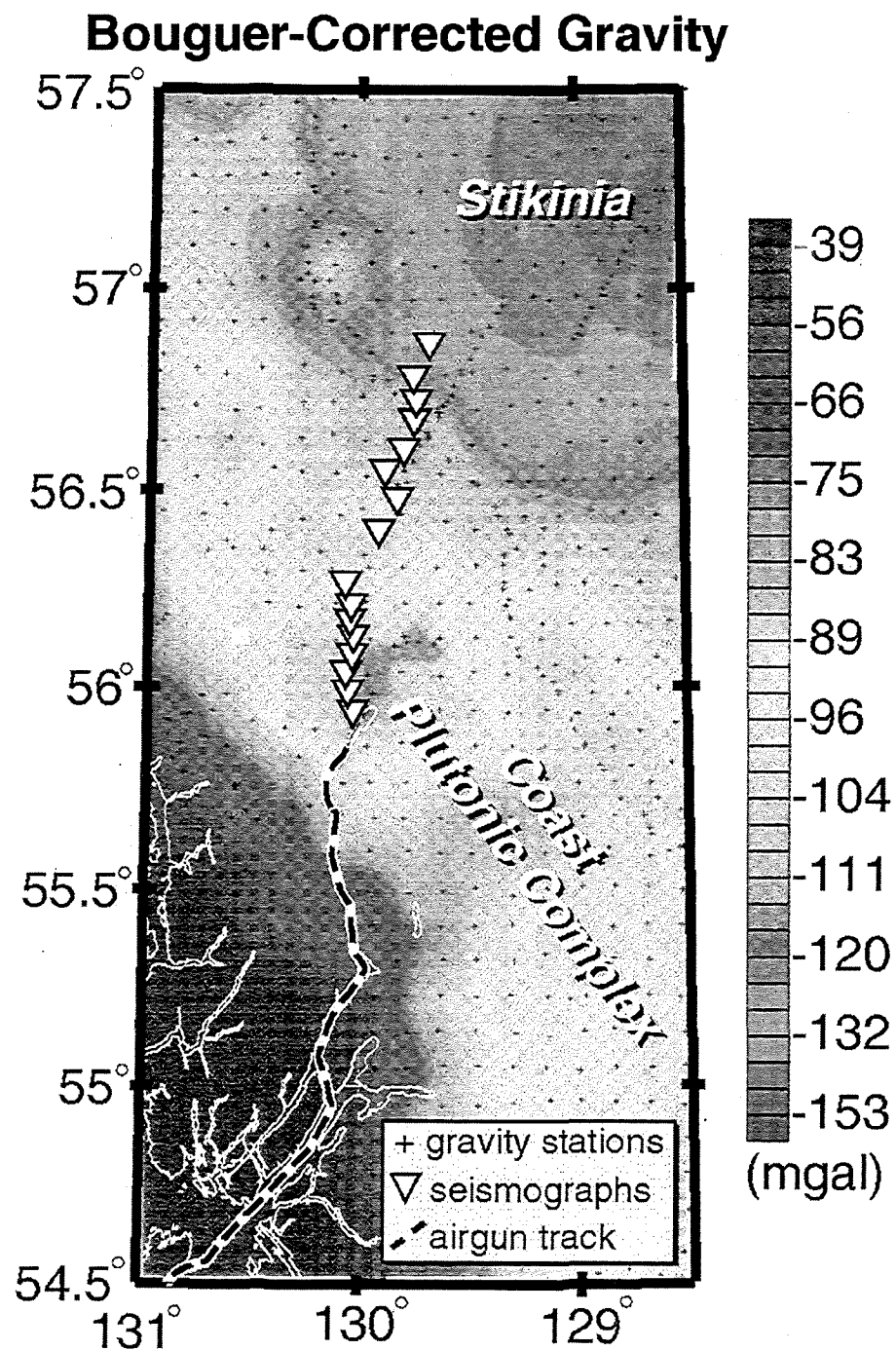


Figure 9. Gravity data (+) along the Portland Canal inline corridor. The onshore gravity data is Bouguer (2.67 g/cm^3) and terrain corrected. Offshore data is free-air with no terrain correction (data courtesy of C. Lowe, GSC-PGC).

SUMMARY

The velocity structure models derived from the unreversed northern seismograph dataset indicate that a significant change in crustal velocity occurs across the transition between the Coast Plutonic Complex (CPC) and Stikinia. The models exhibit several robust features required by the data:

- Upper crustal velocities beneath the Skeena Fold and Thrust Belt are significantly slower than velocities beneath the Coast Plutonic Complex (CPC)
- Average crustal P-velocities decrease from 6.55-6.6 km/s (CPC) to 6.3 km/s (Stikinia). Therefore, the slower velocities within Stikinia are not restricted to the thin-skinned Skeena Fold Belt, but extend to the lower crust.
- A mid-lower crustal reflector is consistently observed. This impedance contrast may be associated with the proposed detachment beneath Stikinia (Evenchick, 1991).

Support for the velocity structure models is provided by the strong northeastward gradient in the Bouguer gravity field observed along the same transect [Fig. 9].

Ongoing work includes finalizing 2-d velocity models for both P- and S-wave data using travel time inversion and ray amplitude forward modeling.

In addition, the velocity models will be integrated with the gravity data to generate a density structure model. Ambiguities in the velocity models resulting from the unreversed dataset will be resolved by designing the wide-angle refraction component of SNORCLE Corridor 2 to provide reversed coverage along the ACCRETE inline profile. Further geophysical constraints to tectonic interpretations of the region will be added by the SNORCLE multichannel reflection and MT experiments. The combination of the ACCRETE and SNORCLE transects will yield a near-continuous multidisciplinary transect reaching from the Archean Slave Province across the Phanerozoic Cordilleran orogen to the Pacific Plate [Fig. 10].

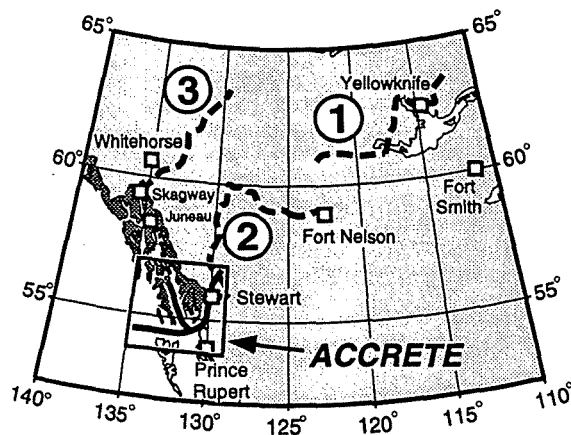


Figure 10. Location of ACCRETE transect (box and solid lines) and the LITHOPROBE SNORCLE Transect (dashed lines).

REFERENCES

- Crawford, M.L., L.S. Hollister, and G.L. Woodsworth., 1987. Crustal deformation and regional metamorphism across a terrain boundary, Coast Plutonic Complex, British Columbia, *Tectonics*, 6:343-361.
- Diebold, J., T. Das, L. Hollister, and K. Rohr, 1996. Seismic reflection interpretations along the fjords of the ACCRETE transect, southeast Alaska and northern British Columbia, Conference Abstract: 7th Deep Seismic Profiling of the Continents Symposium, Asilomar, CA, p. 59.
- Engelbreton, D.C., A. Cox, and R.G. Gordon, 1985. Relative motions between oceanic and continental plates in the Pacific Basin, *Geol. Soc. Am. Sp. Pap.* 206, GSA, 59 p.
- Evenchick, C.A., 1991. Geometry, evolution and tectonic framework of the Skeena Fold Belt, North Central British Columbia, *Tectonics*, 10:537-546.
- Heah, T.S.T., 1990. Eastern margin of the Central Gneiss Complex in the Shames River Area, Terrace, BC, in: *Current Research, Part E, Geological Survey of Canada Paper 90-1E*, Geological Survey of Canada, 159-169.
- Morozov, I.B., S.B. Smithson, and L. Hollister, 1996. Refraction velocity model and crustal reflectivity along ACCRETE corridor from wide-angle data, Conference Abstract: 7th Deep Seismic Profiling of the Continents Symposium, Asilomar, CA, p. 60.
- Rohr, K.M.N., and J.R. Dietrich, 1992. Strike-slip tectonics and development of the Tertiary Queen Charlotte Basin, offshore western Canada: evidence from seismic reflection data, *Basin Research*, 4:1-19.
- Zelt, C.A., and R.B. Smith, 1992. Seismic traveltimes inversion for 2-D crustal velocity structure, *Geophys. J. Int.*, 108:16-34.

LIFESTYLES OF THE HOT AND BUOYANT: DYNAMIC MANTLE CONTROL ON THE LONGEVITY OF THE PACIFIC OCEAN

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In the context of plate tectonics, the Pacific Ocean represents a fundamentally different evolutionary history than the Atlantic Ocean. Since the late Precambrian (Neoproterozoic) the Atlantic has undergone two incarnations as an ocean basin, first as Iapetus in the Paleozoic and then as the present Atlantic with the break-up of Pangea in the Mesozoic. It was these tectonic cycles that led J. Tuzo Wilson to suggest a cycle of ocean opening and closure that would bear his name as the familiar Wilson Cycle. In contrast, the continental masses that bound the present Pacific Ocean contain no evidence for closure since the birth of the Pacific nearly 700 Ma. Our present understanding of the history of the Pacific Ocean suggests that it formed in the wake of Neoproterozoic rifting which led to continental separation (ca. 700 Ma) between western Laurentia and the conjugate continental counterpart, likely some configuration of Australia and/or Antarctica. Subsequent evolution of the Pacific margin, as exemplified by the North American Cordillera, has been dominated by marginal rift events, arc magmatism, accretion and back arc-extension. The persistence of the Pacific Ocean for more than 700 m.y. and its unique tectonic style argue for a large scale tectonic control quite distinct from the Atlantic. One could even suggest that the Wilson Cycle might have had a dramatically different form if Tuzo Wilson had grown up in Vancouver.

The advent of global seismic networks, powerful computers as well as geocentric-orbiting satellites has led to new developments in mapping first-order internal structure of the Earth. The deviations in the Earth's shape (the geoid) from the theoretical smoothly spherical or elliptical body has now been accurately mapped using deviations in satellite orbits. Such deviations are known as geoid anomalies and appear to have ca. 110 m of maximum deflection (positive or negative sense). A major geoid high occurs in the western Pacific and corresponds to ca. 110 m of positive topography over a wavelength of several thousand kilometres. The observed geoid high corresponds with a seismically slow mantle as constrained by earthquake tomography suggesting a connection with thermally warm (upwelling) mantle. A complicating factor is the contribution from subduction of cold slabs which can be removed leaving a dynamic slab residual which still shows that the western Pacific geoid high is present although in a somewhat diminished form. Thus, the geoid high likely corresponds to dynamically supported topography due to the convective transfer of heat from the lower to upper mantle.

The time scale over which dynamic topography in mantle could persist has been suggested to be ca. 200 m.y. but it is possible that such anomalies may persist

for a much longer period of time given uncertainties in mantle viscosity. This paper suggests that the geoid high in the western Pacific corresponds to dynamic topography that has persisted since the break-up of Rodinia ca. 700 Ma and that the persistence of this anomaly in the mantle has dictated the tectonic style of the Pacific basin. The geoid high has acted as an impediment to ocean closure and plate collision and aborted completion of a Pacific Wilson Cycle. Subduction along the eastern Pacific, constrained to have started in the Devonian of the Canadian Cordillera, never led to closure of the Pacific. The reason may have been the inability of a subducting plate to "drag" the rest of the plate "uphill" over the dynamic high in the central or western Pacific. As a consequence, the Devonian subduction system slowed in terms of relative rates of plate convergence and was thrown into extension during roll-back of the lower plate, leading to back arc basin formation and birth of the Slide Mountain marginal basin. Such a system of complex plate convergence, roll-back and formation of marginal basins is the theme of Mesozoic plate tectonics along the Canadian Cordillera and persists in the present western Pacific (coincidentally on the "downhill" side of the geoid high). This hypothesis is in accord with recent models that are beginning to recognize connections between the first-order structure of the Earth's mantle and surface tectonic processes.

Structural and Tectonic Implications of a Palaeomagnetic Study; Lewis Thrust Sheet, southeast Canadian Rocky Mountains.

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The main objectives of this study were:

- to test the hypothesis that there has been a 30° clockwise structural rotation between the N-trending Flathead Range and NW-trending Clark Range segments of the Lewis Thrust Sheet, suggested by superimposed thrusting and folding patterns at the Crowsnest Deflection (Price, 1967).
- to investigate the depth of a pervasive mid-Cretaceous chemical remagnetization, of Devonian-Carboniferous rocks of the southern Rocky Mountains and Foothills (Enkin et al., in press).
- to compare results with an investigation of the Mesoproterozoic sequence of Montana and Idaho (Elston and Bressler, 1980).

Samples were collected throughout the stratigraphic column in the Lewis Thrust Sheet, from the Mesoproterozoic Alton Fm. through the Devonian Fairholme Gp.; from both limbs of the Akamina Syncline (to provide a regional scale fold test), and north across the Crowsnest Pass cross-strike discontinuity, as far as the Crowsnest Pass. Magnetic directions were obtained by measuring thermally cleaned specimens in a Geofyzika JR-5A spinner magnetometer. Multiple magnetizations were discovered.

The results show no significant vertical-axis rotation between the NW-trending and N-trending segments of the Lewis Thrust Sheet, around the Crowsnest Deflection, despite field evidence to the contrary. The Cretaceous remagnetization discussed by Enkin et al. (in press), however, was found to persist on an irregular basis, as both a primary magnetic overprint, and an intermediate temperature component overprint, throughout the Belt-Purcell sequence, to the lowest horizon sampled. Mesoproterozoic palaeomagnetic directions and stratigraphy are in accord with those determined for the Belt Sequence in Montana and Idaho by Elston and Bressler (1980). The fact that the "Belt-Purcell" palaeomagnetic direction, has a small to negligible variation over the great thickness of the Belt-Purcell sequence, indicates deposition over a short geologic interval; and this is in accord with new radiometric dating which indicates that most of the Belt-Purcell Supergroup was deposited between 1468±2 Ma and 1449±10 Ma, a depositional interval of only 20 to 30 Ma (Aleinikoff et al., 1996).

References

Aleinikoff, J.N., Evans, K.V., Fanning, C.M., Obradovich, J.D., Ruppel, E.T., Zieg, J.A., and Steinmetz, J.C., 1996. **SHRIMP U-Pb Ages of Felsic Igneous Rocks, Belt Supergroup, Western Montana.** Abstracts with Programs, Geological Society of America annual meeting, Denver, CO.

Elston, Donald P. and Bressler, Stephen L., 1980. **Paleomagnetic Poles and Polarity Zonation from the Middle Proterozoic Belt Supergroup, Montana and Idaho.** Journal of Geophysical Research, vol. 85, no. B1.

Enkin, R.J., Osadetz, K.G., Wheadon, P.M. and Baker, J., in press. **Paleomagnetic Constraints on the Tectonic History of the Foreland Belt, Southern Canadian Cordillera - Preliminary Results.** Canadian Journal of Earth Science, in press.

Price, R.A., 1967. **The Tectonic Significance of Mesoscopic Subfabrics in the Southern Rocky Mountains of Alberta and British Columbia.** Canadian Journal of Earth Sciences, vol. 4, p. 39-70.

**NEOPROTEROZOIC AND EARLY PALEOZOIC CRUSTAL EXTENSION AND ITS
INFLUENCE ON MESOZOIC CRUSTAL THICKENING ON THE
OUTBOARD MARGIN OF ANCESTRAL NORTH AMERICA
(SOUTHERN CANADIAN CORDILLERA)**

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Neoproterozoic/Paleozoic extension faults and changes in properties of underlying lithosphere controlled styles of Mesozoic crustal thickening along the outboard Cordilleran margin.

A zone of structural divergence and sedimentary facies and thickness changes extending from Alaska to Washington lies at the western edge of the Cordilleran thrust and fold belt, and immediately to the east of the Jurassic "suture" between North America and accreted terranes. In southeastern British Columbia, sharp structural and stratigraphic contrasts between the Kootenay Arc (an arcuate belt of high-amplitude, west-verging folds) and the Purcell anticlinorium (a broad belt of east-verging, thinned-skinned deformation) mark this zone.

New and previously published geological mapping and palinspastically restored maps and cross sections of outboard North American supracrustal strata illustrate fundamental differences between several episodes of Neoproterozoic and Early Paleozoic crustal attenuation. Restored cross sections, coupled with radiometric age data and pressure data, also illustrate the Mesozoic tectonic evolution of the continental margin during subsequent compressional deformation.

Neoproterozoic (Windermere Supergroup) extension was characterized by an abrupt rift basin margin with deep subsidence of a single basin to the west and uplift and erosion to the east. Two sets of normal faults, northeast- and north-trending, controlled the configuration of the basin and the distribution of sediment. Eocambrian extension was characterized by a wide, low-gradient margin, less subsidence, little local uplift and north-trending growth faults that defined a series of distinct, parallel half grabens. Lower Paleozoic shelf strata overlie these half grabens above a regionally extensive "breakup" unconformity. Both Neoproterozoic and Eocambrian faults were reactivated during differential subsidence of the Lower Paleozoic "passive" margin, resulting in formation of several emergent crustal "highs" on the outboard edge of the continental platform.

Allochthonous terranes were obducted eastward over the edge of the rifted margin prior to 187-178 Ma. By 173 Ma, west-verging folding and thrusting were underway as an underlying "wedge" of North American Neoproterozoic to Lowermost Paleozoic strata was driven eastward beneath Lower Cambrian strata. The upper detachment of the wedge is inferred to have followed the regional "breakup" unconformity. West-verging shortening above the wedge was concurrent with rapid crustal thickening and tectonic burial (up to 27 km), followed by rapid exhumation (10 km), as the wedge impinged upon a major west-facing ramp associated with one of the crustal "highs" inherited from the Neoproterozoic/Early Paleozoic sedimentary basin (173-164 Ma).

Tectonic thickening provided gravitational potential to drive deformation eastward over the ramp (164-157 Ma). The basal décollement and east-verging thrust splays propagated through cooler, stiffer metasedimentary rocks in the Purcell anticlinorium (Late Jurassic-Cretaceous) and through the Front Ranges and Foothills of the Rockies (Late Cretaceous-Paleocene).

Thin, perhaps hotter lithosphere west of the ramp responded to crustal thickening by deep, localized subsidence with no foreland basin. Tectonic loading of progressively thicker, stiffer lithosphere to the east is recorded by the narrow Kootenay Group (155-135 Ma) and much broader Blairmore Group (115-95 Ma) and Laramide (90-60 Ma) foreland basins.

The Selkirk fan structure of the southeastern Canadian Cordillera: Tectonic thickening in response to inherited basement structure

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A revised cross-section through the Selkirk fan structure, a segment of the regional zone of structural divergence that extends along the Omineca belt from northeast Washington to east-central Alaska, provides the basis for a new model for the Middle Jurassic tectonic evolution of the southern Omineca belt. Palinspastic restoration of this cross-section shows that the southwest-verging structures along the west flank of the Selkirk fan structure formed as a result of tectonic wedging of distal North American strata (Clachnacudainn complex) beneath more proximal North American strata, and that the Selkirk fan structure developed outboard from a crustal ramp (Dogtooth high), inherited from Late Proterozoic - Early Paleozoic rifting along the western margin of North America.

The first episode of Mesozoic deformation in southeastern British Columbia corresponds to the northeastward juxtaposition of the Intermontane superterrane over the outer part of the North American continental terrace wedge. This occurred between 187-173 Ma and resulted in deep burial (20-25 km) of the outer margin of North America. A crustal ramp, localized along the western edge of the Dogtooth high, impeded the continued northeastward displacement of the orogenic wedge comprising the Intermontane superterrane and imbricate northeast-verging thrust sheets within the North American cover sequence. Tectonic wedging and southwest-verging deformation occurred as a result of internal deformation of the orogenic wedge, and resulted in significant shortening and thickening of the wedge as it re-established its critical tapered slope. Southwest-verging deformation in the Illecillewaet synclinorium, a broad regional structure in the west flank of the Selkirk fan structure, occurred between approximately 173-168 Ma and was accompanied by ca. 10 km of exhumation. Exhumation of the west flank of the Selkirk fan structure was probably the result of synorogenic extension contemporaneous with compressional deformation at deeper levels of the orogen. The attainment of a critical taper was most certainly slowed by synorogenic extension at high levels of the orogen, because there is no indications of significant detritus from the Cordillera into the foreland basin, to the east, before the Upper Jurassic (154-151 Ma). It may be inferred that the first indications of lithospheric flexure of the North American plate at ca. 154 Ma also mark the time at which the orogenic wedge over-rode the crustal ramp of the Dogtooth high and advanced onto relatively thick and rigid continental crust. The tectonic model proposed for the Selkirk fan structure illustrates how the configuration of the rifted margin influenced the style of crustal thickening during subsequent compressional deformation.

Late Proterozoic Carbonate Platforms of the Jasper Region; Genesis, Stromatolite Morphology and Stratigraphic Significance.

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The Yellowhead and Monarch Platforms are two well-exposed Neoproterozoic carbonate platforms that occur in the Canadian Rockies near the township of Jasper. The platforms are upto 400 meters thick, composed entirely of dolomite and contain, in ascending order, a stromatolitic and talus facies, an oncolitic facies and a siliciclastic facies. The scale of lateral facies changes are extreme, pointing to the dynamic setting in which these platforms formed. Recent detailed mapping and stratigraphic analysis has lead to an improved understanding of the genesis of these platforms as well as their regional tectonic significance.

The Yellowhead Platform is best exposed along the flanks of Mount Fitzwilliam and Mount Clairvaux (53° 00' Lat; 118° 25' Long.) in a region approximately 23 km west-south-west of Jasper. The stromatolitic facies of the Yellowhead Platform is dominated by crinkly to undulatory algal laminations, and less frequently, branching digitate stromatolites. These structures form laterally persistent horizons, as well as individual bioherms, some of which are upto 30 meters long and 10 meters high. Smaller-scale bioherms below the reef rim are seen to coalesce, forming larger structures which form a barrier rim on the platform. This barrier rim had significant topographic relief and presumably provided shelter for the back-reef area. Oncolites of the Yellowhead Platform are dominated by compound, elongate to sub-spherical grains which show multiple phases of component lamination and agglomeration and reach sizes upto 5cm long (long axis). The presence, and general dominance of this type of coated grain is suggestive of a sheltered back reef area where constant agitation and/or current activity was not present, thus enabling gelling of individual components on the substrate prior to successive laminating events.

The Monarch Platform is best exposed on the west and south faces of Monarch Mountain, located approximately 25 km north-west of Jasper (53° 00' Lat; 118° 25' Long.). The platform shows a wide range of stromatoforms. These include well-formed, crudely-formed and branching digitate stromatolites, *Conophyton* and more simple undulatory and crinkly algal laminations. These structures form large bioherms, which comprise the base of the platform, and laterally persistent stromatolitic horizons seen to underlie the oncolitic facies. The largest observed bioherm is domical in shape and reaches an estimated height of 25 meters. On the north side of Monarch Mountain large bioherms appear to coalesce, forming extensive algal surfaces. The large bioherms have wave cut notches and platforms and are flanked by talus breccias, attesting to a very high-energy environment. The stromatolite-dominated base is overlain by the

oncolitic facies, composed of massive sheets of oncolitic wackestone, and less commonly oncolitic packstones and grainstones. The oncoids are dominantly simple, spherical to near spherical oncolites ranging in size from 2 mm, to upwards of 13 mm. Compound oncoids are present, although not as prevalent as simple oncoids, and reach sizes upwards of 4 cm (long axis). These compound oncoids are generally seen as elongate, to occasionally semi-spherical structures which exhibit multiple phases of lamination and agglomeration of components. The size of these exceptionally large coated grains and their complex growth patterns point to an environment characterized by infrequent, but very energetic, wave reworking, and gives a measure of the magnitude of water agitation present during formation of this facies, as well as the dominance of microbially-assisted carbonate precipitation.

Termination of the growth of these platforms appears to have resulted from a combination of subaerial exposure and/or suffocation beneath the overlying fluvial to marine clastic facies, composed of arkosic sands and conglomerates. On the Yellowhead Platform a transgressive lag immediately overlies the platform in near-shore areas, where this contact is represented by an exposure surface. Near the platform rim however, this contact is gradational with no evidence of exposure. A similar association is seen on the Monarch Platform, however the limit and inaccessibility of outcrop prevented detailed examination of this contact. In some areas evidence for the exposure of the top of the Monarch Platform was observed, in the form of minor karstification, but was seen to be absent in other areas. This surface is then overlain by fluvial to marine arkosic sands and gravels that buried the platform and signify termination of platform growth.

The Mineralogical composition of the siliciclastics associated with these platforms, as well as their geometric relationships to the carbonates, hold particular importance for the interpretation of the stratigraphic position and tectonic setting of the platforms. In particular, the presence of potassium feldspar in these arkosic units contrasts with the predominance of plagioclase feldspar in the underlying Windermere Supergroup and indicates erosion of newly exposed continental rocks in the source area for the clastics. Evidence for tectonic activity during platform sedimentation includes the isolated nature of the platforms, abundant, large scale slumps and soft-sediment deformation and the rapid facies changes seen across the platforms, especially where the carbonate facies inter-finger with the arkosic clastics. It is proposed that these platforms are lateral equivalents of the lower Jasper Member, and not of the upper Miette Group (Windermere Supergroup), as traditionally thought. As an aside, the lack of definitive Cambrian fossils within the Jasper Member (and its recognized equivalents), raises the possibility that the Precambrian/Cambrian boundary may be stratigraphically higher than currently thought. We suggest that the deposition of the Yellowhead and correlative platforms was syntectonic with rifting in western Canada in the latest Proterozoic/earliest Cambrian.

NEW CRITERIA TO DISTINGUISH THE MONASHEE COMPLEX AND SELKIRK ALLOCHTHON, W FLANK OF THOR ODIN CULMINATION, MONASHEE MOUNTAINS, SOUTHEASTERN BRITISH COLUMBIA.

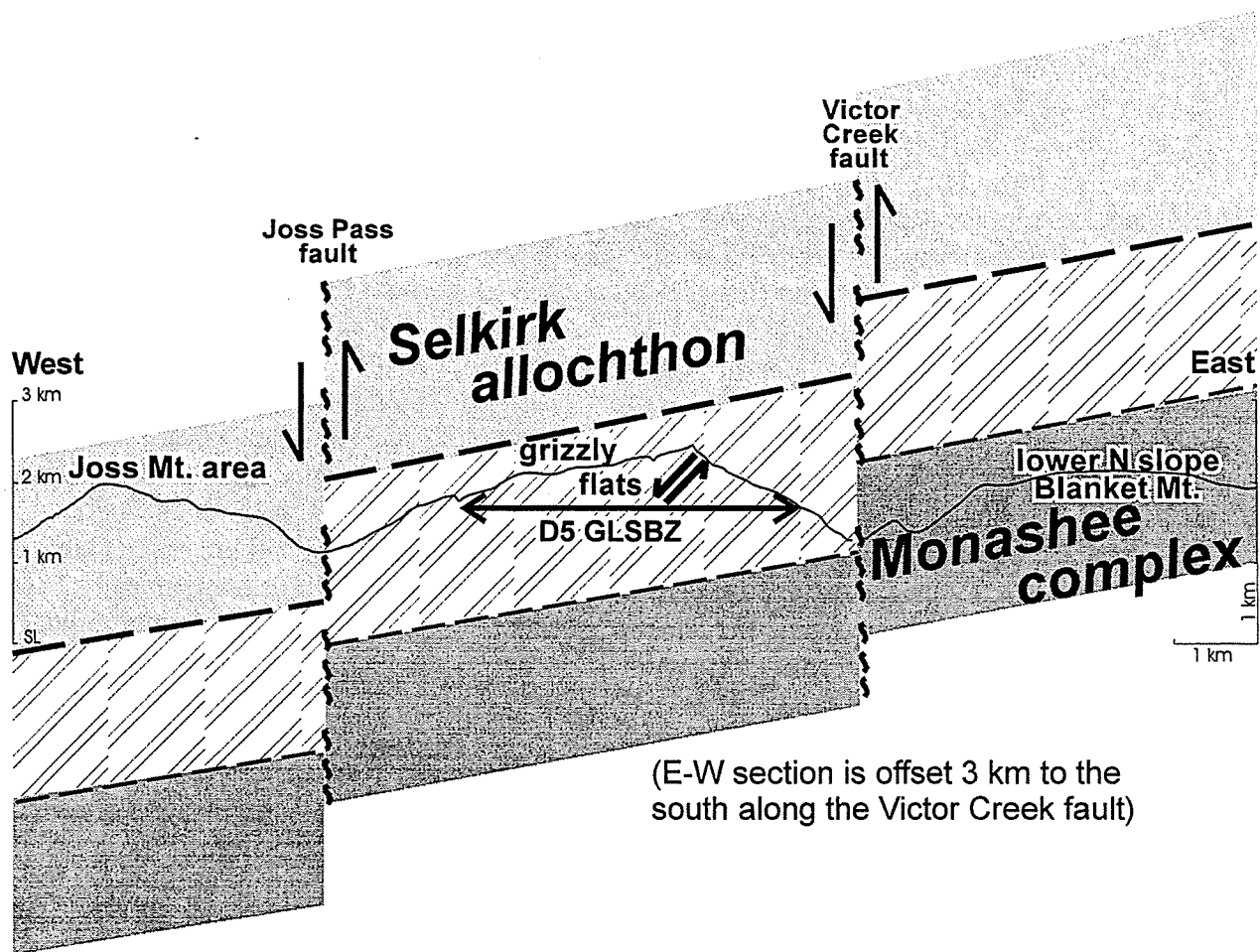
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Thor Odin (TO) and Frenchman Cap (FC), two major antiformal culminations of high-grade metamorphic rock, comprise the Monashee complex (MC) in SE British Columbia. A kilometre-thick NE-directed thrust zone, the Monashee décollement (MD), previously mapped at FC and inferred at Caribou Alp at the SW margin of TO, separates the MC from the overlying Selkirk allochthon (SA). In our study area along the W flank of TO, NE-directed shear was not restricted to a narrow zone but rather was distributed throughout the culmination (4-5 kilometre thickness exposed). In the absence of a discrete MD, we have established new criteria to distinguish the MC from the overlying SA.

Defining the W flank of TO culmination is a thick panel of rock in which the regional transposition foliation (S_2) dips consistently to the W. Above and below this panel the strike and dip of S_2 are variable. Contained within the W-dipping panel is an approximately 2 kilometre thick zone in which W-dipping, top-to-W extensional shear bands are abundant; this zone is herein termed the Greenbush Lake shear band zone (GLSBZ). The shear bands, and tourmaline-bearing pegmatite dykes sheared (top-to-W) along discrete S_2 surfaces, indicate significant ductile slip on S_2 during D_5 extension. D_5 reactivated slip truncated mesoscopic F_2 and F_3 folds. A W-trending stretching lineation, L_5 , occurs within the GLSBZ.

The GLSBZ alone does not separate MC and SA (Fig. 1). NE-verging F_3 folds, NE-directed shear sense indicators and Early Eocene peak temperatures (per metamorphic zircon U-Pb closure age) all occur above the GLSBZ as far W as Joss Pass; here a late normal fault drops the inferred MC/SA contact to the subsurface. The MC is also distinguished from the SA by the sporadic occurrence of previously reported $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages which are older than nearby U-Pb zircon and monazite ages of this study and by the preservation of pristine kyanite (K) or kyanite after sillimanite (KS_U and KS_L). We believe complete resetting of the $^{40}\text{Ar}/^{39}\text{Ar}$ system in hornblende and transformation of kyanite to sillimanite occurred as a result of proximity to localized heat maxima, presumably near intrusions. Rocks not in proximity to intrusions were less affected, resulting in the localized preservation of kyanite and apparently old hornblende ages. The intrusions may have formed during emplacement of the SA above the MC and/or during D_5 decompression – U-Pb ages, and the youngest of the $^{40}\text{Ar}/^{39}\text{Ar}$ ages (i.e., fully reset), are consistent with either scenario.

New U-Pb dates indicate ductile top-to-W extension in the GLSBZ was approximately coeval with documented Early Eocene top-to-E ductile extensional deformation along the E flank of the MC (Columbia River fault: ca. 55 Ma). A comparison of new U-Pb monazite cooling ages and the youngest of nearby $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages previously reported indicates very rapid cooling of the MC. Much slower cooling is indicated for rocks in the SA (Joss Mt. and Three Valley Lake). Complimentary coeval ductile extensional zones on the E and W flanks of TO culmination lead us to believe that the distinctive rapid cooling of the MC was the result of D_5 unroofing, rather than erosion.



Structural levels	S ₂ Dip	F ₃ vergence	Top-to-NE D ₃ shear (annealed)	Top-to-W D ₅ shear bands (not annealed)	thermal peak per U-Pb, Ma	cooling ages hbl > Zr or Mz cooling ages	Al-Sil. zone
Joss Mtn.	varied	SW	No	rare	90-94	No	S
Joss Pass							
grizzly flats	West	NE	yes	abundant in GLSBZ	56.5	Yes	S KS _u K KS _L
Blanket Mtn.	varied	N	yes	absent	55-57	Yes	KS _L

Figure 1. Summary of evidence from the study area indicating Joss Pass marks the western boundary between the Monashee complex and Selkirk allochthon.

U-PB GEOCHRONOLOGIC CONSTRAINTS ON THE AGE AND INTENSITY OF METAMORPHISM IN THE MONASHEE COMPLEX, BRITISH COLUMBIA

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The Monashee complex lies beneath a crustal-scale thrust fault, the Monashee décollement, in a deep structural exposure in the southern Canadian Cordillera. An inverted metamorphic sequence is considered to exist across the décollement into the complex because sillimanite-K-feldspar rocks overlie kyanite-sillimanite-muscovite $\pm$ staurolite rocks. U-Pb isotopic data from the northern part of the complex show that the age and intensity of this metamorphism, which is a result of Cordilleran orogenesis, vary with structural level. The amount of Pb loss that occurred during this event, as determined from discordant linear arrays of U-Pb isotopic analyses, is used to interpret the thermal significance of concordant and reversely discordant monazite and xenotime U-Pb dates that young downward from ~64 Ma in the highest level to ~49 Ma in the deepest level. Upper intercepts of the arrays are Paleoproterozoic and Cretaceous, and lower intercepts suggest that the discordance in the analyses, some of which are composed of single grains, resulted from an early Tertiary overprint. The discordance is mostly attributed to Pb loss rather than overgrowth because the samples generally lack U-Pb evidence for mineral growth at the lower intercept ages. The amount of Pb loss in the deepest structural level (6-22% in monazite and 25-43% in titanite) is significantly less than that in higher levels (23-50% in monazite and ~95% in titanite). Quantitative estimates of the metamorphic intensity are made by modeling Pb diffusion in episodes of heating of fixed duration and temperature, specific combinations of which were calculated by solving equations for measured fractional Pb loss and assumed diffusion radius and geometry. Diffusion coefficients are taken from natural and experimental data. If peak temperatures were ~700-750° C and similar throughout, consistent with mineralogy and a petrogenetic grid, then Pb loss occurred within 1 m.y. in the deeper levels and within 2-5 m.y. in higher levels. However, the differences in Pb loss amounts could also be due to the attainment of greater temperatures (up to 50° C) in higher levels. The knowledge that Pb loss in monazite throughout this metamorphism was incomplete leads to the interpretation that the downward younging dates of 64-49 Ma from monazite and xenotime closely reflect the ages of mineral growth. These growth ages are taken to closely represent the thermal peak based on (i) the calculated short durations of elevated temperatures, (ii) previously obtained $^{40}\text{Ar}/^{39}\text{Ar}$ dates that indicate rapid cooling occurred immediately after the peak, (iii) the widespread and consistent nature of the U-Pb dates, and (iv) U-Pb ages that indicate kyanite- and sillimanite-bearing leucosomes were generated at this time. A major conclusion made from this interpretation is that the thermal peak in the complex was diachronous according to structural level.

Age constraints and net-slip estimates of strike-slip deformation along Matthew Fault in the Penfold Creek area, Cariboo Mountains, British Columbia.

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The timing of strike-slip deformation along Matthew Fault has previously been constrained by the cross-cutting relationships with the Hobson Lake Pluton which is cut by Matthew Fault and the Murtle Lake Pluton which stitches Matthew Fault. Geochronological work on these intrusions by other studies constrains the timing of faulting between 174 Ma to 51 Ma. Recent $^{40}\text{Ar}/^{39}\text{Ar}$ dating completed during this study gives a potential lower age limit of 111.5 ± 5 Ma. for the beginning of strike-slip deformation; based on the cooling age for retention of argon in hornblende collected from a tectonized amphibolite from within the Matthew Fault fault zone. Strike-slip deformation had to have started by at least 111.5 Ma along Matthew Fault. This age may also apply to the more regional scale dextral deformation event for the northwest Cariboo Mountains.

Displacement along the Matthew Fault may be inferred by the 60 kilometres of separation between the Hobson Lake Pluton and the Little River Stock; two intrusions of nearly identical composition that may have been cut and offset by Matthew Fault. Displacement may also be inferred by the offset of metamorphic mineral zones which indicate approximately the same displacement as that inferred from the offset of the Hobson Lake Pluton. Dextral offset along Matthew Fault is supported by the sharp increase in metamorphic grade across Matthew Fault, the along-strike change in metamorphic mineral assemblages on either side of the fault and the prevalence of dextral shear bands along a narrow zone that parallels Matthew Fault. In the Penfold Creek area the SW side of Matthew Fault comprises kyanite zone and higher grade paragneisses and schists that may correlate with the Neoproterozoic/Lower Cambrian Cariboo Group. These rocks were juxtaposed with garnet zone and lower grade metasedimentary rocks of the Neoproterozoic Kaza Group.

Thermobarometric work completed on one sample from the low grade side of Matthew Fault has given conflicting results. The pressure and temperature conditions determined from microprobe analyses of the assemblage garnet, biotite, muscovite, plagioclase, chlorite and ilmenite indicate this assemblage formed at approximately 6500 kilobars and 510 °C. These calculated PT conditions are not supported by the fine grained textures observed in the field and in thin section which indicate much lower pressure and temperature conditions.

STRUCTURAL CORRELATION ACROSS THE SUPRASTRUCTURE - INFRASTRUCTURE TRANSITION (CARIBOO MOUNTAINS, BRITISH COLUMBIA): POSSIBLE, IMPOSSIBLE OR WORK IN PROGRESS?

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The core zone of Cordilleran-type orogenic belts is dominated by high-grade, polydeformed rocks and their low-grade counterparts known as the infrastructure and suprastructure respectively. In order to fully understand the evolution of core zones in orogenic belts there are a number of key questions which need to be addressed. What is the relationship of the high-grade metamorphic rocks to low-grade metamorphic rocks of the core zone (i.e. relationship between infrastructure and suprastructure)? How is strain distributed throughout the core zone and what is its relationship to larger tectonic processes? What is the relationship between timing of deformation in the core zone and the adjacent belts? The Omineca Crystalline Belt is a morphogeological belt which contains the internal core zone to the eastern Canadian Cordilleran Orogen. It is characterized by regional Barrovian metamorphic complexes, which range from chlorite to sillimanite grade, and core complexes bounded by low-angle Eocene extensional shear zones and related faults, typical of orogenic core zones.

The Cariboo Mountains are located in the southern Omineca Crystalline Belt. The regional structures of the Cariboo Mountains are dominated by large-scale northwest-trending anticlinoria and synclinoria which have an overall northwest plunge. The result of this northwest plunge is that high tectonic levels and low metamorphic grades are seen in the northern Cariboo Mountains and progressively deeper levels of the infrastructure are seen to the southeast. This feature makes the Cariboo Mountains one of the ideal places in the Omineca Crystalline Belt to examine the changes which occur between shallow and deep structural levels in the core zone. Numerous research projects have been carried out in the Cariboo Mountains over the past two decades in the suprastructure, infrastructure and in the transition zone, however, significant gaps exist between study areas which makes correlating structures at the different structural levels difficult. The relationship between the timing of deformation and metamorphism in the suprastructure and infrastructure is still poorly understood. At the suprastructure level, the earliest structures (D_1 structures) include east-verging thrust faults, isoclinal folds and a bedding-parallel cleavage which is associated with peak metamorphism (M_1). The age of D_1 and M_1 is inferred to be pre-174 Ma based on the relationship of D_1 structures to the Hobson pluton. At the infrastructure level, the earliest structures (D_1 structures) include southwest-verging large-scale nappes which are equivalent to the Scripps Nappe of the northern Monashee Mountains. Peak metamorphism is post D_1 and D_2 in the infrastructure and has been found to have occurred at 135 Ma. The main regional northwest-trending structures in the Cariboo Mountains (D_2 structures), which form the main regional anticlinoria and synclinoria change their geometry along strike from the suprastructure to the infrastructure level. In the suprastructure F_2 folds are upright to overturned with open to closed intralimb angles, whereas in the infrastructure, F_2 folds are overturned to recumbent with closed interlimb angles. The age of F_2 folding also changes from the suprastructure

to the infrastructure. In the suprastructure, F_2 folds are interpreted to have formed pre-174 Ma based on the relationship of F_2 structures to the Hobson pluton. In the infrastructure, F_2 folds are interpreted to have occurred between 168 Ma and 135 Ma based on the ages of deformed and undeformed pegmatites respectively.

The difference in ages and geometry of structures between the suprastructure and infrastructure, as well as the gaps between study areas, have made correlation of regional structures in the Cariboo Mountains challenging. The wide map coverage in the Cariboo Mountains provides a strong base within which to trace out large-scale structures from the suprastructure to infrastructure level, and potentially into the northern Monashee Mountains, where the Scrip Nappe occurs. The next step for mapping in the Cariboo Mountains should be to trace out large-scale structures along strike from the suprastructure to the infrastructure in order to ascertain the correlations and to tie such field-based studies to detailed geochronology. Understanding these structures is important in order to determine the history of the Omineca Crystalline Belt as a whole, and to address the questions stated above which remain largely unanswered.

TERTIARY DRAINAGE PATTERNS IN CENTRAL BRITISH COLUMBIA: IMPLICATIONS FOR OLIGOCENE TO MIOCENE TECTONICS

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A digital elevation model (DEM) of the Canadian Cordillera, enhanced with equal-area stretch, clearly shows a drainage pattern in central British Columbia that predates existing watersheds. It images a watershed within the interior of British Columbia that tapped highlands to the north, west, and south and emptied through channels dissecting the Omineca and Cariboo Mountains. The watershed is considered younger than the peneplanation that followed Middle Eocene uplift of the Vanderhoof Metamorphic Complex, whose uplift is dated by recently obtained $^{40}\text{Ar}/^{39}\text{Ar}$ ages and preliminary fission track analyses. Changes in drainage directions have been hinted at by previous paleogeomorphological studies, primarily by W.H. Mathews, in the southern part of this area. Of note is the change to southerly flow by the Fraser River, which captured much of the paleowatershed, probably during the latest Pliocene or Pleistocene.

In question is the flow direction of the paleowatershed's outlet. The present outlet is truncated by the Rocky Mountains, but the paleodrainage could have flowed north or south along the Southern Rocky Mountain Trench, or traversed easterly across the Rocky Mountains, via either the Yellowhead Pass or Peace River valleys. The drainage pattern in the DEM is obscured at the Rocky Mountain Trench and the western front of the Rockies. We suggest that the paleowatershed drained to the east and was later diverted by uplift in the Rocky Mountains. This notion is also supported by metamorphic minerals preserved in upper Tertiary gravels from east of the Rockies, in the Swan Hills. If dating of the metamorphic minerals demonstrates that they were derived from the Cariboo Mountains, as proposed by Vonhof (1969), it would suggest that the paleo-Fraser River flowed eastward along the Yellowhead Pass valley, and down-cutting kept pace with uplift at least until the early Miocene. The southerly offset of the paleo-Fraser River, along the Rocky Mountain Trench, may reflect dextral strike-slip motion concurrent with mid-Tertiary uplift of the central Rockies.

Vonhof, J.A. 1969. Tertiary gravels and sands in the Canadian Great Plains. unpublished Ph. D. thesis, University of Saskatchewan, 279p.

CONTROL OF THE WESTERN CONTINENTAL MARGIN OF NORTH AMERICA BY THE CORDILLERAN FAIRWEATHER-QUEEN CHARLOTTE-WALLOWA FAULT SYSTEM*

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***Summary.** Steep crustal-scale faults recognized in the Cordilleran interior continue onto the submerged continental margin off British Columbia and SE Alaska, where they define the continent-ocean crustal transition at the western North America plate boundary. The WNW-trending Olympic-Wallowa zone of crustal weakness runs from southern Idaho, and the SSE-trending Fairweather fault zone runs from inside Alaska. Both these continental structural zones continue on the continental shelf and slope and define the western margin of the North American continent. This plate-boundary zone is tens of kilometers wide and contains continental, transitional and oceanic crustal blocks bounded by high-angle faults. This conclusion is drawn from combined analysis of geological as well as seismic and potential-field data.*

Subduction of the oceanic Juan de Fuca plate at the continental margin in Washington and British Columbia is thought by many workers to be dying. In Oregon and Washington, teleseismic data show the subducted slab is steep and disintegrating. From global plate reconstructions, the North America-Juan de Fuca convergence rate in the Late Tertiary slowed down dramatically. Decay of this subduction zone is progressing from its southern and northern ends, where the remaining plate convergence is taken up by internal deformation of Juan de Fuca plate segments. Both southern (Gorda) and northern segments of this plate have contorted or broken magnetic stripes and diffuse seismicity. Seismic data show the northern Juan de Fuca plate crust has a variable thickness and is heavily faulted.

The Gorda segment is commonly recognized to be deforming internally, but for the northern Juan de Fuca plate segment oceanic-lithosphere rigidity and normal subduction are still assumed. Based on this assumption, the current plate tectonic model includes ongoing subduction under Vancouver Island, a sharp trench-ridge-fault triple junction off Queen Charlotte (QC) Sound, and dextral North America-Pacific plate movements off QC Islands. For years, this model has been used as a guide to drive the interpretation of geophysical data and earthquake-hazard assessments along the British Columbia continental margin.

Seismic methods, which were used extensively to test these interpretations, are suitable for detecting subhorizontal crustal discontinuities. They are not as good at imaging subvertical discontinuities. In keeping with the prevailing tectonic ideas, Vancouver Island and the adjacent submerged continental margin were interpreted as a thrust stack of east-dipping, largely oceanic, crustal slices. Steep faults have mostly been omitted - even though geologic field mapping and detailed geophysical studies show that in the westernmost Insular Belt of the Cordillera, of which Vancouver and QC islands are parts, high-angle faults are prevalent.

Without adequate geological constraints, geophysical interpretations are inherently not unique. Deep continental drilling worldwide shows that many causes can account for seismic reflections in the crystalline crust: fracture delamination, igneous layering, metamorphic fronts, ductile flowage fabrics, anastomosing faults, and so on. To interpret all low-angle crustal seismic events as thrusts ignores the countless other possibilities.

Steep faults are detectable much better with potential-field data. In this study, seismic images and models of crustal structure along the continental margin produced over the years by Lithoprobe are brought together with other types of geophysical and geological data in British Columbia as well as western Oregon, Washington and SE Alaska. Geological information available from field mapping and deep drilling has been used as a primary constraint on geophysical interpretations. The result is an alternative interpretation of the crustal structure and plate dynamics at this part of the continental margin.

Absent in British Columbia are the defining attributes of subduction zones. There is no bathymetric trench. Earthquakes onshore and offshore are shallow (<90 km), and their mechanisms are not thrust. Along the submerged continental margin, in a band tens of kilometers wide, magnetic stripes are lacking. Outcrop evidence on Vancouver Island shows that the major Tertiary faults such as Westcoast, Leech River and San Juan are straight and steep. Geochemical evidence from the small, sparse volcanoes on the mainland which

have been interpreted as a volcanic arc indicates they may have been formed in an intracontinental extensional regime; they seem to lie along a straight crustal fault. Insular Belt crust is continental, usually 25-40 km thick, and its average seismic velocities are low. Measured present-day vertical motions of onshore crustal blocks along the continental margin differ and do not fit a single 2-D flexural model. Drilling on the shelf suggests the same was the case throughout the Tertiary. Normally the circum-Pacific subduction zones are characterized by long, negative geoid anomalies - but off western North America no such anomaly is found.

Crustal geophysical models produced by different workers from the same seismic data across this continental margin have been radically different (even to the point of showing a stepwise Moho-depth increase towards the continent). In the reflection profiles, the same events "E" have been interpreted as zones of shearing related to tectonic underplating, or a fossil subduction megathrust, or non-structural metamorphic fronts. Deeper events "F" have been interpreted as the base of the subducting oceanic crust, or the top of this crust, or just noise. Modeling tests in western Washington have shown that gravity data at the Cascadia subduction zone are unable on their own to resolve the presence or absence of a subducted slab.

Geological and geophysical evidence together suggest steep faults on the western Canada continental shelf and slope run from the continental interior. The WNW-trending graben along the Juan de Fuca Strait, which contains the 8-km-thick Tertiary Fuca sedimentary basin and lies between southern Vancouver Island and the Olympic Peninsula, is part of the Olympic-Wallowa structural zone that runs from Idaho. This zone includes the steep crustal-scale faults, grabens, folds and basins in the Columbia River province, and farther west it separates the North and South Cascades.

The Fuca graben faults were rejuvenated in the Late Tertiary to form the modern Strait of Juan de Fuca. Geologic field evidence and geophysical data show its fault systems on northern Olympic Peninsula and southern Vancouver Island are straight and steep. In contrast to the seismic interpretations of these faults as thrusts, many field geologists have interpreted them as long strike-slip faults. The subvertical San Juan fault, for example, disrupts the underlying seismic events "B" in Lithoprobe reflection line 84-04.

A basement crustal block seems to underlie the Olympic Mts. A rectangular gravity low appears in upward-continued (to 20 km) Bouguer gravity anomaly maps of this area. It is seen in isostatic gravity maps as well. Straight boundaries of this low coincide with known major, steep faults on the surface, including those belonging to the Olympic-Wallowa zone. The prevailing model ascribes the low density of this block to a sedimentary accretionary prism up to 30 km thick (which would be unique in the world). Alternatively, it may be caused by a big unexposed granitoid pluton. The magnetic low over this suspected pluton indicates it is magnetized reversely. Contact-metamorphism patterns in the sedimentary country rocks in the Olympic Mts. core suggest it was emplaced in the Miocene. This light pluton's rise is also raising the mountain core.

Faults of the Olympic-Wallowa system, and other steep faults trending NE-SW, E-W and N-S, run from Olympic Peninsula and Vancouver Island onto the continental shelf and slope off Vancouver Island. Their continuity is indicated by potential-field anomalies and bathymetric lineaments.

Cretaceous sandstones like those on Vancouver Island have been dredged up on the upper continental slope. On the shelf, sharply contrasting Tertiary stratigraphy in the deep Tofino Basin wells which are separated by faults indicates differential movements of basement blocks throughout the Tertiary. Unlike offshore Washington, no accretionary-prism mélangé has been drilled on Vancouver Island shelf. Seismic images of deeper shelf structure are too poor to support the idea of east-dipping accretionary crustal thrust slices. From geologic field relationships on land, the isolated Early Tertiary Crescent basaltic bodies in western Washington, previously considered an accreted oceanic-crust terrane, are now recognized to have been erupted in a rift setting in situ. Felsic rocks are present in their Metchosin equivalent on Vancouver Island. The similar basaltic bodies drilled in the Tofino Basin are associated with discontinuous magnetic anomalies of limited extent, and they do not form a coherent terrane. The combination of geological and geophysical evidence suggests Vancouver Island and its shelf consist of fault-bounded blocks of thick continental crust.

On the adjacent lower continental slope, the crust is thin and some oceanic magnetic stripes appear. Poorly imaged quasi-compressional structures in seismic profiles are similar to structures on passive margins caused by sediment slumping. Under the slumps, deep structure of the slope in seismic profiles is obscure. The resolved reverse faults at the foot of the slope off southern Vancouver Island are steep. They cut the oceanic-crust basement and seem to be inverted normal faults bounding a mini-basin with thick sediments. In contrast, east-dipping low-angle thrusts with intrasedimentary detachments have been imaged clearly and

drilled offshore Oregon. On the continental slope off central Vancouver Island, local alignment of linear oceanic magnetic and continental gravity anomalies indicates interlocking of broken-up continental-crust and oceanic-crust blocks. Here, the magnetic stripes are unreliable for plate reconstructions.

The crustal-scale Fairweather fault in southern Alaska separates the Chugach and Yakutat terranes. It dives underwater off Cross Sound, and continues SSE along the continental shelf and slope. Seismic profiles show two main strands off Cross Sound and three south of Sitka Sound. Some fault segments are covered by thick stratified sediments, but others reach the ocean floor. These undrilled sediments are several kilometers thick, and their basement is obscure. From seismic and gravity data, they are the thickest in relatively undisturbed, downdropped blocks between the steep fault strands. Seismicity and offsets of ocean-floor channels also attest to recent dextral movements. The sediments are largely undisturbed north of Sitka Sound, but their deformation intensity increases to the south. There the Fairweather fault system broadens, reaching 40 km off Dixon Entrance. In seismic refraction and gravity models, the Moho deepens towards the continent stepwise.

This wide fault system continues on the exterior continental shelf and slope past QC Islands, QC Sound and Vancouver Island. Just off QC Islands, under some 2 km of water but still higher than the abyssal ocean floor, lies the QC Terrace, a step-like bathymetric feature 20-30 km wide and running the length of the islands. The QC Terrace has no magnetic stripes. A strong gravity low and seismic refraction data suggest the Moho is 15-20 km deep. The QC Terrace is probably an attenuated, foundered continental crustal block.

Magnetic stripes appear gradually farther outboard over the NNW-trending, 20-30-km wide, fault-bounded QC bathymetric trough. Its crystalline crust is thin (~6 km). From seismic and gravity data, it is probably a slightly downdropped block of oceanic crust within the same fault system.

Small, isolated volcanic mounds (Dellwood, Wilson) off QC Sound litter the sediment-blanketed lower continental slope and abyssal ocean floor. Their map outline is commonly isometric. Their geochemistry is not consistent with sea-floor spreading. Lacking off QC Sound are major gravity anomalies and magnetic stripes; the crust here seems to be near its isostatic equilibrium. In this rather quiescent area, there is no sign of a triple junction.

Continental crust lacking magnetic stripes underlies a NW-trending graben on the lower continental slope off northern Vancouver Island and southern QC Sound. This graben is occupied by the thick Winona sedimentary basin. Seismic refraction and gravity models show the Moho is 10 to >20 km deep. A steep, listric, NNW-trending, west-dipping normal fault is clearly seen in reflection profiles to separate this domain from the continental shelf. This fault controls the steep continental slope. Local anticlines in the Winona Basin are similar to those created in many other basins by mud diapirism. The basement dips mostly to the east (though the graben becomes more symmetrical in the south). Sedimentary strata dip towards the steep inboard basin-bounding normal fault fan-like, and their dip increases downsection. This deep basin was probably formed by gradual syndepositional block tilting in an extensional regime. The outer edge of the Winona Basin is marked by the subparallel Revere-Dellwood fault some 70 km to the west, outboard of which the crust is by all parameters oceanic. This fault continues NW past the mouth of QC Sound and nearly meets the outer fault scarp of the QC Terrace continental-crust block. It truncates the oceanic magnetic stripes sharply. Except for some isolated anomalies caused by local volcanic bodies, the Winona Basin, like the QC Terrace, is magnetically quiet.

The broad fault system containing the Winona graben continues along the continental margin in both directions. To the NW, it merges with the Fairweather-QC fault system which forms the margin of the continent but begins in the Alaskan interior. Off southern Vancouver Island, it joins with the Olympic-Wallowa zone on the continental shelf and slope. Off SE Alaska and British Columbia, the combined Fairweather-QC-Wallowa structural zone running from Alaska to Idaho forms a diffuse plate boundary.

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*ABSTRACTS of
POSTER
PRESENTATIONS*

**New Correlations among Proterozoic successions and intrusive breccias
in the Ogilvie and Wernecke Mountains, Yukon**

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Abstract

New field studies in northwestern Yukon reveal that the Ogilvie Mountains breccias in strata of the Early Proterozoic Wernecke Supergroup developed prior to deposition of the Middle to Upper Proterozoic Fifteenmile Group. The Ogilvie Mountains breccias, and related metasomatic aureoles characterized by hydrothermally precipitated hematite, alkali feldspar, carbonate, and chlorite, do not penetrate strata of the Fifteenmile Group. Instead, the Fifteenmile Group unconformably overlies regolith developed on breccia and related metasomatic rock. This finding indicates that the Fifteenmile Group was deposited on breccia and Wernecke Supergroup after an interval of Middle Proterozoic erosion and weathering, a relationship which strengthens correlations with units in northeastern Yukon. The Ogilvie Mountains breccias are now unambiguously correlated with the Wernecke breccias; the lower Fifteenmile Group is now correlated with certainty with the Pinguicula Group; and the upper Fifteenmile Group is correlated with the Callison Lake dolostone.

Introduction

In Yukon, inliers of Early to Late Proterozoic strata are exposed beneath Paleozoic strata of Ogilvie and Mackenzie Platforms from the Northwest Territories to the Alaska border (Fig. 1). They record platformal to miogeoclinal sedimentation and minor volcanism spanning about a billion years. Similarities among the successions in these inliers and others in the arctic islands have led to regional stratigraphic correlations most of which have become generally accepted. For example, all the Lower Proterozoic strata in the area are considered to belong to the Wernecke Supergroup (Sequence A of Young et al, 1979), whereas the youngest Proterozoic rocks are identified as strata of the Windermere Supergroup (Sequence C). However, correlations among strata which lie between the Wernecke and Windermere Supergroup (Sequence B), known locally as the Pinguicula Group, Fifteenmile group, and Callison Lake dolostone have remained tenuous. One of the most important constraints on correlation is the relationship of these intermediate-aged strata to intrusive hematitic breccias, known as the Wernecke and Ogilvie Mountains breccias. The Wernecke breccias in the Wernecke Mountains only intrude the Wernecke Supergroup and are unconformably overlain by the much younger Pinguicula Group, but the Ogilvie Mountains breccias were thought to not only intrude the Wernecke Supergroup but also the lower Fifteenmile Group. With this constraint, only two correlations were possible. Either the lower Fifteenmile Group and Pinguicula group were correlative, and there were two significantly different ages of breccia (Cook and McLean, 1995) or the lower Fifteenmile group was significantly older than the Pinguicula Group and there was one age of breccia (Rainbird et al, 1996). This paper provides results from new field investigations which establish that the Ogilvie Mountains breccias do not intrude the lower Fifteenmile group and that the lower Fifteenmile Group correlates with the Pinguicula Group.

Recent studies in the Hart River inlier in the eastern Ogilvie Mountains by Abbott (1993, in press), and in the Wernecke Mountains by Thorkelson and Wallace (1993a,b, 1994a,b, 1995a,b) and the realization that both the Fifteenmile Group and the Pinguicula Group unconformably overlie the Wernecke Supergroup

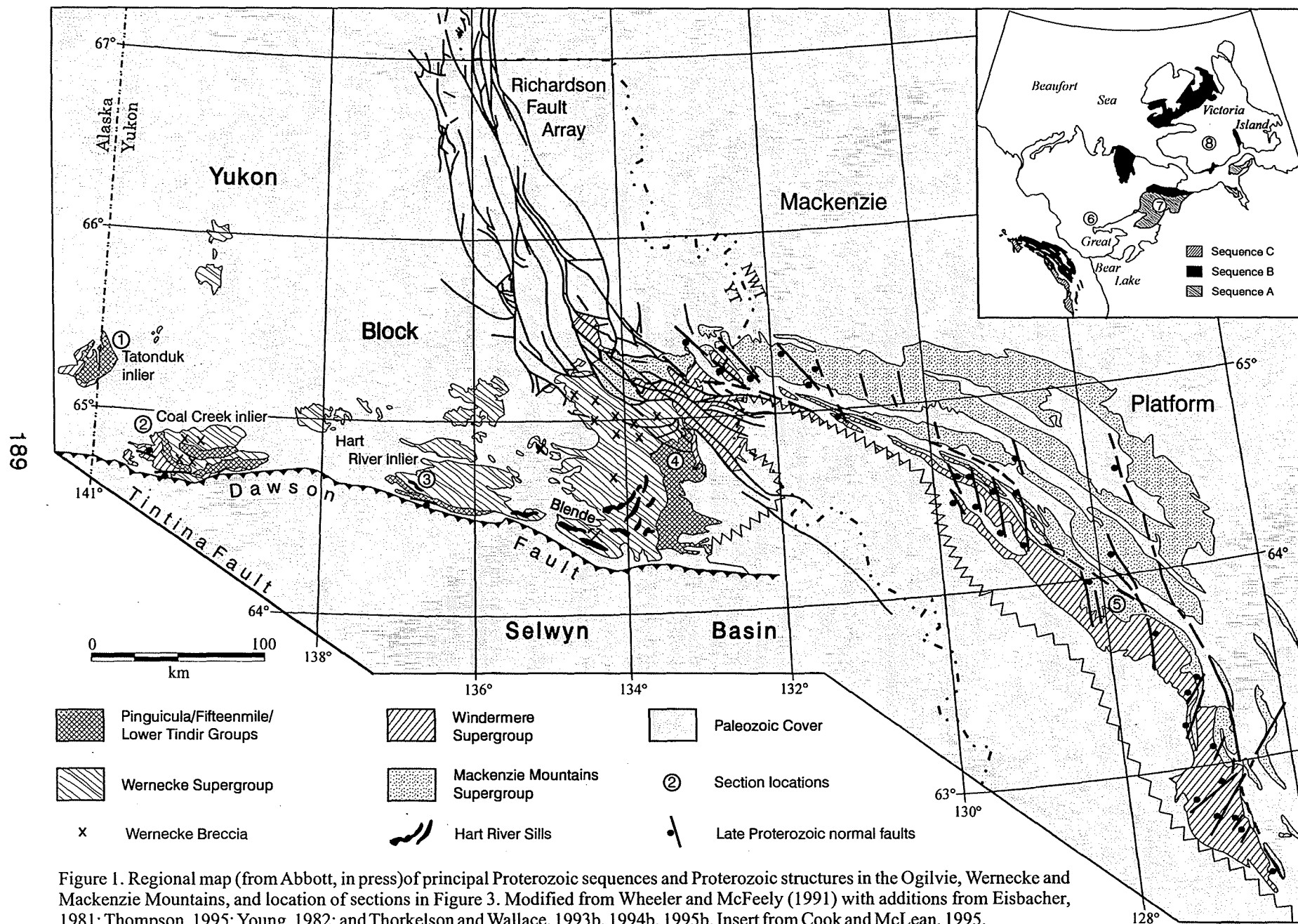


Figure 1. Regional map (from Abbott, in press) of principal Proterozoic sequences and Proterozoic structures in the Ogilvie, Wernecke and Mackenzie Mountains, and location of sections in Figure 3. Modified from Wheeler and McFeely (1991) with additions from Eisbacher, 1981; Thompson, 1995; Young, 1982; and Thorkelson and Wallace, 1993b, 1994b, 1995b. Insert from Cook and McLean, 1995.

and intrusive breccias, for the first time permit convincing correlation of Proterozoic sequences across the Ogilvie and Wernecke Mountains. A more complex stratigraphic and structural history than had previously been thought is now apparent. We propose here that Sequence B includes three laterally consistent, unconformity-bounded sequences: a lower shoaling upward clastic-carbonate sequence, a middle shallow-water clastic-dominated sequence, and an upper carbonate sequence.

Relationships between strata and intrusive breccias

Numerous breccia zones ranging in size from a few tens of m² to 5 km² are scattered throughout much of the Wernecke and Western Ogilvie (Coal Creek) inliers (Archer and Schmidt, 1978; Bell and Delaney, 1977; Lane, 1990). They crosscut their host strata, and are generally considered to be intrusive bodies resulting from forceful emplacement. The breccias consist of variably altered clasts of the Wernecke Supergroup and minor diorite set in a matrix of hydrothermally precipitated minerals dominated by hematite, chlorite, quartz, carbonate and feldspar. Metasomatic aureoles surrounding the breccia zones typically extend into the country rock for tens of metres. Recent work in the Wernecke Mountains indicates that the breccias were generated after a period of deformation and localized schist formation in the Wernecke Supergroup. The breccias are targets of ongoing mineral exploration for gold, copper and cobalt. Earlier suggestions that they originated as evaporite or mud diapirs (Bell, 1989; Lane, 1990) have been superseded by models involving explosive expansion of volatile-rich fluids related to igneous intrusions (Hitzman et al., 1992; Thorkelson and Wallace, 1994). A U-Pb date of 1.27 $\pm$ 0.04 Ga on monazite was obtained from an outlying breccia zone in the Richardson Mountains (Parrish and Bell, 1988). Recently, we obtained a preliminary U-Pb (sphene) date of ca. 1.6 Ga on one of the main breccia zones in the Wernecke Mountains, at the Slab mineral occurrence. We postulate that breccia formation and initial metasomatism occurred at 1.6 Ga., and was followed at 1.27 Ga by hydrothermal activity possibly related to emplacement of the Mackenzie dyke swarm.

In the Wernecke Mountains, the breccias intrude the Wernecke Supergroup and probably the Slab volcanics, a locally preserved succession of mafic lava flows. The Pinguicula Group unconformably overlies the Wernecke Supergroup and the breccias, as indicated by an abrupt truncation of both breccia textures and metasomatic alteration. For 1-6 m beneath the unconformity, Wernecke breccia is commonly leached and locally displays weak supergene oxide enrichment marked by malachite staining. These features are regarded as products of regolith formation during an interval of Middle to Late Proterozoic weathering (Thorkelson and Wallace, 1994a).

In the Coal Creek inlier (Fig. 2), the breccias have been interpreted as intruding not only the Wernecke Supergroup, but also the lower Fifteenmile Group (Lane, 1990; Thompson et al., 1992). Our recent investigations of critical localities have revealed that the Ogilvie Mountains breccias *do not intrude any strata of the Fifteenmile Group*. Instead, the Fifteenmile Group rests nonconformably on breccia that has been leached and locally silicified. At locality A, a cliff face exposes mudrock and sandstone of the basal Fifteenmile Group (PR1) resting on crumbly, yellowish breccia (Pbx). This "leached" breccia extends downwards for about 1 m where it abruptly grades into breccia with normal characteristics such as green-red mottled colour, disseminated specular hematite, and a chlorite-carbonate matrix. At the base of the leached zone, malachite staining is locally present. The metasomatic alteration which is pervasive in the breccia is nowhere evident in the overlying Fifteenmile strata. Similar observations were made at locality B where Unit PR5 of the lower Fifteenmile Group is preserved in a syncline on the crest of a ridge. There, the leached zone in the underlying breccia is 5-10 m thick, the top 1-2 m of which is strongly silicified by red and white chalcedony. Above the unconformity, buff carbonate and maroon shale of the lower Fifteenmile Group show no evidence of brecciation or metasomatism.

At locality C, part of a breccia body mapped by Thompson et al. (1992) is considered to be younger than, and unrelated to, the Ogilvie Mountains breccias. The breccia is developed in lower Fifteenmile group dolostone (Unit PR3) as intensely fractured dolostone surrounded by veins of red-weathering white dolomite spar. Overburden separates this breccia from true Ogilvie Mountains breccia to the north and east. Nowhere does the breccia show evidence of iron and silica metasomatism ubiquitous to the Ogilvie Mountains and Wernecke breccias. Rather, the breccia at locality C belongs to a common type of carbonate-only breccias, probably related to dewatering, which occurs sporadically in most Early Proterozoic to Early Paleozoic dolostone in the Ogilvie and Mackenzie mountains.

Figure 2. Generalized geological map of Coal Creek inlier (modified from Wheeler and McFeely, 1991) and detailed geological maps showing the location of critical localities A, B, and C (from Thompson et al., 1992). Map units are described in the text.

Other localities where zones of Ogilvie Mountains breccia have been interpreted to lie within the Fifteenmile Group were also investigated. In all cases, the Fifteenmile Group is either faulted against or unconformably overlies the breccia bodies. Evidence for Ogilvie Mountains breccia crosscutting any of the Fifteenmile strata is completely lacking, and we conclude that the Fifteenmile Group, like the Pinguicula Group, was deposited on a substrate of Wernecke Supergroup and its hosted breccia zones after a lacuna involving erosion and weathering.

Correlations of Sequence B strata

The three subdivisions proposed here for Sequence B in the Wernecke and Ogilvie Mountains consist of a lower shoaling upward clastic-carbonate sequence, a middle shallow-water sandstone-rich sequence, and an upper carbonate sequence (Figure 3). In the Hart River inlier, the lower and middle sequences belong to the Pinguicula Group and the upper is represented by the Callison Lake dolostone. In the Coal Creek inlier, the lower and middle sequences belong to the lower Fifteenmile group, and the upper sequence belongs to the upper Fifteenmile Group. In the Wernecke inlier, the lower and middle sequences belong to the Pinguicula Group and the upper sequence is absent, possibly because of erosion prior to deposition of the Windermere Supergroup. A disconformity separates the middle sequence from the lower strata in the Hart River and Coal Creek inliers whereas in the Wernecke inlier the contact is conformable and apparently gradational. Another locally angular unconformity separates the upper and middle sequences.

Lower sequence

The lower sequence remains remarkably consistent across the Wernecke Mountains and into the Hart River inlier, a distance of 180 km, but differs somewhat in the Coal Creek inlier. In the Wernecke and Hart River inliers, it is up to 2600m and 1100m thick respectively and comprises three units of the Pinguicula Group: dark shale and siltstone with basal conglomerate and arkose (Unit A) overlain by orange to buff weathering well bedded silty carbonate rocks (Unit B), which is in turn overlain by light to dark grey weathering, massive to thick bedded dolostone, locally with stromatolites or pronounced "zebra" texture (Unit C). In the Coal Creek inlier, descriptions of the lower Fifteenmile Group (Thompson and Roots, 1982; Thompson, 1995) are sketchy and the internal stratigraphy of the sequence not entirely clear. The lower Fifteenmile Group forms two dissimilar belts. In the northern belt, the lower sequence includes dark shale and siltstone interbedded with dolostone and dolostone olistoliths (Unit PR1), which is overlain by orange weathering dolomitic mudstone, lesser dolostone breccia and massive dolostone (Unit PR2) containing grey stromatolitic dolostone lenses (Unit PR2a). The southern belt consists of shallow water carbonate (Units PR3+4). Grey dolostone (Unit PR3), whose stratigraphic relations with older rocks are not exposed, occurs in one locality. Grey dolostone containing breccia, oolitic packstone and stromatolites (Unit PR4) disconformably overlies the Wernecke Supergroup and the one exposure of Unit PR3, but is nowhere mapped in contact with Units R1 or R2. Whether Unit R4 is a facies equivalent of Units PR1 and /or PR2, or if it is younger and separated from them by an unconformity remains unclear. Abrupt variations in thickness of Units PR1 and PR2 have been attributed by Roots and Thompson (1992) to syndepositional listric normal faulting. Perhaps these units represent relatively deep-water sedimentation confined to down-thrown blocks whereas Unit PR4 represents concurrent shallow-water deposition on upthrown blocks.

Middle sequence

The middle clastic-dominated sequence is characterized by a highly variable internal stratigraphy defined by shallow-water clastic rocks including quartzite, siltstone, shale, and carbonate. Distinctive lithofacies and sedimentary structures such as micaceous siltstone, mudcracks and interference ripples are common to all three areas. In the Wernecke and Hart River inliers, the middle sequence consists of Unit D of the Pinguicula Group (Unit D of Thorkelson and Wallace, 1995, includes Units D, E (Corn Creek quartzite), and F of Eisbacher, 1981). In the Wernecke inlier, it is about 1050 m thick and comprises a basal, ~100 m thick sequence of interbedded black shale and dolostone overlain by interbedded thin to very thick bedded buff, grey and orange weathering, locally stromatolitic dolostone; black weathering shale; thin to medium bedded, black, maroon, and buff weathering, locally muscovite-bearing siltstone; finely laminated grey to maroon weathering nodular limestone; and thick-bedded grey weathering quartz arenite. Carbonate predominates in the lower portions of the sequence, and quartz-rich sandstones predominates in the upper part where it includes mappable units up to 200 m thick of quartz arenite in three or more

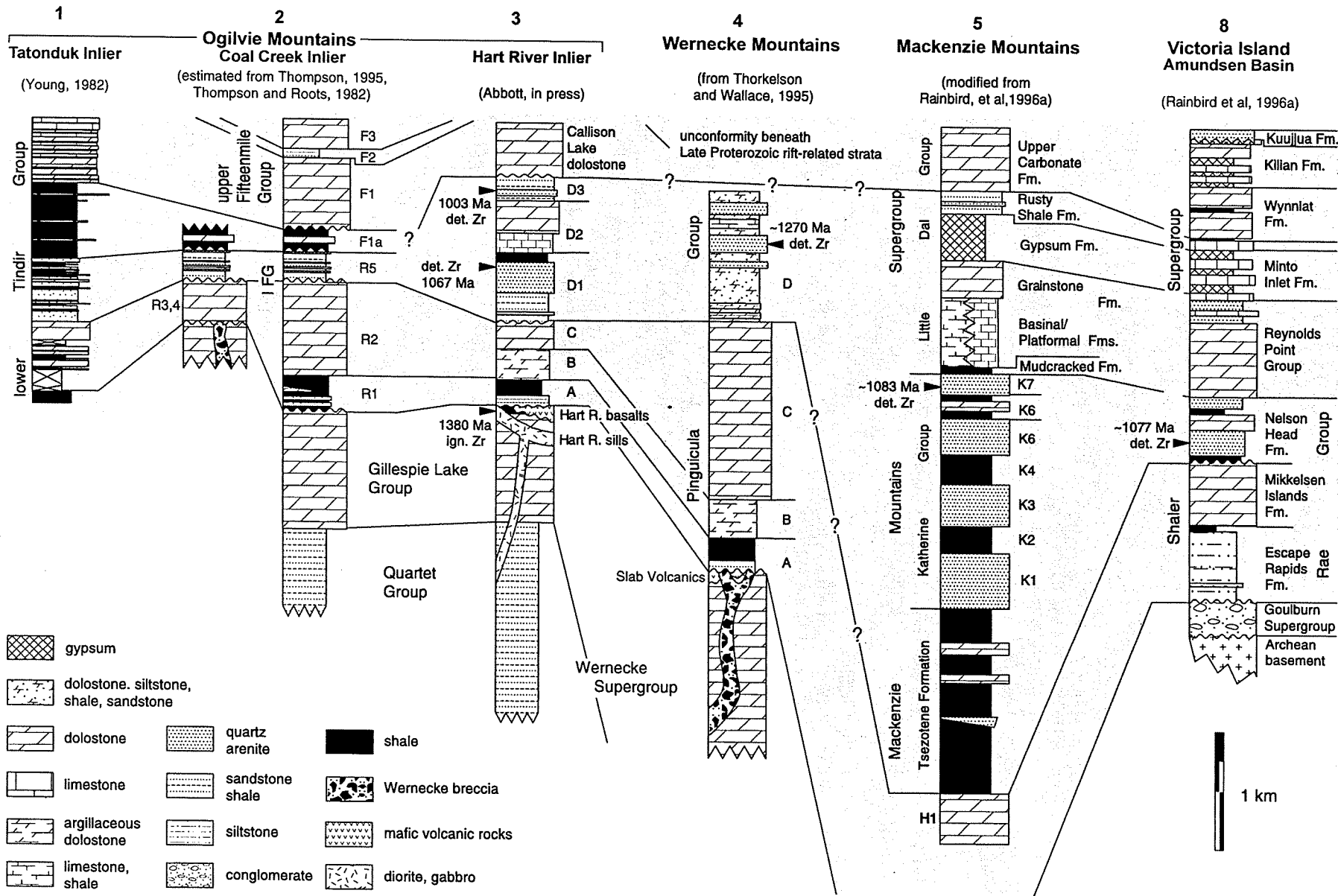


Figure 3. Correlation of Middle and Early Proterozoic sequences in the Ogilvie, Wernecke and Mackenzie Mountains, and Victoria Island (from Abbott, in press). Shaded area denotes strata belonging to Sequence B of Young et al (1979). Location of sections shown on Figure 1.

stratigraphic positions. In the Hart River inlier, correlative strata are 780 m thick and belong to Units D1, 2, and 3. Unit D1 includes basal siliciclastic rocks, a middle thick-bedded quartzite member and a thin upper member of maroon and green shale. Unit D2 includes a lower thin-bedded limestone member and an upper well bedded dolostone member. Unit D3 includes dark weathering thinly laminated to thick bedded quartzite and sandstone interbedded with varying amounts of shale and micaceous siltstone and orange dolostone. In the Coal Creek inlier, equivalent units belonging to the Fifteenmile Group include Unit PR5 and possibly Unit PF1. Unit PR5 is about 300 m thick (Thompson and Roots, 1982) and consists primarily of black, maroon and olive shale, interbedded with micaceous siltstone, quartz sandstone, and lesser stromatolitic limestone, pebbly mudstone, diamictite, and near the base, thin pebble conglomerate. Unit PR5a consists of thin discontinuous lenses of light grey dolostone in Unit PR5.

Upper sequence

The upper sequence, restricted to the Hart River and Coal Creek inliers, consists almost entirely of dolostone and limestone. The Callison Lake dolostone is well bedded, light grey weathering, and forms resistant craggy bluffs. Sedimentary structures are well preserved and include delicate algal laminations, stromatolites, pisoliths, and intraformational breccias. Lenses of grey to black chert up to 10 cm thick are common and characteristic. The upper Fifteenmile Group overlies the lower Fifteenmile Group disconformably, and locally with angular unconformity, and includes four units with a total thickness of at least 1200 m (Thompson and Roots, 1982; Thompson et al., 1992; Thompson, 1995). Unit PF1a occurs only locally beneath Unit PF1 and consists of interbedded argillite and dolostone (Thompson, 1995). The "craggy dolostone" (Unit PF1) consists of resistant, medium to dark grey, fetid, crystalline stromatolitic dolostone with variable thickness in the order of 600 m. The "craggy dolostone" is overlain by a marker about 60 m thick (Unit PF2) of black and brown weathering shale and siltstone with thin interbeds of red-weathering quartzite. It is overlain by the "cryptalgal dolostone" (Unit PF3) a heterogeneous unit of laminated to thinly bedded dolostone up to 250 m thick. The dolostone is locally stromatolitic and includes chert and dolomitic breccia. The Callison Lake dolostone most closely correlates with Unit PF1 of the upper Fifteenmile Group. Strata equivalent to Units F2 and 3 may never have been deposited in the Hart River inlier or were removed by erosion prior to deposition of Late Proterozoic strata.

Regional implications

Recognition that strata assigned to Sequence B in the Ogilvie and Wernecke Mountains consist of three successions for the most part separated from one another by unconformities, and recent revisions to the ages of underlying older rocks invites reexamination of previous correlations with other successions in Sequence B (Figure 4) and of the significance of Sequence B itself. Sequence B was originally considered to be an essentially continuous sedimentary sequence that unconformably overlies rocks as young as 1.27 Ga in the Wernecke Mountains and in the Coppermine Homocline in the western Arctic (Young et al, 1979; Cook and McLean, 1995; Rainbird et al, 1996). The youngest rocks beneath the Pinguicula Group are now known to be the ~1.6 Ga Wernecke breccias in the Wernecke inlier and the 1.38 Ga Hart River sills in the Coal Creek inlier (M.L. Bevier, in Abbott, in press). In the Coppermine Homocline a 1.27 Ga rift event is documented by the Coppermine lavas and by faults truncated by younger strata (Cook and McLean, 1995). In the Hart River and Wernecke inliers, quartzite from the middle sequence contains detrital zircons as young as 1.0 and 1.27 Ga respectively, indicating correlation with quartzite with similar age zircons in the Shaler Supergroup and the Mackenzie Mountains Supergroup (Rainbird et al., in press). However, the possibility that the unconformity separating the lower and middle sequences represents the 1.27 Ga rift event cannot be discounted. If the lower sequence is older than 1.27 Ga it could correlate with the Dismal Lakes Group in the Coppermine Homocline. The significance of the unconformity separating the middle and upper sequences is unclear. Correlation of the upper Fifteenmile Group and Callison Lake dolostone with carbonate rocks in the upper part of the Mackenzie Mountains and Shaler Supergroups as proposed by previous workers remains likely.

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References

- Abbott, J.G., in press. Geology of the upper Hart River Area, Eastern Ogilvie Mountains, Yukon Territory (116A/10. 116A/11); Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Bulletin 9.
- Abbott, J.G., 1993. Revised stratigraphy and new exploration targets in the Hart River Area (NTS 116A/10, 116A/11), southeastern Yukon. *In* Yukon Exploration and Geology, 1992, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 13-23.
- Abbott, J.G. and Roots, C.F., 1993a. Geological map of sheet 116A/10. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs, Canada, Open File 1993-7
- Abbott, J.G. and Roots, C.F., 1993b. Geological map of Two Beaver Lake map area (116A/11). Exploration and Geological Services Division, Yukon, Indian and Northern Affairs, Canada, Open File 1993-8.
- Archer, A. R. and Schmidt, U., 1978. Mineralized breccias of Early Proterozoic age, Bonnet Plume River District, Yukon Territory. *CIM Bulletin* v.71, no.796, p. 53-58.
- Bell, R.T., 1986. Megabreccias in northeastern Wernecke Mountains, Yukon Territory. *In*: Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p.375-384.
- Bell, R. T., 1989. A conceptual model for development of megabreccias and associated mineral deposits in Wernecke Mountains, Canada, Copperbelt, Zaire, and Flinders Range, Australia. *In*: Uranium resources and geology of North America; proceedings of a technical committee meeting organized by the International Atomic Energy Agency and held in Saskatoon, Canada (1987), p. 149-169.
- Bell, R. T. and Delaney, G.D., 1977. Geology of some uranium occurrences in Yukon Territory. *In*: Current Research, Part A. Geological Survey of Canada Paper 77-1A, p. 33-37.
- Cook, D. G., and MacLean, B.C., 1995. The intracratonic Forward orogeny, and implications for regional correlations, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, Vol. 32, p. 1991-2008.
- Eisbacher, G.H., 1981. Sedimentary tectonics and glacial record in the Windermere Supergroup, Mackenzie Mountains, northwestern Canada. Geological Survey of Canada, Paper 80-27, 40 p.
- Hitzman, M. W., Oreskes, N., and Einaudi, M. T., 1992. Geological characteristics and tectonic setting of Proterozoic iron oxide (Cu-U-Au-REE) deposits. *In*: G. Gall and K. Schulz (Eds.): Precambrian Metallogeny Related to Plate Tectonics. Precambrian Research. vol. 58.
- Lane, R. L., 1990. Geologic setting and petrology of the Proterozoic Ogilvie Mountains breccia of the Coal Creek inlier, southern Ogilvie Mountains, Yukon Territory. Unpublished M.Sc. thesis, University of British Columbia, Vancouver Canada, 223 p.
- Parrish, R. R. and Bell, R.T., 1987. Age of the NOR breccia pipe, Wernecke Supergroup, Yukon Territory. *In* Radiogenic and Isotopic Studies: Report 1, Geological Survey of Canada, Paper 87-2, p. 39-42.
- Rainbird, R. H., Jefferson, C. W., and Young, G. M., 1996. The early Neoproterozoic Succession B of northwestern Laurentia: Correlations and paleogeographic significance. *Geological Society of America Bulletin*, v.108, p. 454-470.
- Rainbird, R. H., McNicoll V. J., Theriault, R. J., Heaman, L. M., Abbott, J.G., Long, D.G.F., and Thorkelson, D. J., in press. Pan-continental river system draining Grenville orogen recorded by U-Pb

- and Sm-Nd geochronology of Neoproterozoic quartzites and mudrocks, northwestern Canada. *Journal of Geology*.
- Roots, C.F., and Thompson, R. I., 1992. Long-lived basement weak zones and their role in extensional magmatism in the Ogilvie Mountains, Yukon Territory. *In* Hyndman, D.W. Mogk, D.W., and Mason, R. (eds.), *Basement Tectonics 8: Characterization and Comparison of Ancient and Mesozoic Continental Margins- Proceedings of the 8th International Conference on Basement Tectonics* (Butte Montana), p. 359-372.
- Thompson, R. I., 1995. Geological compilation (1:250 000) of Dawson map area (northeast of Tintina Trench); Geological Survey of Canada, Open File 3223.
- Thompson, R. I., and Roots, C. F., 1982. Ogilvie Mountains Project, Yukon; Part A: a new regional mapping program. *In* *Current Research, Part A*, Geological Survey of Canada, Paper 82-1A, p. 403-411.
- Thompson, R. I., Roots, C.F., and Mustard, P. S., 1992. Geology of Dawson Map area (116B,C) (northeast of Tintina Trench); Geological Survey of Canada, Open File 2849 (13 sheets, scale 1:50 000).
- Thorkelson, D. J. and Wallace, C.A., 1993a. Development of Wernecke Breccias in Slats Creek(106D/16) map area, Wernecke Mountains, Yukon. *In* *Yukon Exploration and Geology*, 1992. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 19-30.
- Thorkelson, D. J. and Wallace, C.A., 1993b. Geological map of Slats Creek (106D/16) map area, Wernecke mountains, Yukon. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Open File 1993-2-G.
- Thorkelson, D. J. and Wallace, C.A., 1994a. Geological setting of mineral occurrences in Fairchild Lake map area (106C/13), Wernecke Mountains, Yukon. *In* *Yukon Exploration and Geology* 1993. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 79-92.
- Thorkelson, D. J. and Wallace, C.A., 1994b. Geological map of Fairchild Lake map area (106C/13), Wernecke Mountains, Yukon. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Open File 1994-6.
- Thorkelson, D. J. and Wallace, C.A., 1995a. Geology and mineral occurrences of the "Dolores Creek" map area (106C/14), Wernecke Mountains, northeastern Yukon. *In* *Yukon Exploration and Geology*, 1994. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 19-30.
- Thorkelson, D. J. and Wallace, C.A., 1995b. Geological map of the "Dolores Creek" Map Area (106C/14), Wernecke Mountains, northeastern Yukon. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, Open File 1995-6.
- Wheeler, J. O. and McFeely, P., 1991. Tectonic assemblage map of the Canadian Cordillera and adjacent parts of the United States of America; Geological Survey of Canada, Map 1712A, scale 1:2 000 000.
- Young, G. M., Jefferson, C.W., Long, D.G.F., Delaney, G.D., and Yeo, G.M., 1979. Middle and Late Proterozoic evolution of the northern Canadian Cordillera and Shield. *Geology*, Vol. 7, p.125-128.

Geological setting and character of Jura-Cretaceous plutonic rocks and the associated Endako molybdenite deposit, Nechako River area, central B.C.

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The northwesterly-trending Jura-Cretaceous Endako batholith in eastern Stikinia (Fort Fraser-Nechako River map areas (NTS 93F, K)) hosts the Endako porphyry molybdenite (Mo) deposit. It has been variously considered part of the Jurassic Topley Intrusions, Endako Intrusions and Early Cretaceous Francois Lake Plutonic Suite. New mapping, geochronology, and chemical and isotopic analyses define at least 5 constituent suites: 1) unmineralized Late Triassic (ca. 220 Ma) Boer plutonic suite; 2) poorly-mineralized Middle Jurassic (171-163 Ma) Stag Lake suite; 3) well-mineralized Late Jurassic (158-155 Ma) Francois Lake Plutonic Suite which hosts the Endako-style, low-fluorine, porphyry Mo deposits; 4) Early Cretaceous (147-145 Ma) intrusions which are likely coeval with the mineralization; and 5) unmineralized, satellitic mid- to Late Cretaceous Fraser Lake suite and Eocene(?) stocks.

Late Triassic Boer plutonic suite mafic biotite-hornblende diorite and gabbro are characterized by pervasive, post-emplacement, planar and linear fabrics of unknown age.

Middle Jurassic Stag Lake intrusions define the eastern and northeastern batholith margins and consists of older mafic (biotite-hornblende diorite and gabbro), and younger intermediate (hornblende-biotite quartz monzodiorite and granodiorite) phases; biotite quartz monzonite to monzogranite may represent related felsic phases. The rocks are commonly mesocratic and xenolith-, clinopyroxene- and titanite-bearing. Mineral and xenolith foliation is most common near contact zones between mafic and intermediate phases. The suite is compositionally heterogeneous but is generally of calc-alkaline, metaluminous, moderate-potash and volcanic arc affinities and closely resembles the coeval Three Sisters Plutonic Suite in northeastern Stikinia north of the Stikine River.

Late Jurassic Francois Lake and unnamed Early Cretaceous biotite monzogranite plutons northwest of the Stag Lake suite are the most quartz-rich, leucocratic, and mineralized of all and are further subdivided based on grain size, biotite abundance, degree of alteration, intergranular textures, intrusive relationships and age. Both suites record a complex, protracted history that included: emplacement, solidification, locally intense veining, Mo and pyrite mineralization and alteration, and late dyking, fracturing, and jointing. The Late Jurassic suite is coeval with Upper Jurassic volcanic rocks to the north and south. The structural control on the co-spatial but

younger (≤ 145 Ma) Mo mineral deposits hosted by the Late Jurassic suite suggests a possible dextral, trans-tensional tectonic environment for emplacement of the coeval Early Cretaceous intrusions. The Late Jurassic-Early Cretaceous plutons are distinctly high silica, calc-alkaline, weakly peraluminous, moderately to high potash, and of volcanic arc affinity with a relatively primitive or juvenile radiogenic and stable isotopic character.

INVESTIGATION OF A DISPLACEMENT-TRANSFER ZONE BY 3-D SEISMIC INTERPRETATION AND PHYSICAL MODELLING

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In the context of fold-thrust tectonics, a displacement-transfer zone is a three-dimensional region between the terminations of two en echelon thrust faults. As a case study of this phenomenon, interpretation has been done on a 3-D seismic data set from the Rocky Mountain Foothills of northeastern British Columbia. The volume is interpreted to include three foreland- and three (possibly four) hinterland-vergent thrusts. The initiation of backthrusting appears to be related to the presence of pre-existing antiforms as the fault cuts up-section through the strained rocks in the back-limb. One backthrust cuts a detachment fold above an older forethrust and another cuts what may be a buckle or fault-bend fold. It may be important to recognize that complex zones of displacement transfer exist between foreland- and hinterland-vergent faults and that pop-up features and larger backthrusts may play an important role in the distribution of strain. The unit juxtaposition created by backthrusting through synchronous or older folds may be significant when targeting such features as structural hydrocarbon traps. Some exploratory scaled physical modelling using the centrifuge technique has been carried out and will be employed in later stages of study to investigate the strain distributions and structural features which may be associated with such zones.

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U-Pb GEOCHRONOLOGY CONSTRAINTS ON EARLY CRETACEOUS AND PALEOCENE METAMORPHISM IN THE MOUNT CHEADLE AREA, SHUSWAP COMPLEX, SOUTHERN BRITISH COLUMBIA. Carr, S. D., Ghent, E. D., Simony, P.S. and Digel, S.

Two generations of sillimanite have been documented in Late Proterozoic metasedimentary rocks of the Mount Cheadle area of the northeastern Shuswap complex. Sillimanite coexists with kyanite throughout the matrix of the rocks (termed matrix sillimanite), and it also occurs within local sheared quartz-rich layers and metre-scale pods (termed pod sillimanite) that postdates matrix sillimanite. U-Pb geochronology studies were carried out on monazites from schists characteristic of the zone of matrix sillimanite-kyanite outside of the zone of pod-sillimanite overgrowth, and from within the pod-sillimanite zone. Data are consistent with Early Cretaceous regional metamorphism overprinted by monazite growth, leucosome formation, and by association, pod-sillimanite growth and localized shearing in the Paleocene at ~62-65 Ma.

Monazites from the sillimanite-kyanite zone are discordant and interpreted to have undergone Pb-loss at ca. 65 Ma. $^{207}\text{Pb}/^{206}\text{Pb}$ ages range from ~90-135 Ma and the upper intercepts of discordia chords are 130 +/- 25 Ma and 140 Ma +/- 8 Ma. In each of the samples dated there are reversely discordant ~65 Ma monazites interpreted to have grown below the monazite closure temperature for diffusion of Pb. Within the pod-sillimanite zone, zircons from migmatite leucosome grew at ~62-65 Ma, and reversely discordant monazites from the leucosome as well as from nearby schists grew below the ~700°C closure temperature at ~62-65 Ma.

Our data, taken together with that of Currie (1988) from the Cariboo Mountains to the northwest and Sevigny (unpublished data 1994) from Howard Ridge to the northeast indicate that the peak of metamorphism and the regional sillimanite isograd within this portion of the Shuswap complex is Early Cretaceous (~125-140 Ma). In the Mount Cheadle area, pod-sillimanite metamorphism occurred at ~62-65 Ma. It may be related to fluid influx into hot rocks, perhaps associated with igneous activity manifested to the south of the area by 63 Ma leucogranites (Sevigny et al. 1989).

The Ravens Throat area: a new mapping project in the Mackenzie Mountains, Northwest Territories

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The proposed Ravens Throat Project is a 1:50,000-scale mapping project with a primary objective of delineating the stratigraphy which hosts numerous Cu and Zn-Pb showings. The proposed map area lies to the immediate north of the Redstone Copper deposit, located near Coates Lake. The Ravens Throat area is ideally situated for incorporation of recent stratigraphic studies into a more detailed regional synthesis, and to investigate stratigraphic and structural (?) controls on mineralization.

The Ravens Throat area is underlain by Neoproterozoic strata of the Mackenzie Mountains and Windermere Supergroups, and by Cambrian to Devonian strata of the lower to mid-Paleozoic Mackenzie Platform (Table 1). The area lies along the west flank of the Redstone Arch, a late Proterozoic - early Paleozoic culmination where terminal Neoproterozoic (Windermere) to Devonian strata overlie the Neoproterozoic Mackenzie Mountains Supergroup along a series of overstepping unconformities.

Rocks of the Windermere Supergroup record the late Proterozoic rifting of northwestern Laurentia and were (in part) deposited in restricted, fault-bounded basins, developed upon a "basement" of Mackenzie Mountains Supergroup strata. Current tectonic interpretations (e.g., Ross, 1991; Narbonne and Aitken, 1993; and others) show the lower part of the Windermere Supergroup (Coates Lake and Rapitan Groups) as a rift-clastic section and the upper Windermere (Twitya to Blueflower Formations) as a passive margin sequence (Dalrymple and Narbonne, 1996). It is currently believed that continental separation (from Antarctica-Australia: Dalziel, 1991; Moores, 1991; Young, 1992) had occurred by the end of Rapitan deposition in the northern Cordillera. In contrast, recent work in the southern Cordillera (e.g., Bond and Kominz, 1984; Bond et al., 1985; Lickorish and Simony, 1995; Warren, 1996) indicates that rifting also occurred in latest Proterozoic - Early Cambrian time (recorded in units equivalent to the Backbone Ranges Formation of the Mackenzie Mountains), and it is suggested that continent separation may not have occurred until earliest Cambrian time. Indications of block faulting during deposition of the lower part of the Backbone Ranges Formation (Fritz et al., 1991) suggest that early Cambrian "rifting" may have also occurred in the northern Cordillera. Furthermore, occurrences of volcanic and coarse clastic rocks in the Lower Paleozoic strata of the Selwyn basin, and a series of overstepping unconformities within the Lower Paleozoic sequence of the Mackenzie Platform (Redstone Arch), are evidence of intermittent extensional deformation throughout the Lower Paleozoic (Cecile and Norford *in* Fritz et al., 1991).

The structural style of the central and northern Mackenzie Mountains is dominated by the Plateau fault; an east-verging Mesozoic thrust fault which follows a bedding-plane glide along the "Gypsum formation" of the Little Dal Group (Mackenzie Mountains Supergroup). The Plateau thrust runs through the center of the

Table 1: Stratigraphy of the Ravens Throat area

Era	Period	Super-group	GROUPS	FORMATIONS	LITHOLOGIES
Paleozoic	Devonian	Miss.		Besa River	shale
				Nahanni	limestone
				Headless	argillaceous limestone
				Landry	limestone
				Arnica	dolostone
				Sombre	dolostone
				Camsell	dolostone/limestone
				Delorme	dolostone
				Whittaker	cherty dolostone
				Broken Skull	dolostone
	Cambrian	Sil. Ord.		Rockslide	argillaceous limestone
				Sekwi	limestone
				Vampire	shale
				Backbone Ranges	sandstone
Neoproterozoic				Ingta	shale
				Risky	dolostone
				Blueflower	mudstone
				Gametrail	dolostone
				Sheepbed	mudstone
				Ice Brook/Keele	diamictite/dolostone
				Twitya	mudstone
				Shezal	diamictite
				Sayunei	glacial rhythmites
				Coppercap	limestone
				Redstone River	red mudstone/evaporites
				Little Dal	Upper carb. Rusty shale Gypsum dolostone shale evaporites
				Lower	Platform/Grainstone Mudrocks limestone shale/sandstone
				Katherine	"upper" (K7) "middle" (K6) "lower" (K1-K5) sandstone shale sandstone shale
				Tsezotene	shale

proposed study area and dies out immediately south, near Coates Lake. The Tsezotene fault, which diverges from the Plateau thrust just north of the Ravens Throat area, bounds the proposed map area to the east, and apparently dies out near Dal Lake, within the study area. The intervening area, between the Plateau and Tsezotene faults, is dissected by numerous faults which are presumed to be partly late Proterozoic in age. The proposed study area provides an opportunity to investigate the interplay between early (Proterozoic-Paleozoic) extension faults and later Mesozoic structures, and the extent to which the Mesozoic deformation has been influenced by pre-existing structures. In addition, some of the faults in the area (e.g. Hayhook fault, Gabrielse et al., 1973) may also have a strike-slip component, and the significance and timing of this deformation are enigmatic.

Two styles of mineralization have been identified in the proposed study area: (1) sediment-hosted stratiform copper (Kupferschiefer-type); and (2) Mississippi Valley-type (MVT) zinc-lead. Copper showings occur within the basal limestone of the Coppercap Formation (Neoproterozoic Coates Lake Group), near the contact with the underlying red mudstone of the Redstone River Formation. Detailed stratigraphy of the Coates Lake Group has been defined near Coates Lake (to the south, Jefferson, 1983) and has only been mapped locally within the proposed map area. Exploration work by Firesteel Resources Inc. in 1995 identified several new showings and previously unmapped exposures of the Redstone River and Coppercap Formations within the Ravens Throat project area.

Zinc-lead mineralization in the Ravens Throat area appears to be spatially associated with occurrences of the Manetoe hydrothermal dolomite facies. The Manetoe facies, a sparry dolomite, is most commonly developed at the base of the Middle Devonian Landry Formation, near its contact with the underlying Arnica Formation. The Manetoe facies was originally mapped by Douglas and Norris (1960) and Gabrielse et al. (1973) as a stratigraphic unit, but it is now apparent that the Manetoe dolomite is a diagenetic replacement facies (Morrow et al., 1986; Morrow and Cook, 1987), similar to the Presqu'île dolomite which hosted the Pine Point zinc deposit. In the Ravens Throat area, significant zinc mineralization has been discovered at the Kap prospect, and Firesteel Resources Inc. had an active exploration program centered around this prospect, in 1995 and 1996.

Additional potential for mineralization may also be present at other stratigraphic levels: (1) MVT Zn-Pb mineralization occurs within the Neoproterozoic Little Dal Group at Gayna River, 270 km NW of the Ravens Throat area. Extensive dolomitization and karstification in the upper part of the Little Dal Group was noted during a brief field visit in the Ravens Throat area in 1996. (2) The Katherine Group (Mackenzie Mountains Supergroup) is correlative with rocks of the Shaler Supergroup (Victoria Island) which host sediment-hosted (redbed-type) stratiform Cu deposits. (3) Rocks of the Rapitan Group locally contain bedded, hematite-jaspilite iron formations. These occurrences are most likely exhalative in origin (Yeo, 1981), and may be (laterally) associated with base metal deposits (?). (4) The latest Neoproterozoic Risky dolomite (Windermere Supergroup) is host to MVT zinc mineralization at Goz Creek in the eastern Yukon. The upper formations of the Windermere Supergroup (including the Risky) are undifferentiated on existing maps of the Ravens Throat area. (5) As discussed above, the tectonic setting in which the late Proterozoic to early Paleozoic strata of the Mackenzie Mountains were deposited (i.e. rifting and intermittent extension) is favorable to the development of hydrothermal systems and, by extension, to base metal deposition. (6) Finally, Paleozoic rocks in the footwall of the Plateau thrust have been proposed as a potential hydrocarbon play (Cecile et al., 1982; 1995).

References Cited

- Bond, G. and Kominz, M. A., 1984, Construction of tectonic subsidence curves for the early Paleozoic miogeocline, southern Canadian Rocky Mountains: Implications for subsidence mechanisms, age of breakup and crustal thinning: *Geological Society of America Bulletin*, v. 95, p. 155-173.
- Bond, G. C., Christie-Blick, N., Kominz, M. A. and Devlin, W. J., 1985, An early Cambrian rift to post-rift transition in the Cordillera of western North America: *Nature*, v. 315, p. 742-746.
- Cecile, M. P., Cook, D. G. and Snowdon, L. R., 1982, Plateau overthrust and its hydrocarbon potential, Mackenzie Mountains, Northwest Territories, in *Current Research, Part A: Geological Survey of Canada, Paper 82-1A*, p. 89-94.

- Cecile, M. P., Cook, D. G. and Snowdon, L. R., 1995, Plateau Overthrust - a Lewis-thrust type hydrocarbon play, Mackenzie Mountains, Northwest Territories: Canadian Society of Petroleum Geologists - Canadian Well Logging Society v. Program and Abstracts,
- Dalrymple, R. W. and Narbonne, G. M., 1996, Continental slope sedimentation in the Sheepbed Formation (Neoproterozoic, Windermere Supergroup), Mackenzie Mountains, N.W.T.: Canadian Journal of Earth Sciences, v. 33, p. 848-862.
- Dalziel, I. W. D., 1991, Pacific margins of Laurentia and East Antarctica-Australia as a conjugate rift pair: Evidence and implications for an Eocambrian supercontinent: *Geology*, v. 19, p. 598-601.
- Douglas, R. J. W. and Norris, D. K., 1960, Virginia Falls and Sibberton Lake map areas, Northwest Territories (95F, G): Geological Survey of Canada, Paper 60-19.
- Fritz, W. H., Cecile, M. P., Norford, B. S., Morrow, D. and Geldsetzer, H. H. J., 1991, Cambrian to Middle Devonian assemblages, Chapter 7, in Gabrielse, H. and Yorath, C. J., eds., *Geology of the Cordilleran Orogen in Canada*: Geological Survey of Canada, *Geology of Canada*, no. 4, p. 151-218. (*also Geological Society of America, The Geology of North America*, v. G-2).
- Gabrielse, H., Blusson, S. L. and Roddick, J. A., 1973, *Geology of Flat River, Glacier Lake and Wrigley Lake map-areas, District of Mackenzie and Yukon Territory*: Geological Survey of Canada, Memoir 366 (Part I and II), 421 p.
- Jefferson, C. W., 1983, The Upper Proterozoic Redstone Copper Belt, Mackenzie Mountains, N.W.T. [Ph.D. thesis]: University of Western Ontario, 445 p.
- Lickorish, W. H. and Simony, P. S., 1995, Evidence for late rifting of the Cordilleran margin outlined by stratigraphic division of the Lower Cambrian Gog Group, Rocky Mountain Main Ranges, British Columbia and Alberta: *Canadian Journal of Earth Sciences*, v. 32, p. 860-874.
- Moores, E. M., 1991, Southwest U.S.-East Antarctic (SWEAT) connection: A hypothesis: *Geology*, v. 19, p. 425-428.
- Morrow, D. W. and Cook, D. G., 1987, The Prairie Creek embayment and Lower Paleozoic strata of the southern Mackenzie Mountains: Geological Survey of Canada, Memoir 412, 195 p.
- Morrow, D. W., Cumming, G. L. and Koepnick, R. B., 1986, Manetoe facie -- a gas-bearing, megacrystalline, Devonian dolomite, Yukon and Northwest Territories, Canada: *American Association of Petroleum Geologists Bulletin*, v. 70, p. 702-720.
- Narbonne, G. M. and Aitken, J. D., 1993, Neoproterozoic of the Mackenzie Mountains, northwestern Canada: *Precambrian Research*, v. 73, p. 101-121.
- Ross, G. M., 1991, Tectonic setting of the Windermere Supergroup revisited: *Geology*, v. 19, p. 1125-1128.
- Warren, M. J., 1996, Contrasts between the Windermere and Hamill/Gog rift basins in the southern Canadian Cordillera: New insights into differences in basin configurations and upper crustal behaviour during extension, in Cook, F. and Erdmer, P., eds., *Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting: Lithoprobe Report No. 50*, p. 156-157.
- Yeo, G. M., 1981, The Late Proterozoic Rapitan glaciation in the northern Cordillera, in Campbell, F. H. A., ed., *Proterozoic basins of Canada*: Geological Survey of Canada, Paper 81-10, p. 25-46.
- Young, G. M., 1992, Late Proterozoic stratigraphy and the Canada-Australia connection: *Geology*, v. 20, p. 215-218.

THE SIGNIFICANCE OF MAFIC VOLCANIC ROCKS IN GREENSTONE BELTS OF THE SLAVE STRUCTURAL PROVINCE: AN EXAMPLE FROM THE PELTIER FORMATION, POINT LAKE, NORTHWEST TERRITORIES

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The 2.69-2.7Ga Peltier Formation, located in the north-central Slave Structural Province, is a prominent subaqueous mafic volcanic succession that unconformably overlies a granitic basement represented by the 3.15Ga Augustus Granite. The volcanic sequence is characterized by massive, pillowed and brecciated mafic rocks as well as 1-30m-thick dykes and sills that also crosscut the Augustus Granite. The pillowed facies is predominant. Locally, magnetite precipitated in hyaloclastites between pillows, suggestive of low-temperature hydrothermal venting on the Archean ocean floor. Sampling in conjunction with a detailed mapping project was conducted in order (i) to establish the relationship between the clastic sedimentary rocks of the Keskarrh Formation and the volcanic rocks of the Peltier Formation, (ii) to characterize the Peltier Formation from a geochemical and volcanological standpoint, and (iii) to resolve the problem between the turbiditic Contwoyto Formation and the other sedimentary and volcanic sequences. The overriding theme is to characterize the supracrustal succession in the Point Lake area and to establish the influence of the north-trending, crustal-scale Beniah Lake fault on the evolution of the central Slave Province. Three unconformities were documented: (1) Augustus Granite/Keskarrh Formation, (2) Contwoyto/Keskarrh Formations, and (3) Peltier/Keskarrh Formations. A fourth unconformity between the Augustus Granite and Peltier Formation is inferred. The Beniah Lake fault may have played a significant role in the evolution of this area and had a protracted history as suggested by the numerous unconformities that span 400Ma.

Preliminary results from the mafic rocks of the Peltier Formation at Cyclops Peninsula (65° 15' 30" N, 113° 08' 30" W) reveal the importance of this volcanic succession to the evolution of the Slave Province. The mafic volcanic rocks have <55% SiO₂ (LOI-free) and most display a narrow SiO₂ range of 49 to 53%. The Mg# values vary between 35 and 65. Additionally, there are tholeiitic Fe- and Ti-enrichment trends with increasing differentiation. Compared to primitive island arc tholeiites, the basalts have higher abundances of Ti and other high-field-strength-elements. The TiO₂ contents range between 0.7 and 2.7%. Chondrite-normalized REE abundances in the tholeiitic basalts have either flat REE patterns with (La/Yb)_n ratios ~1 or are slightly enriched in light REE (LREE) with (La/Yb)_n ratios ~2. The patterns of mantle-normalized abundances of incompatible trace elements in the tholeiites are characterized by a relative depletion in Nb with respect to the large-ion-lithophile elements and LREE. The initial ϵ_{Nd} -values range from -3.2 to +1.9 and correlate negatively with (La/Yb)_n. The studied volcanic rocks differ from MORB-like basalts of other Archean greenstone belts such as Abitibi belt in that a negative Nb anomaly is absent. The basalts were probably generated by melting of a heterogeneous mantle source at shallow depths in the spinel stability field followed by fractional crystallization. Basalts with isotopic and chemical signatures similar to the Peltier Formation are generally compared to a depleted subcontinental lithospheric mantle that exhibits an imprint of an older subduction-related process. The Peltier Formation compares favourably with back-arc basalts formed on continental crust.

TERTIARY EPISODIC COOLING IN THE SOUTHWESTERN CANADIAN
CORDILLERA AND CENTRAL COAST MOUNTAINS (NASS RIVER AREA):
EVIDENCE FROM APATITE FISSION TRACK THERMOCHRONOMETRY

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ABSTRACT

New apatite fission track ages and model cooling histories derived from confined horizontal track length histograms reveal a complex Cretaceous to Cenozoic low temperature cooling history for southwestern British Columbia. In combination with other geologic constraints, rapid cooling events are inferred to be linked to tectonic causes. Mid-Cretaceous cooling and a coeval unconformity are attributed to the surface uplift and erosion of the thrust belt that formed along the continental margin at that time. Cooling along the western margin of the southern Coast Mountains at ~67 Ma is temporally linked to thrusting in the Rocky Mountains, but the direct cause of cooling is not clear. Ca. 50 Ma rapid cooling recorded along the eastern margin of the southern Coast Mountains probably reflects normal faulting related to transcurrent faulting east of the Coast Mountains.

A ~40 Ma reheating event has been elucidated by modelling of thermal histories from apatite fission track length histograms. This event is mostly likely linked to the formation of the Cascade Magmatic Arc, above the subducting, oceanic Juan de Fuca Plate. Slightly younger ca. 30 Ma cooling ages along the eastern margin of the southern Coast Mountains reflect cooling as the magmatic arc migrated toward the west. Late Miocene ages from the Meager Creek area probably reflect annealing of fission tracks due to recent high heat flow.

The role of tectonics in the formation of the spectacular topography of the central Coast Mountains is not clear. Preliminary results from apatite and zircon samples from Observatory Inlet suggest that the Coast Mountains near 55°N cooled through ~100°C (the closure temperature for the retention of fission tracks in apatite) between 5 and 17 Ma, and through ~240°C (the closure temperature for the retention of fission tracks in zircon) between 19 and 49 Ma. Not surprisingly, samples from farther inland and higher elevations have older apatite fission track ages (32 to 50 Ma).

The Queen Charlotte Basin and Coast Mountains: A Paired Belt of Subsidence and Uplift Caused by a Low-Angle Normal Fault

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The Queen Charlotte Basin and Coast Mountains are a paired belt of synchronous subsidence and uplift which formed inboard of the Queen Charlotte Fault in the Neogene, accompanied by regional basaltic volcanism. We propose that a combination of simple shear on a lithosphere-scale low-angle normal fault and pure shear could have been responsible for the observed vertical motions. Extensive crustal thinning in the basin decreases towards the Coast Mountains, and has resulted in net subsidence of typically 3 km since 20 Ma. Subsidence formed the current broad continental shelf and a potentially petroliferous basin. The >3.5 km uplift of a low-lying coastal plain to a rugged mountain belt east of the basin, in the Coast Mountains has had significant impact on regional climatic and biogeographic patterns over the last 14 Ma.

When subduction gave way to a transform motion about 47 Ma on the Pacific-North America plate boundary, the overthickened continental crust became unstable. A possible trigger for the initiation of normal faulting may have been an increase in heat flow related to the passage of the Anahim “hot-spot”. Widespread brittle extension of the crust beneath the Queen Charlotte Basin could be an indication of where the low-angle normal fault broke the upper lithosphere. Farther inland where the fault thinned the lower lithosphere, uplift of the Coast Mountains may be due to thinning of the upper mantle and its replacement with less dense asthenosphere. Magmatic activity over the last 25 Ma in the basin and mountain belt could have been caused by decompression melting. This is the first time that a mechanism linking these phenomena has been proposed.

If correct, this model could have implications for mineral deposit models and exploration strategies. The Specogna epithermal gold and silver deposit (also referred to as the Babe or Cinola deposit) is located along a north to north-northwest striking, east-side down normal fault that crops out on Graham Island. The fault has an unknown strike-slip component of displacement and is considered one of the western-most faults related to extension in the Queen Charlotte Basin. Hydrothermal alteration associated with the deposit has been dated at 14 Ma, and motion on the fault postdates intrusion of an Early Miocene rhyolite dyke.

PHYSICAL MODELLING OF FOLD-THRUST PROCESSES: REACTIVATION OF EXTENSIONAL FAULTS, LINKAGE OF SHORTENING BETWEEN STRUCTURAL LEVELS, AND FORMATION OF POP-UPS AND TRIANGLE ZONES

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We investigate processes associated with fold-thrust tectonics by physical modelling using the centrifuge technique. In a thin-skinned setting, a pre-existing extensional (growth) fault can be reactivated as a thrust during contractional deformation. Reactivation can initiate ahead of the advancing fold-thrust deformation front and the resulting inversion structure may be larger than the fold-thrust structures. When the primary fault has a strike that is oblique to the superimposed compression direction, the timing and amount of reactivation vary with the distance from the thrust front. These relationships have implications for petroleum exploration because reactivation may form localized structural traps early enough to trap an early hydrocarbon charge.

In a thick-skinned setting, reactivation of a basement fault as a thrust channels shortening into the cover strata and shelters the underlying basement from internal deformation. Linkage of shortening at different structural levels, such as basement and sedimentary cover or different levels within the cover, is strongly dependant on the character (thickness and strength) of the intervening unit. The models also show how strain is accommodated within a weak unit above a thrust that ramps upward through a competent unit.

Pop-up structures and type-I triangle zones develop in the models at sites where there is concurrent fore- and backthrusting, and this occurs above a weak decollement horizon or a thick incompetent unit where the axis of maximum compressive stress is oriented at a shallow angle to mechanical layering. Type-II triangle zones are rare in the models, but they have been observed to develop without being nucleated by abnormal pore pressure or abnormally weak decollement horizons, so these are not requisite conditions.

Digital Geologic Map of Yukon

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The Yukon Digital Map Project will produce a digital compilation at 1:500,000 scale of Yukon bedrock geology available on CD-ROM, and a wall-map of Yukon bedrock geology at 1:1,000,000 scale by the fall of 1998. Funding for the project originates from the Yukon Government, Indian and Northern Affairs Canada, and the Geological Survey of Canada. The CD-ROM will provide a regional synthesis and up-to-date compilation of Yukon bedrock geology in a single source. The data will be made available in multiple formats whereby features of interest can be directly imported into the user's illustration, CAD, or GIS programs. Digital bedrock geology can be more easily manipulated than traditional paper overlays and when combined with cultural, topographic, geophysical and other data forms the basis of resource assessment, exploration, and land use decisions. The wall map, a derivative of the digital data set, will be a valuable educational resource and useful in regional scientific and exploration program planning.

DATA STRUCTURE

The Yukon digital geologic map will encompass a large amount of geological and topographical data. To be accessible in manageable-sized pieces, the data is organized both by geographic area and information type. The Yukon is divided into 45 tiles corresponding to the 1:250 000 scale National Topographic System, within which different types of information comprise separate themes. With this organization, single or multiple types of information can be easily extracted for a given area and used without having to manipulate the entire data set.

The digital data is compiled using ARCINFO software by ESRI Inc., a high-end geographic information system used extensively at the Geological Survey of Canada. Other software packages utilized include ARCVIEW, AUTOCAD, DBASE and QUATTRO PRO.

DATA SETS AND METHODS

Compilation of bedrock geology is the largest component of the project. Data is obtained from various, mostly non-digital sources. An ink-on-mylar overlay is compiled for each 1:250,000 map-area, which is then scanned to produce an image (TIF format). The image is imported into ARCINFO, and a conversion to vector format done automatically. The quality of linework produced is excellent, more precise than that capable by hand digitizing, and is accomplished much faster. Many subsequent steps are required to attribute the lines (ie to classify them as defined, approximate, assumed, thrust fault, normal fault, etc), make and label polygons (ie rock units), and input geological names. Several other databases are compiled concurrently, including a list of data sources, original rock unit legends, a compilation legend, as well as tectonic assemblage and terrane descriptions. Information in these related tables can be extracted, displayed or queried for each polygon on the map.

Mineral (Yukon Minfile) and fossil occurrences (Geol. Surv. Can.) as well as isotopic age data (U.B.C.) will be added as point data, without revision from the original sources. Information in the related data tables can be extracted, displayed or queried for each point on the map.

Topographic data (Digital Chart of the World, 1:1,000,000 scale) are obtained in ARCINFO digital format. Using the ARCINFO software the data are being re-organized into the various themes and divided into the tiles as appropriate for the Yukon. This topographic data set is the only one available in a consistent format across the territory. It can also be re-released without royalty.

PERFORMING QUERIES

The linework and related databases are structured for analysis in a geographic information system, with which spatial and related data of different themes can be queried separately or together. With the appropriate software (eg. ARCVIEW, MAPINFO), one could extract a map of all of the granitic rocks in the Yukon, or a map of only those granitic rocks which have associated gold or tungsten occurrences for a portion of the territory. The bedrock geology theme will be able to be queried on geologic unit, rock type, age, source(s) of information, named geological features, tectonic assemblage and terrane.

MAGNETIC FABRICS IN THE SPARROW GRANITE PLUTON: MARKERS OF THE LATE ARCHEAN STRAIN FIELD IN THE SOUTHERN YELLOWKNIFE DOMAIN, SLAVE PROVINCE, CANADA

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The Sparrow Pluton is part of the Late Archean Prosperous Suite of two-mica granites that outcrop within cordierite and andalusite bearing meta-greywackes of the southern Yellowknife Domain, in the Slave Province of the Canadian Shield. The pluton is situated along the SNORCLE Lithoprobe deep-seismic transect, and is presently being dated by the Geological Survey of Canada using high-resolution U-Pb techniques.

Field relations show that the pluton was emplaced during some stage of the regional D2 structural event, which represents a regional dextral transpression. The northern part of the pluton has a roughly rectangular shape, whereas the southern part is an elongate "tail" that has apparently been deflected sinistrally. Microstructures in the pluton indicate only minor subsolidus deformation of the still hot granites.

The anisotropy of magnetic susceptibility (AMS) was used to map the internal magmatic structure and confirm the timing of pluton emplacement with respect to the main D2 event. The AMS is dominated by biotite and locally by pseudomorphich chlorite replacing biotite, possibly with minor contributions from secondary oxides. The magnetic foliation strikes NNW-SSE, and swings to NW-SE in the southern "tail", consistent with S2 trajectories in the surrounding country rocks and with the pluton shape. In the northern part of the pluton, the foliation poles define a girdle, whereas in the elongate southern part the foliation is steeply to moderately NE-dipping. The magnetic lineations plunge shallowly and show the progressive deflection from NNW-SSE in the northern part to NW-SE in the "tail". In the absence of regional extension lineations in the country rocks, the magnetic lineations provide the best indicators of the strong component of horizontal stretching associated with regional D2. The average susceptibility defines a gross compositional layering which appears to have been folded during tectonic deformation of the partly crystallized pluton. The strongest magnetic anisotropies ($P'=1.10$) occur along the central axis of the pluton "tail", suggesting that tectonic strain was concentrated in the parts that crystallized and cooled latest.

The magnetic fabric data and microstructures are consistent with the Sparrow Pluton having undergone a pervasive tectonic deformation as it crystallized during the main D2 regional event. The internal fabric and compositional patterns also indicate that the pluton has a horizontal internal compositional zonation, or layering. The magmatic structure, revealed by the AMS, suggests that the Sparrow Pluton may represent the exposed parts of a syntectonic laccolith. This interpretation may also be extended to the rest of the Prosperous Suite. A shallowly eastward dipping horizon, interpreted from the SNORCLE seismic-reflection profile to extend from the surface (near Yellowknife) to a depth of 5 km (near Tibbit Lake), may correspond to a structural décollement along which the laccolithic granite intrusions of the Prosperous Suite were localized. Alternatively, pluton emplacement may have been localized by the contact between metasediments and underlying metavolcanic rocks.

CONSTRAINTS ON THE GEOLOGIC EVOLUTION AND TECTONIC AFFINITY OF THE KLINKIT ASSEMBLAGE

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The informally named Klinkit assemblage stretches as a mappable and internally consistent, orogen-parallel belt approximately 300 km from north central Teslin (105C) through south west Wolf Lake (105B) map areas in southern Yukon, to the southern edge of Jennings River (104O) map area in northern British Columbia, where it underlies the central third of that 1:250 000 scale map area. The Klinkit assemblage (Harms and Stevens, 1996a) consists of:

- 1) thick, massive, commonly black or purple-grey, clean quartz sandstone, or black, clean quartz sandstone interbedded with black shale and chert. These two types of sequences may be lateral facies equivalents. Minor interbedded limestone in the latter facies has yielded Middle-Late Triassic conodonts (M. Orchard, Report No. MJO-1997-7, GSC Locality Number C-302650);
- 2) thick heterogeneous volcanic accumulations that include both fine and very coarse volcanoclastics and mafic flows;
- and 3) one or more Pennsylvanian carbonate horizons (Gabrielse, 1970; Abbott, 1981; M. Orchard, Report No. MJO-1997-7, GSC Locality Number C-302661).

These units are variable in thickness. Some of this variability can be attributed to original facies changes, but a component is also due to tectonic thinning in the overturned limbs of map scale folds. Rocks of the Klinkit assemblage occur in folds several km in wavelength and amplitude with WNW trending axes (oblique to regional NW trends in the orogenic belt), and have steep, axial planar cleavage developed in outcrop.

The Klinkit assemblage is in contact with several different Mesozoic and inferred-Mesozoic units mapped by Gabrielse (1970) in northernmost British Columbia. These are:

- 1) the Simpson Peak and Nome Lake batholiths. Conventional K-Ar analysis has yielded early Jurassic ages (Woodsworth et al, 1991; Armstrong, 1988) from these granodiorite to quartz diorite plutons (Gabrielse, 1970);
- 2) a volumetrically-small occurrence of undated aphanitic and augite-pheric flows tentatively correlated with the Triassic Shonetak Formation of Quesnellia by Gabrielse (1970);
- and 3) an undated greywacke, in apparent depositional unconformity over the Klinkit assemblage, inferred to be lower Jurassic by Gabrielse (1970) on the basis of possible correlation with the Inklin Formation.

These cross-cutting and overlap relationships suggest that the Klinkit assemblage constitutes a basement to poorly preserved, Quesnellia-like Mesozoic rocks in the northern Cordillera and, as such, has an analogous position to the Harper Ranch and Okanagan subterranean of southern British Columbia. The timing of contractional deformation within the Klinkit assemblage (elaborated below), the lithologic character of the assemblage and the probable tectonic setting in which it developed, and the faunal affinity of rare macrofossils in the assemblage, all suggest that the Klinkit assemblage may be most closely related to rocks of the Harper Ranch and Okanagan subterranean (Harms and Stevens, 1996a). The 1996 field season was dedicated to examining

potential stitching relations between the Klinkit assemblage and Mesozoic or ?Mesozoic units in Jennings River map area, and to sampling those Mesozoic rocks for an improved description of their character and affinity.

Lithologic contacts and fold axes within the Klinkit assemblage have a low-angle obliquity with the margins of the Simpson Peak and Nome Lake batholiths, suggesting but not requiring intrusion after Klinkit deformation. Neither the Simpson Peak nor Nome Lake plutonic rocks are regionally foliated. Intrusive contacts can be directly observed along the southeastern flank of the Nome Lake pluton. Taken together, these relationships serve to tightly constrain the date of the bulk of deformation in the Klinkit assemblage to between Middle-Late Triassic and Early Jurassic. This corresponds to the age of Read and Okulitch's (1977) Tahltanian Orogeny, recognized by a pre-Late Triassic angular unconformity between deformed and metamorphosed Paleozoic basement subterrane and the overlying Nicola Group in southern British Columbia. On the other hand, the southern margin of the Simpson Peak batholith is mylonitized where it is in contact with the Klinkit assemblage (see also Gabrielse, 1970). At least some deformation and displacement in the region occurred after the mid-Jurassic.

North of the Jennings River, in the westernmost part of Jennings River map area, a small body ($\approx 5 \text{ km}^2$ and 200 m thick) of aphanitic and augite-phyric volcanic flows flank the Klinkit assemblage (unit 17? of Gabrielse, 1970). Thirty or more 3-10 m thick subhorizontal (average orientation 116/13) flows can be readily observed in a cliff face exposure. These volcanic rocks are extremely hard and appear unaltered in hand specimen, which distinguishes them from aphanitic igneous rocks of the Klinkit assemblage. The contact between these flows and the Klinkit assemblage is covered but is tightly constrained in its location. It appears to be a shallowly dipping boundary that overlaps steeply dipping, folded lithologic contacts within the Klinkit assemblage. There is no sign of shearing in rocks of either unit 0.25 km from the contact. An extrusive contact across an erosional unconformity is inferred. Part of this contact has probably been intruded by the Simpson Peak batholith, but once again, this relationship is not directly exposed. If these mutual contact relationships are correct, the aphanitic and augite-phyric flows must be Late Triassic to Early Jurassic in age and could correlate with the Shonektaw, Takla, and/or Rossland volcanics of Quesnellia. Preliminary major and trace element geochemistry of the flows suggests they are calc-alkaline basalts and fall within the compositional range known from coeval Quesnellian volcanics (e.g. Mortimer, 1987). Complete geochemical analysis of these flows and of Shonektaw volcanics from Quesnellia south of the Jennings River are underway. If a reasonable comagmatic relationship can be established between the flows in contact with the Klinkit assemblage and typical Mesozoic Quesnellian volcanics, then the former constitute an overlap assemblage that ties the Klinkit assemblage to Quesnellia and demonstrates the Klinkit assemblage's affinity to other Quesnellia basement subterrane. This relationship is substantiated by the occurrence of augite-amphibole phenocrystic dikes that cross-cut the Klinkit assemblage in several places in Jennings map area and that may represent feeder dikes to Mesozoic Quesnellia flows. These dikes are also being analyzed geochemically.

Gabrielse (1970) mapped a small ($\approx 30 \text{ km}^2$) unit of clastic sedimentary rocks (unit 18) south of the Swift River in Jennings River map area. Because they appear to lie depositionally over rocks of the Klinkit assemblage, Gabrielse inferred an early Jurassic age for the strata, an age that suggests correlation with Jurassic clastic sequences of Quesnellia. Our detailed mapping in this unit provides important clarification of its character. The unit is dominated by massive and bedded greywacke with common interbedded thin chert horizons and rare carbonate lenses. Most importantly, the unit is very tightly folded and contains a strong, penetrative axial planar cleavage and localized crenulation cleavage. In lithologic character and in degree of deformation and recrystallization the unit correlates well with a distinctive suite of undated greywacke, phyllite, and metachert occurring along the east flank of the Klinkit assemblage in southern Wolf Lake and northern Jennings River map areas, informally named the Swift River assemblage (Harms and

Stevens, 1996b). The relationship between the Klinkit and Swift River assemblages throughout the region is not clear; the contact between Gabrielse's (1970) unit 18 and rocks of the Klinkit assemblage is also covered. The style and degree of deformation of Swift River rocks is, however, consistent with that characteristic of the Klinkit assemblage. On this basis, we provisionally reinterpret Gabrielse's (1970) unit 18 as a Paleozoic sequence rather than a Mesozoic overlap assemblage.

REFERENCES

- Abbott, J.G., 1981, Geology of the Seagull tin district, *in* Yukon Geology and Exploration 1979-1980, Indian and Northern Affairs Canada, p. 32-44.
- Armstrong, R.L., 1988, Mesozoic and early Cenozoic magmatic evolution of the Canadian Cordillera; Geological Society of America Special Paper 218, p. 55-91.
- Gabrielse, H., 1970, Geology of Jennings River map-area, British Columbia (104-O): Geological Survey of Canada, Paper 68-55.
- Harms, T.A., and Stevens, R.A., 1996a, A Working hypothesis for the tectonostratigraphic affinity of the Stikine Ranges and a portion of the Dorsey Terrane; *in* Cook, F., and Erdmer, P. (compilers), Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary, LITHOPROBE Report No. 50, p.93-95.
- Harms, T.A., and Stevens, R.A., 1996a, Assemblage analysis of the Dorsey Terrane; *in* Cook, F., and Erdmer, P. (compilers), Slave-Northern Cordillera Lithospheric Evolution (SNORCLE) Transect and Cordilleran Tectonics Workshop Meeting (March 1-3), University of Calgary, LITHOPROBE Report No. 50, p.199-201.
- Mortimer, N., 1987, The Nicola Group: Late Triassic and Early Jurassic subduction-related volcanism in British Columbia; Canadian Journal of Earth Science, v. 24, p. 2521-2536.
- Read, P.B., and Okulitch, A.V., 1977, The Triassic unconformity of south-central British Columbia; Canadian Journal of Earth Science, v. 14, p. 606-638.
- Woodsworth, G.J., Anderson, R.G., and Armstrong, R.L., 1991, Plutonic regimes, Chapter 15, *in* Geology of the Cordilleran Orogen in Canada, H. Gabrielse and C.J. Yorath (ed.); Geological Survey of Canada, Geology of Canada, no. 4, p. 491-531.

Subsurface 3-D Geometry and Structural History of the Southern MacKenzie Mountains, N.W.T., Yukon and B.C.

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Renewed interest in seismic interpretation of the southern MacKenzie Mountains reveals a complex structural history of compressional and oblique motion on low angle thrusts, high angle reverse faults and reactivated normal faults. At the surface, this complex history is expressed through the northeast deflection of the Rocky Mountain fold and thrust belt at 60°N latitude and the oblique trend of several structural elements, including the Pointed Mountain Thrust, the La Biche anticline and the Liard syncline. Reversals in thrust vergence are quite common and can be found in the La Biche and Kotaneelee Ranges.

Seismic interpretation has focused on two seismic lines from northeastern British Columbia, producing a regional picture of the structural geology, including fault linkages, within the study area. Together, the seismic lines form a regional east-west cross-section that extends from the Beaver River Gas Field to slightly east of the Bovie Lake Fault Zone. The interpretation involves a thin-skinned compressional overprint on a thick-skinned framework of half grabens active during the deposition of middle Devonian to Mississippian sediments. The thrust faults generally have relatively low ramp angles and sole into a lower detachment. Where possible, stratigraphic information was incorporated in the interpretation through the use of surface maps and well data. Locations and orientations of the growth faults were determined on the basis of structuring in the seismic sections and observations of thickening and thinning of stratigraphic intervals.

A number of key features are documented in the seismic interpretation: the existence of an original extensional geometry, which is evident from the thickening of strata, generally from east to west; subsequent overprinting by Laramide compression involving reactivation of the normal faults or development of new thrust faults localized at sites of normal faulting; and the existence of a sub-Nahanni and possibly sub-Arnica (middle to lower Devonian) detachment fault. A zone of growth faulting and later thrusting is interpreted to exist in the three kilometre gap between the two seismic lines based on stratigraphic, structural and physiographic observations. This fault zone has not been mapped previously by the G.S.C. reconnaissance mapping. This is probably due to Quaternary cover and the small amount of displacement on the fault.

Evidence for late (Miocene?) extension across the Coast Mountains

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The ACCRETE project (Fig. 3a; <http://geo.princeton.edu/accrete/accrete.html>) acquired MCS seismic reflection profiles along Portland Canal on the Alaska-British Columbia border and a loose grid of lines over the northern end of the Tertiary Queen Charlotte Basin including east Dixon Entrance (Fig. 3b). In addition, wide angle reflection and refraction data were collected by 60 seismometers spaced at 3-5 km intervals along Portland Canal and in-line extensions to the northeast and southwest.

One of our results was the finding of at least three distinctive south to west dipping reflecting bands between Hecate Strait and Stewart (Fig. 4). One band appears to cross the vertical projection of the Coast shear zone at about 25 km depth and can be traced to a depth of about 15 km under Mt. Dent, some 60 km northeast of the Coast shear (Figs. 2a, 3). It was clearly imaged in the wide angle data. A second extends from about 10 km depth at the Coast shear to about 3 km above the Moho under east Dixon Entrance, for line 1255, and under Dundas Island for line 1253. The third is parallel to the second, but about 40 km further to the west. The reflecting zones have these features:

- 1) They are imaged in north-south to east-west transects and therefore are dipping southwesterly; there is 3-d control for the two west of the Coast shear (Fig. 4).
- 2) At their southwest ends, they merge with lower crustal reflecting horizons above where the Moho shallows.
- 3) There are no ductile structures mapped on the surface that dip south to west.
- 4) Where the two western bands project to about 10 km depth, an extensional structure bounded by brittle faults extends to the surface. These grabens are clearly imaged in the MCS data. East of Mt. Dent (Figs. 1, 3) is an extensional structure extending from Terrace to at least the Recent lava flow at New Aiyansh (Woodsworth, pers. com.); the eastern reflector may project to below this structure.

We conclude that these structures are extensional and younger than 50 Ma, and probably Miocene or younger (1) because two terminate under young grabens, (2) because the eastern band appears to cut the Coast shear zone, a feature as young as 55 Ma, (3) because the eastern band is straight and coherent across the central gneiss complex which was deformed and intruded by plutons as young as 50 Ma, and (4) because their eastern terminations are approximately at the present-day brittle-ductile transition. If they are young ductile features, they would not reach the present surface; rather, they would terminate at steep brittle extensional faults as they appear to do. The Moho shallowsings are also consistent with a young extensional overprint on the Coast orogen.

The seismic data are still being processed and analyzed, and therefore these conclusions are preliminary; but the weight of evidence points to late extension, probably Miocene, affecting the western cordillera from west Dixon Entrance (Rohr and Dietrich, 1991) at least as far as the eastern side of the Coast Mountains.

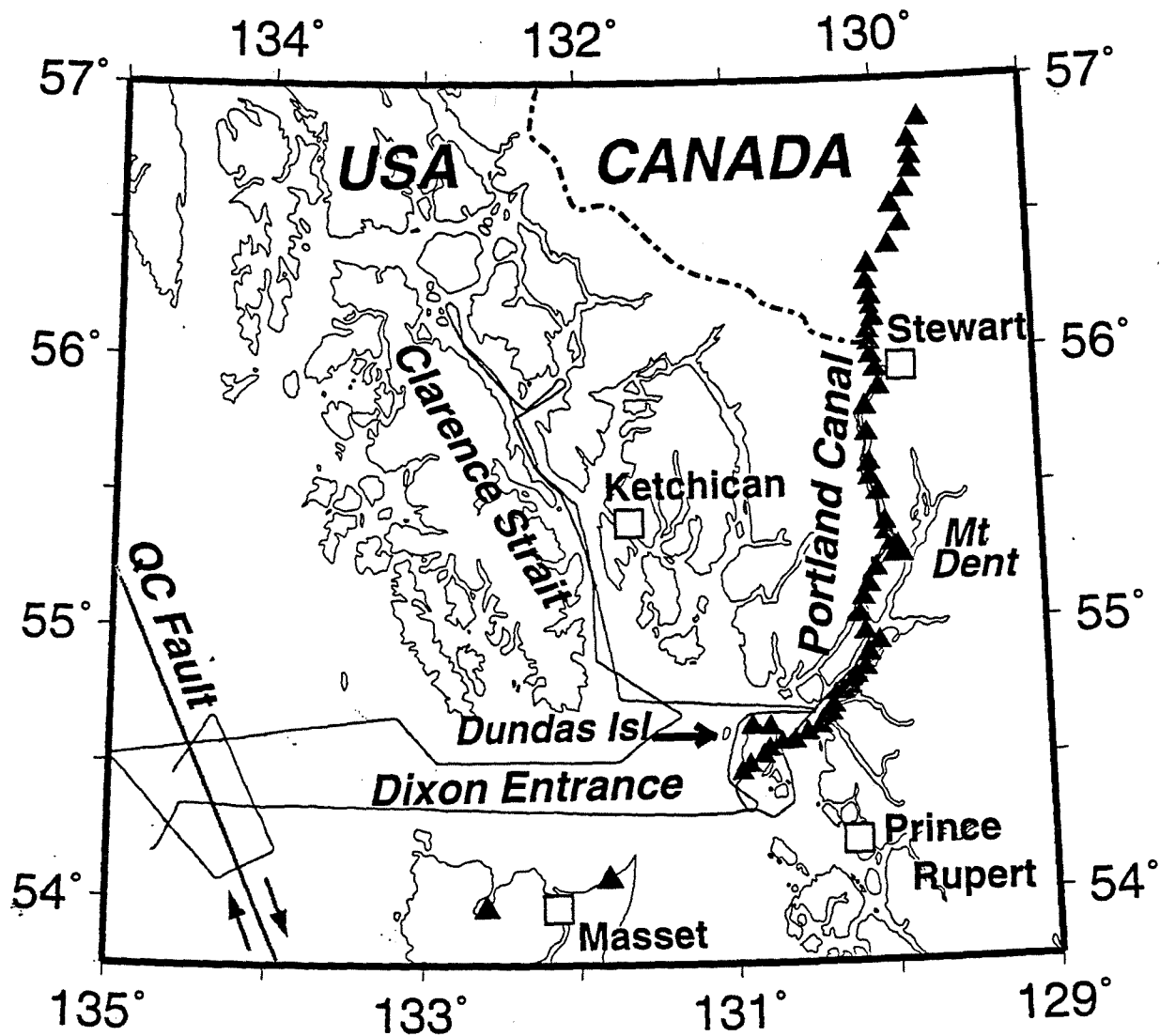


Figure 3a. Ship-track of the R/V EWING in Sept. 1994. Triangles show locations of Reftek portable seismometers.

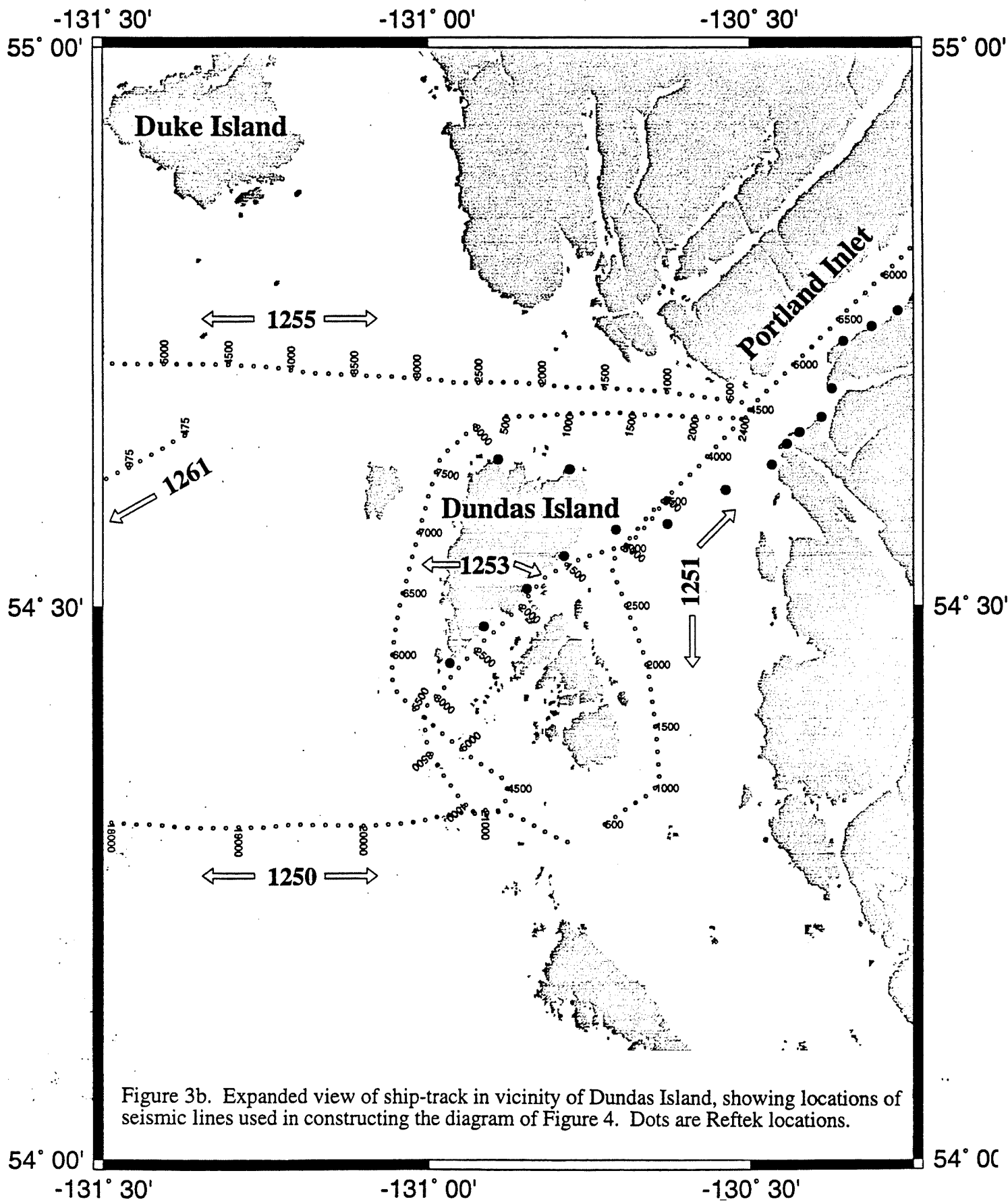
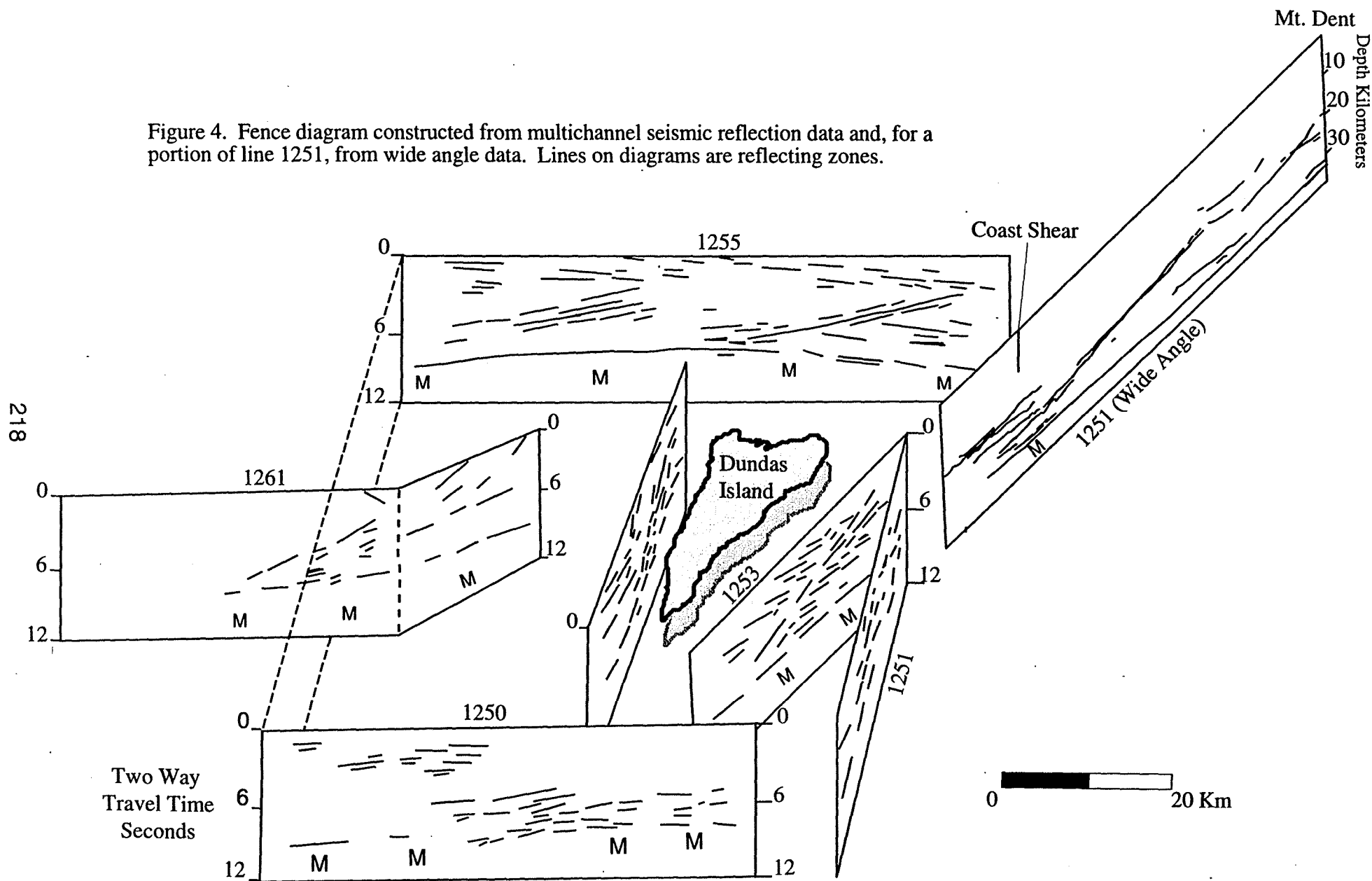


Figure 3b. Expanded view of ship-track in vicinity of Dundas Island, showing locations of seismic lines used in constructing the diagram of Figure 4. Dots are Reftek locations.

Figure 4. Fence diagram constructed from multichannel seismic reflection data and, for a portion of line 1251, from wide angle data. Lines on diagrams are reflecting zones.



Late Cretaceous-Tertiary Tectonic Evolution of the Beaufort Sea-Northern Yukon Region

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Regional crustal shortening in northern Yukon and adjacent Alaska occurred episodically from Late Cretaceous to Late Miocene (locally Holocene) time, with a major culmination in the Paleocene to Middle Eocene, and a second culmination in the Late Miocene. The structural trends are strongly arcuate in the offshore Beaufort Foldbelt and adjacent onshore areas, and broadly north-south through northern Yukon and adjacent eastern Alaska. The continuity of structures southward from the Beaufort Sea through northern Yukon supports the interpretation that structures north of 65°N comprise a single orogenic entity.

A new 220 km long regional crustal-scale cross-section crosses the Beaufort Foldbelt from near Herschel Island in the southwest, nearly to the front of Tertiary deformation. It incorporates industry seismic reflection data and crustal structure data derived from modelling of Geological Survey regional refraction profiles and gravity data. The deformed belt is detached on a basal décollement lying at or near basement which consists of thinned continental and oceanic crust. Simple retrodeformation indicates that total shortening by folding and thrust faulting is near 20% for the earliest Tertiary part of the succession.

The Beaufort-Mackenzie region is a major frontier petroleum province containing discovered reserves of 1.7 billion barrels of oil and 11.7 TCF of natural gas. Tertiary structures are responsible for trapping many of the important petroleum accumulations in the basin.

The Beaufort-Mackenzie region is 1000 km from the nearest plate margins, thus the plate-tectonic setting is not obvious. Late Cretaceous-Early Tertiary east-west shortening in the region is estimated at 150-220 km, accommodated by right-lateral displacements on the Kaltag and Kobuk fault systems of western and central Alaska. This shortening relates to convergence between the North American and Eurasian plates behind the pole of opening during Late Cretaceous-Early Tertiary north Atlantic Ocean spreading.

Late Cretaceous-Holocene northward shortening across Arctic Alaska and the northern Canadian Cordillera probably reflects the convergent component of transpression between North America and the Pacific (and its precursor, the Kula) plates. In the Beaufort Foldbelt, Miocene structures which comprise long linear structures far offshore, may reflect minor north-northeastward shortening related to North America-Pacific convergence.

Progress Report of the Southeastern Cordillera NATMAP Project (1996-1997)

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The Southeastern Cordillera NATMAP project, charged with remapping the eastern edge of the Cordillera in southern Alberta, is nearing completion. When complete, the project will produce a digital geoscience information base for an area that is an important geological province, with significant reserves and resource potential for natural gas, oil, sulphur, thermal coal, coal bed methane and possibly diamonds, and is also a region of significant rural population where land-use management and hazard assessment are of paramount importance.

Key products of the project are new 1:50,000 scale bedrock geology maps, from the international border to north of Turner Valley, and accompanying structural cross-sections. Our new surface mapping, which accurately portrays structural concepts such as folded thrusts and the triangle zone at the eastern margin of the Foothills belt, provides a coherent as well as stratigraphically and structurally consistent view of the geology for over 225 km along strike. In 1996/97, four new bedrock maps were published (NTS 82G/16E, 82H/6, 82H/12, 82H/13) and field work was completed for four more areas (82G/8, 82G/16W, 82H/5, 82J/1E). Only 82J/8 will remain incomplete following the 1997 season.

Accurate cross-section construction is dependent to a large degree on industry seismic reflection data. To date, seismic data worth \$1.3 M have been donated and/or made available to the project by the petroleum industry. These donations "in kind" have led to fruitful, creative, collaborations between industrial, academic and government researchers which have not only enhanced our ability to construct cross-sections, but has afforded informed surface structural and stratigraphic interpretations. In addition, the extent of Paleozoic thrust sheets in the subsurface is being delineated, and the styles of deformation affecting these is being better understood. In total, 18 new regional, balanced, cross sections of the Eastern Cordillera will be published with the final maps.

Currently, seismic data interpretation is being integrated with data derived from surface mapping to produce a three-dimensional digital geological atlas. This digital database is designed to facilitate the creation of derivative maps involving a variety of data, including the distribution of potential aquifers, potential sources of aggregate, level of thermal maturation, as well as stratigraphic, structural and natural hazard information. The maps and database will be useful to petroleum explorationists, hydrogeologists, engineering geologists, land use planners, resource assessment agencies, academia and the public.

The project has become a focus for application of new digital mapping technology which has enabled preliminary map publication soon after completion of field work. New digital imagery mapping tools allow 3D visualization of surface and subsurface geology, especially useful in mapping the steep ridges of the Front Ranges, or the very shallowly dipping beds in the Porcupine Hills.

HEAT FLOW STUDIES NEAR THE SNORCLE TRANSECT

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There are nearly 50 sites in northern B.C., southern Yukon and the N.W.T. in the regions of the planned SNORCLE transects from which heat flow data have been gathered. The results from approximately half of these sites are already published (Bentkowski and Lewis, 1989, 1994; Jessop et al, 1984; Lewis and Wang, 1992; Majorowicz and Jessop, 1981; Matthews, 1972). Lewis (1991) summarized heat flow results for the Cordillera published before 1990. Data are still being processed and conductivities are being measured for some of the remaining sites, most of which should yield reliable values. The distribution of sites, determined by suitable boreholes being available from the mineral exploration industry and a few wells from the hydrocarbon industry in the sediments, covers the region fairly well, except for the Slave province.

The average heat flow in this region is high: for 20 Cordilleran sites, it averages 82 mW/m². At Yellowknife in the Archean Slave province it is 51 mW/m². Heat generation values from borehole samples and surface samples are also available throughout most of the area (Lewis and Bentkowski, 1988; unpublished data). Crystalline rocks southwest of the Tintina Fault, except for the mid-Cretaceous Surprise Lake batholith and similar bodies, have generally lower heat generation than those to the northeast of the fault.

REFERENCES:

- Bentkowski, W.H. and T.J. Lewis, Thermal measurements in Cordilleran boreholes of opportunity, 1984-1987, Geological Survey of Canada Open File 2048, 30 pp., 1989.
- Bentkowski, W.H. and T.J. Lewis, Heat flow determinations in the Cordillera: 1988-92, Geological Survey of Canada, Open File #2981, 34 pp, 1994.
- Jessop, A.M., J.G. Souther, T.J. Lewis and A.S. Judge, Geothermal Measurements in northern British Columbia and southern Yukon Territory, Canadian Journal of Earth Sciences, 21, 599-608, 1984.
- Lewis, T.J., Heat FLux in the Canadian Cordillera, *in* Slemmons, D.B., Engdahl, E.R., Zobak, M.D. and Blackwell, D.D. (eds.), Neotectonics of North America: Boulder, Colorado, Geological Society of America, Decade Map 1, 445-456, 1991.

Lewis, T.J. and W.H. Benthowski, Potassium, uranium and thorium concentrations of crustal rocks: A data file, Geological Survey of Canada, Open File #1744, 1988.

Lewis, T.J. and K. Wang, Influence of terrain on bedrock temperatures, *Global and Planetary Change*, 6, 87-100, 1992.

Majorowicz, J.A. and A.M. Jessop, Regional heat flow patterns in the Western Canadian Sedimentary basin, *Tectonophysics* 74, 209-238, 1981.

Matthews, W.H. (1972), Geothermal data from the Granduc area, northern Coastal Mountains of British Columbia, *Canadian Journal of Earth Sciences*, 9, 1333-1337.

Petrologic Nature of the Lower Crust and Upper Mantle Beneath the Archean Slave Province, NWT, Canada.

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A detailed study of the petrology of lower crustal and upper mantle xenoliths entrained in kimberlites from a variety of locations in the central, SE and SW Slave Province is underway. The kimberlites range in age from Ordovician to Cretaceous. Xenolith samples were obtained from drill core provided by three diamond exploration companies working in the Slave Province. The study provides a direct record of the petrologic nature of both the lower crust and upper mantle beneath the Slave Province during the Cretaceous, as well as indirectly providing constraints on the depth to paleo-Moho and regional variations in metamorphic grade. Additionally, geothermobarometry provides insights into the thermal state and thickness of the Slave craton. Recognizing thermal perturbations and relating the timing and magnitude of these events spatially and temporally should prove invaluable in delineating the thermal history of the Slave craton. As well, establishing lithospheric thickness using geothermobarometry provides a good standard for comparison with seismic studies.

Studies of lower crustal xenoliths have provided insights into the petrological nature of the crust at depth and have revealed a variety of lithologies from felsic/mafic granulites (plag+gt+cpx±opx±ksp±sp±tit±rut) as well as metagranitoids and gneisses of varying genesis. Samples from the upper mantle include garnet and spinel peridotites (gt+ol+opx±sp±cpx), eclogites (cpx+gt±amp), and pyroxenites (opx±cpx).

A variety of geothermobarometers, namely $T_{O'Neill}$ (Fe/Mg:gt-ol), T_{EG} (Fe/Mg:cpx-gt), P_{BKN} (Al:opx-gt), and TWEEQU [1] have been applied to xenolith samples from the Grizzly, Torrie, and Koala pipes. The peridotitic samples have yielded pressure and temperature (PT) conditions consistent with a 40-45 mWm⁻² geotherm (Fig.1). The current heat flow, measured at Yellowknife is 50-55mWm⁻² [2] suggesting either regional variations in the heat flow and/or thermal erosion of the lithosphere since the Cretaceous. Additionally, the deepest mantle peridotite collected records a PT condition corresponding to a lithospheric depth of ~180 km at the time of kimberlite magmatism (Cretaceous). However, tomographic studies [3] show the presence of a deep, cold mantle root beneath the Slave craton today, suggesting little, if any, regional thermal erosion since the Cretaceous.

Calculated PT conditions for granulites using TWEEQU and T_{EG} (Fe/Mg:cpx-gt) indicate they lie on a ~90mWm⁻² geotherm (Fig.1). This elevated geotherm is likely the result of a 2-2.5 Ga metamorphic event in the lower crust as indicated by U-Pb geochronology [4]. Additionally, both felsic and mafic granulites show similar PT conditions suggesting that the two rock types may lie at the same stratigraphic level in the crust.

We define the Moho, petrologically, as the maximum PT recorded by the lower crustal samples and the minimum PT recorded by the upper mantle samples. Using this criteria, It has been evidenced that the Moho in the Cretaceous was at a depth of ~30-40 km, similar to the present day Moho of 33-38 km [5] described using seismic data.

Presently, we have obtained more samples from kimberlites near Dry Bones Bay and Kennedy Lake in the SW and SE Slave craton, respectively. More information will be become available to establish the nature of the lower crust and upper mantle regionally and temporally. Additionally, new data from across the Slave Province will provide a means to establish regional correlations regarding: 1) depth to paleo-Moho, 2) age and conditions of metamorphism and 3) lithospheric thickness and thermal history.

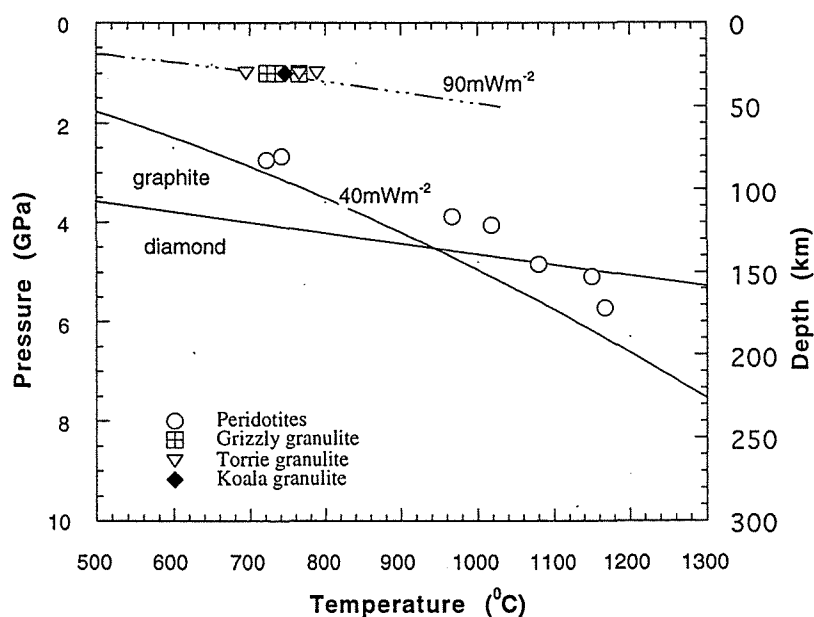


Figure 1: Pressure-Temperature diagram showing positions of the Slave peridotite and granulite xenoliths calculated using T_{ONeill} , P_{BKN} and T_{EG} at 1 GPa relative to 40mWm^{-2} and 90mWm^{-2} geotherms respectively and the graphite/diamond transition.

References:

- [1] Berman RG (1991) *Canadian Mineralogist* **29**: 833-855
- [2] Lewis TJ, Wang K (1992) *Palaeogeography, Palaeoclimatology, Palaeoecology* **98**, 87-10
- [3] Polet J, Anderson DL (1995) *Geology*: v.**23**, 205-208
- [4] Davis WJ, MacKenzie JM, Canil D (unpubl. data).
- [5] Cassidy JF (1995) *Can. J. Earth Sci.* **32**: 938-951

THE MATTHEW CREEK METAMORPHIC HIGH WEST OF KIMBERLEY B.C.

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The enigmatic Matthew Creek Metamorphic High (MCMH) is a NNW trending pocket of severely strained mica-schists which crop out in the core of a broad anticline in lower Purcell strata, <5km SW of the Sullivan Mine near Kimberley B.C. Since it was first mapped by S.J. Schofield in 1915 and again by H. Rice in 1937, the MCMH has been cited numerous times in a variety of papers even though its boundaries and origins remain poorly understood. Over a distance of < 2 km approaching the MCMH, there occurs a transition from Chl-Bt-greenschist Purcell metasediments to Ms-Bt-Grt-Sil schists indicating an anomalously high geothermal gradient (ca. 100 C/ km). Previous workers attributed the origin of these high-grade schists to a contact metamorphic event accompanying the intrusion of some unexposed granodioritic body of similar age and origin to the Hellroaring Creek Stock (1360Ma) which crops out SW of the high-grade zone. Metamorphic monazite from high-grade schist at Matthew Creek has been dated at ca. 1300Ma (R. Parrish, personal commun.)

Detailed mapping and sampling of the MCMH area was carried out during the summer of 1996. Excellent exposure through the transition zone on the south side of the St. Mary River reveals a subtle increase in schistosity and metamorphic grade as structural depth increases. The transition moving north along Matthew Creek is also characterized by a similar subtle transition. No major high-angle reverse or normal faults were encountered in these transition zones. The MCMH is a NW trending doubly plunging open anticline which also contains a NE-SW trending sillimanite lineation in foliation planes throughout the area. Large muscovite-rich pseudomorphs set in the anastomosing schistosity have been identified as andalusite and garnet. In thin section many unaltered andalusites have been partially pseudomorphed by sillimanite prior to their replacement by coarse muscovite. A second generation of garnet overprints the schistosity, which with the late muscovite, suggest static metamorphism following the high-strain event. The high-grade area also contains numerous small laccoliths and sills of Ms + Tur + Beryl pegmatitic tonalite-granodiorite which appear to have an anatectic origin. The margins of these small stocks are severely deformed, suggesting they were emplaced before or during the development of the foliation. U-Pb dating of these small stocks will help to bracket the timing of metamorphism. Mineralization in the high-grade zone is limited to graphite and minor galena and pyrite in fault zones.

The origin of the MCMH remains unclear. Textural evidence suggests its development may involve an early high-T low-P metamorphic event overprinted by a later ductile shearing episode, the latter telescoping the isograds and creating the strong lineation and foliation now seen.

The Colville Igneous Complex, NE Washington and S British Columbia: Implications for upper, middle and lower crustal ages and compositions.

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Introduction

The Eocene Colville Igneous Complex of Northeast Washington and Southern British Columbia, located at the southern end of the Omineca Crystalline Belt, consists of three distinct phases of igneous activity: The Keller Butte Suite; the Sanpoil Volcanic Formation and its associated intrusive phases, the Devils Elbow Suite and the Herron Creek Suite; and the Klondike Mountain Formation (Figure 1).

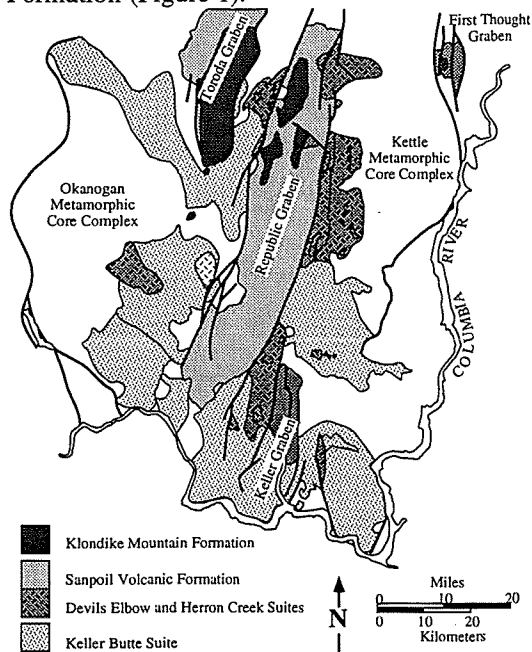


Figure 1. Geological map of the Colville Igneous Complex. Adapted from Holder and Holder (1988), Stoffel (1990) and Morris (1996).

Detailed major, trace, rare earth element and isotope geochemistry (Morris, 1996; Morris and Hooper, submitted) suggests that the three phases of the Colville Igneous Complex were formed by partial melting of 3 distinct crustal sources, with contributions from a sub-continental lithospheric mantle source in the final phase (the Klondike Mountain Formation). The driving force for magma production was not Eocene subduction, as proposed by Lipman et al. (1972), Ewing

(1980), Coney (1987) and others, but due to post-Laramide orogenic collapse.

Based upon interpretations of deep seismic data (Varseck and Cook, 1994) and gravity models (Sobkzyk, 1994), which both use LITHOPROBE (Canada) and COCORP (US) data as a framework, at least three distinct zones can be identified in the crust beneath northeast Washington and southern British Columbia (Figure 2). We suggest that the three crustal sources that we recognise in the petrogenesis of the Colville Igneous Complex, and report here, correspond to three of the crustal zones identified geophysically.

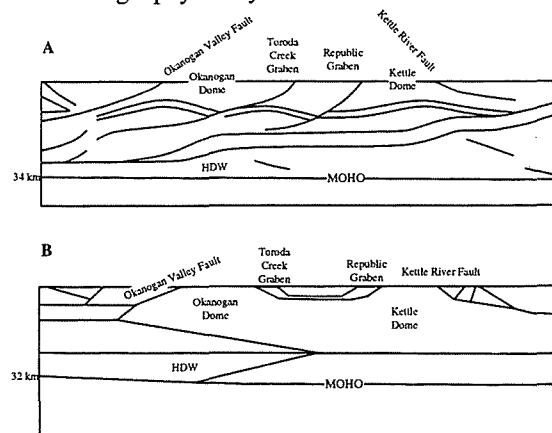


Figure 2. Comparison of seismic interpretation (A; Varseck and Cook, 1994) and gravity model (B; Sobkzyk, 1994) beneath the Colville Igneous Complex. HDW: High Density Wedge.

Keller Butte Suite

Petrology: The Keller Butte Suite is made up of two distinct phases, a granite and a granodiorite. The granite is leucocratic, consisting of less than 5% biotite and minor epidote. It contains phenocrysts of K-feldspar, upto 3cm in length in a medium- to coarse-grained groundmass of plagioclase feldspar, K-feldspar and quartz. The granite also commonly contains garnet, both disseminated throughout the intrusion and concentrated along the borders of individual dykes. Apatite is a common accessory mineral. The

granodiorite is leucocratic, equigranular medium- to coarse-grained. Biotite is the only mafic phase, with oligoclase, quartz and orthoclase making up the bulk of the rock. Allanite and apatite occur as accessory minerals (Holder and Holder, 1988; Morris, 1996).

The mineral assemblage of both the granite and the granodiorite is equivocal. The presence of garnet suggests a sedimentary source (S-type) granitoids, while the presence of apatite and allanite as accessory phases are more typical of igneous source (I-type) granitoids (e.g. Chappell and White, 1992). Garnet is thought to be a restite phase, entrained into the magma during separation from the source.

Geochemistry: The following geochemical indicators were used to assess the source rock of the Keller Butte Suite: Aluminium Saturation Index (granite, 1.02 to 1.08; granodiorite, 1.01 to 1.05); Na_2O v K_2O content (Figure 3); Sr initial ratios (Sr_i : 0.7051 to 0.7073, except Capoose Creek Pluton which returned Sr_i values of 0.7084 to 0.7096, Carlson et al., 1992); and whole rock Oxygen isotope ratios ($\delta^{18}\text{O}$: 8.7 to 10.2‰). According to the classification of Chappell and White (1992), Sr_i values as well as Na_2O v K_2O would place the Keller Butte firmly in their I-type, or igneous sourced granite field. However, ASI and $\delta^{18}\text{O}$ values are equivocal, falling on the boundary between I and S-type granites (Avila-Salinas, 1990).

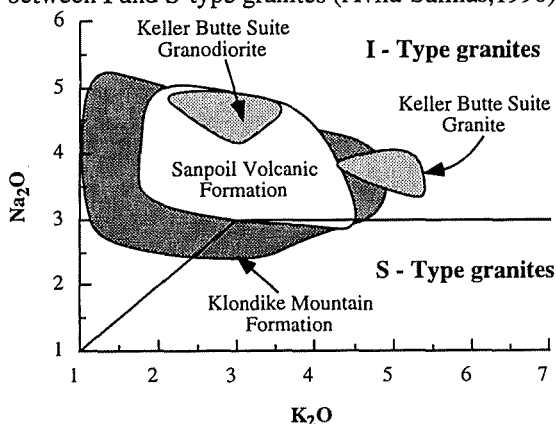


Figure 3. Na_2O v. K_2O values for rocks of the Colville Igneous Complex compared with the I-type and S-type classification of Chappell and White (1992)

Source rock characteristics: Both the Petrology and the geochemistry of the Keller Butte Suite are equivocal when it comes to identifying the nature of the source rock. We suggest that much of the

apparent contradiction is due to the classification scheme itself. The granites on which the original source classification was defined are somewhat unusual in being derived from a very evolved sedimentary source (the Lachlan Fold Belt, Australia). Many of the geochemical indicators used by Chappell and White are affected by weathering and other sedimentary processes. The petrology of a granite is a direct reflection of its chemistry, which is a direct reflection of the source rock chemistry. Therefore, a primitive sediment would bear more resemblance to its igneous source. We suggest that, following the argument of Miller (1986), who worked further south within the US Cordillera, the source of the Keller Butte Suite granites is a rather primitive sediment.

Age of Source: The age of the Keller Butte Suite source is somewhat uncertain. While there is no direct evidence, there exists a number of metasedimentary units in both the Okanogan and the Kettle Metamorphic Core complexes (e.g. Stoffel, 1990). These units contain metamorphic garnet, and have undergone partial anatexis. The composition of the partial melt is similar to that of the Keller Butte Suite. Suggested ages for these units range from Jurassic to Permian. It is therefore suggested that the Keller Butte Suite is derived from a primitive sedimentary source of late Paleozoic to early Mesozoic age, some of which is now exposed in the Okanogan and Kettle Metamorphic Core Complexes (Figure 1). This correlation needs more work!

Sanpoil Volcanic Formation

Detailed work by Holder (1990) has correlated the Sanpoil Volcanic Formation with the intrusive Devils Elbow and Herron Creek Suites. Due to evidence of element mobility in the slowly cooling plutons this study concentrates on the rapidly crystallised Sanpoil Volcanic Formation as a better representative of the developing magmatic system.

Petrology: The Sanpoil Volcanic Formation consists of dacites and andesites with rare basaltic andesites (Figure 4). All rocks are highly porphyritic, with between 30 and 70 % phenocryst content. Phenocrysts are predominantly plagioclase and hornblende with biotite and augite occurring in the youngest flows. Common minor phases are pigeonite, hypersthene and occasional quartz (Holder, 1990; Carlson et al., 1991; Morris, 1996).

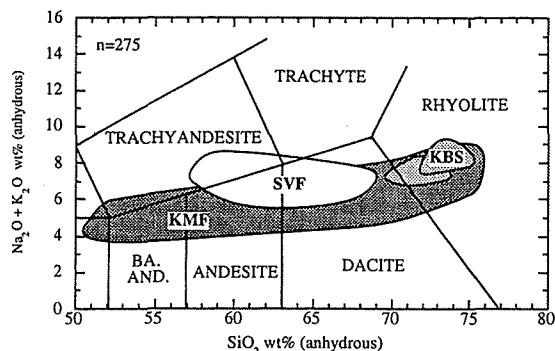


Figure 4. Total alkalis v. silica for the Colville Igneous Complex. KBS: Keller Butte Suite; SVF: Sanpoil Volcanic Suite; KMF: Klondike Mountain Formation. Note the general reduction in alkalis with silica in the Sanpoil Volcanic Suite. Rock classification after Le Matre (1984).

Geochemistry: Compositionally the Sanpoil Volcanic Formation is somewhat more restricted than the later Klondike Mountain Formation, with SiO_2 values between 57 and 67 wt.%. Concentration of alkalis ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) decreases with increasing silica, a trend incompatible with fractionation controlled development (Figure 4). Concentration of incompatible trace elements likewise decreases with increasing silica. This trend is interpreted as the signature of partial melting of a granitic source rock (Morris and Hooper, submitted). All rocks of the Sanpoil Volcanic Suite show the subduction signature of enriched Large Ion Lithophile elements (Sr, Rb, Ba, Th and K_2O) coupled with relatively depleted High Field Strength Elements (Ta, Nb, TiO_2). Total concentration of trace elements decreases with increasing silica. Sr_i and Nd_i isotopic values are typical of crustal rocks (0.7068 - 0.7092; 0.51233-0.511851 respectively; Figure 5).

Source Rock characteristics: Both the petrology and the geochemistry of the Sanpoil Volcanic Formations suggest that the source rock is an ancient subduction related igneous rock. Knaack (1991), working on the intrusive equivalent, the Long Alec Creek pluton of the Herron Creek Suite, proposed that these rocks could be derived from a eutectic melt within the granite system at 8 kBar, or mid-crustal levels. Such a model could explain the limited range of chemical compositions in the Sanpoil Volcanic Formation, as well as the decrease in alkalis and trace elements with increasing silica.

Age of source: Nd model ages suggest an early proterozoic source (1.6 to 2.0 By). D. Parkinson

(pers. comm. in Carlson, 1991) reports an inherited Pb component of 1.7 By, and Wooden and Box (1996) report U/Pb SHRIMP analyses of 1.61 By from zircon cores in the intrusive equivalents to the Sanpoil Volcanic Formation. The presence of an array of model ages, older than Pb and U/Pb dates, suggest an ancient heterogeneous magmatic arc (subduction) source for the Sanpoil Volcanic Formation and related magmas, and virtually precludes the influence of an Eocene arc in their formation. The source of the Sanpoil Volcanic Formation is suggested to be the middle of three zones interpreted by Varseck and Cook (1994) and by Sobczyk (1994) (Figure 2).

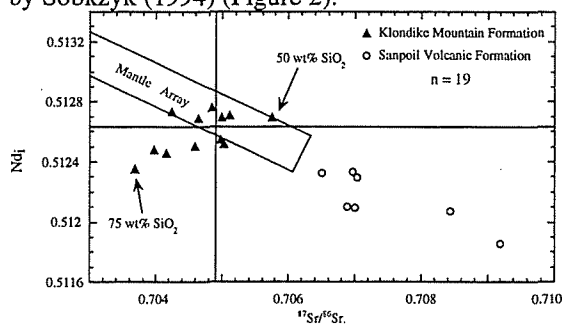


Figure 5. Neodymium versus Strontium isotope plot for the Sanpoil Volcanic Formation and the Klondike Mountain Formation.

Klondike Mountain Formation

Petrology: The Klondike Mountain Formation consists of basalts, basaltic andesites, andesites, dacites and rhyolites (Figure 4). These rocks are distinguished from the Sanpoil by their much lower phenocryst content, between 5 and, rarely, 20% phenocrysts, in a glassy to fine, often devitrified glass, matrix. Basalts and basaltic andesites contain rare microphenocrysts of olivine, CPX and OPX. Andesites through rhyolites contain large skeletal plagioclase, CPX, OPX and olivine. Olivine shows a broad partially resorbed rim where it is in contact with the groundmass. Such a disequilibrium assemblage is interpreted as the result of mixing of a basic and a silicic magma shortly before eruption. Orthopyroxene phenocrysts often have high Al_2O_3 cores (in excess of 7 wt.%, c.w. 0.9 wt.% rims), indicating crystallization at great depth in the crust.

Geochemistry: All geochemical data from the Klondike is consistent with magma mixing between a basalt and a rhyolite. The basalt is a typical sub-continental lithospheric melt and shows no evidence of subduction style enrichment of LIL

elements coupled with depletion of HFS elements. This virtually precludes contemporaneous subduction from the genesis of the Colville Igneous Complex (Morris and Hooper, submitted). The rhyolitic end member however does show the subduction signature. Sr_i and Nd_i analysis shows a range of data points from the mantle array (basaltic end member) to low Sr_i , low Nd_i values (rhyolitic end members; Figure 5). The only known source for such values is granulite facies lower crust. Oxygen isotope values for the Klondike Mountain Formation range from 4.6‰, a basaltic andesite, to 7.3‰, a rhyolite, although there is no clear correlation between silica content or Sr_i ratios. High d_{18O} values connected with low Sr_i values suggest that alteration is not the cause of the low Sr_i , low Nd_i values in rhyolites.

Source rock characteristics: Both the geochemistry and the petrology point to a mixing between a sub-continental lithospheric mantle basalt and a lower crustal, granulite facies sourced rhyolite. The subduction signature is contributed by the rhyolite, the basalt showing no sign of subduction related enrichment. High pressure pyroxene cores and low Sr_i , Nd_i isotope values suggest a granulite source for the rhyolite. This granulite is suggested to be the High Density Wedge invoked in the gravity models of Sobczyk (1994) and the lower crustal zone imaged by LITHOPROBE and COCORP seismics (Varsek and Cook, 1994; Fig. 2).

Age of source: Rhyolitic end members of the Klondike Mountain Formation return Nd model ages (crustal residence ages) of 1.2 By. Model ages decrease with increasing contribution of the basaltic end member. We therefore suggest that the lower crustal zone imaged on the seismics is an early Proterozoic granulite.

References

- Avila-Salinas W.A. (1990) Tin-bearing granites from the Cordillera Real, Bolivia; a petrological and geochemical review. *Geol. Soc. of Am., Spec. Pap.* **241** 145 - 159.
- Carlson D.H., Fleck R., Moyer F.J. & Fox K.F. (1991) Geology, geochemistry, and isotopic character of the Colville Igneous Complex, Northeast Washington. *J. Geophys. Res.* **96** 13,313 - 13,333.
- Chappell B.W. & White A.J.R. (1992) I- and S-type granites in the Lachlan Fold Belt. *Transactions of the Royal Society of Edinburgh*, **83**, 1-26.
- Coney P.J. (1987) The regional tectonic setting and possible causes of Cenozoic extension in the North American Cordillera. in Coward, M.P., Dewey, J.F., and Hancock, P.L., eds Continental Extensional Tectonics. *Geol. Soc. Spec. Publn.*, **28**, 177-186.
- Ewing T.E. (1980) Paleogene Tectonic Evolution of the Pacific Northwest. *Journal of Geology*, **88**, 619-638.
- Holder G.M. (1990) Geochemical character and correlation of contemporaneous volcanic, plutonic and hypabissal igneous activity associated with Eocene regional extension, northeast Washington. *unpublished PhD thesis, Washington State University, Pullman*, 156p.
- Holder R.W. and Holder G.M. (1988) The Colville Batholith: Tertiary plutonism in northeast Washington associated with graben and core-complex (gneiss dome) formation. *Geol. Soc. of Am., Bulletin*, **100**, 1971-1980.
- Knaak C.M. (1991) Geology and Geochemistry of the Long Alec Creek Pluton, Ferry County, Washington. *unpublished MS thesis, Washington State University, Pullman*, 93p.
- Le Maitre R.W. (1989) A classification of igneous rocks and a glossary of terms. Recommendations of the International Union of Geological Sciences Subcommittee on the systematics of igneous rocks. *Blackwell, Oxford*.
- Lipman P.W., Prostka H.J. and Christiansen, R.L. (1972) Evolving subduction zones in the western United States. *Science*, **174**, 821-825.
- Miller C.F. (1986) Comment on "S-type granites and their probable absence in southwestern North America. *Geology* **14** 804 - 805.
- Morris, G.A. (1996) Petrogenesis of calc-alkaline rocks in an extensional environment: the Eocene Colville Batholith of northeast Washington. *unpublished PhD thesis, Washington State University, Pullman*, 139p.
- Morris, G.A., & Hooper, P.R. (submitted) Petrogenesis of the Colville Batholith, N.E. Washington: implications for Eocene tectonics in the northern US Cordillera. *Geology*.
- Sobczyk S.M. (1994) Crustal thickness and structure of the Columbia Plateau using geophysical methods. *unpublished PhD thesis, Washington State University, Pullman*, 208p.
- Stoffel K.L. (1990) Geologic Map of the Orville 1:100 000 quadrangle, Washington. *Washington Division of Geology and Earth Resources, Open File Report 90-11*, 58pp.
- Varseck J.L. & Cook F.A. (1994) Three-dimensional crustal structure of the Eastern Cordillera southwestern Canada & northwestern United States. *Geol. Soc. of Am., Bulletin*, **106**, 803-823.
- Wooden J.L. & Box S.E. (1996) Contrasting inherited zircon populations in an Eocene vs an early Cretaceous intrusive associated with the eastern Kettle Metamorphic Core Complex, NE Washington. *Geol. Soc. of Am., Abst. with Progs.*, **28**, A-444.

THE DORSEY TERRANE: QUESNELLIA NORTH?

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The Dorsey Terrane has been a somewhat problematic tectonic entity since its introduction on the Cordilleran terrane map of Wheeler *et al.* (1991). At that time its internal stratigraphy was very poorly known, and its similarities or ties to other terranes not known at all. Lithoprobe-sponsored mapping by Rob Stevens and Tekla Harms over the last three summers is giving a much clearer picture of this interesting and possibly pivotal tectonic element. In 1996, they introduced a new lithostratigraphic terminology, which subdivides the Dorsey Terrane into a structurally lower Dorsey Assemblage and a structurally higher Klinkit Assemblage (Harms and Stevens, 1996).

During the 1996 field season I mapped two areas within the Dorsey terrane, one in the Dorsey assemblage and one within the Klinkit assemblage (Figure 1). The stratigraphy of the Klinkit assemblage near McNaughton Creek (Figure 2a) bears a strong resemblance to that of the Lay Range Assemblage in the Lay Range (Ferri, in press; and personal field observations in 1992). This correlation supports the hypothesis of Harms and Stevens (1996) that the Klinkit assemblage represents the late Paleozoic basement of Quesnellia. It in turn rests structurally and possibly stratigraphically on the Dorsey assemblage (Stevens and Harms, 1995). The portion of the Dorsey assemblage that I examined this summer near the Little Rancheria River (Figure 3) is a mixed volcanic-volcaniclastic sequence that includes meta-rhyolite tuff (quartz-sericite schist) and limestone of Early Mississippian age: a possible analogue or even correlative of the Yukon Tanana Terrane.

Near McNaughton Creek, the Klinkit assemblage occurs in a series of thrust panels that carry repetitions of a tripartite stratigraphic sequence (Figure 2a,b). The stratigraphically lowest unit is a dull-colored sequence of chert, argillite and quartz and quartz-feldspar sandstone and grit. It is overlain by fossiliferous limestone that contains solitary and colonial corals, fusulinids and crinoids. This limestone is probably equivalent to the early Pennsylvanian Screw Creek limestone, which outcrops 20 kilometres along strike to the northwest (Poole, 1956; Gabrielse, 1969; Stevens and Harms, 1995). Macro- and microfossil identifications are pending. The basal contact of the limestone appears to be depositional and tectonically undisturbed. In the most northerly panels, the limestone interfingers with and is overlain by intermediate plagioclase and hornblende phyric lapilli and crystal tuff and rare flows. A distinctive unit of green to maroon tuff immediately overlies the limestone in all of the thrust panels. The absence of the volcanic unit in the most southerly thrust panel may be due either to increasing structural depth or to a facies change, with the volcanic pile thickening northwards.

The similarities between the tripartite stratigraphic sequence in the Klinkit assemblage near McNaughton Creek, and that in the Lay Range assemblage in the Lay Range, central British Columbia, is shown in Figure 4. In both cases, lower to mid-Pennsylvanian limestone is underlain by a mixed mainly pelagic and siliciclastic unit and overlain by

intermediate volcanoclastics. In the Lay Range assemblage, the upper volcanic unit has yielded late Pennsylvanian to Early Permian microfossil dates (Ferri, in press; Nelson and Bellefontaine, 1996). In both the Klinkit assemblage and in the Lay Range, the Pennsylvanian limestone is directly overlain by a thin, discontinuous, maroon, red and green chert unit. The upper volcanic unit of the Lay Range typically contains mixed lapilli tuffs with clasts of very mature, recrystallized quartz sandstone, suggesting that uplift and erosion of the lower unit and possibly subadjacent quartzitic metasediments accompanied the late Pennsylvanian-Early Permian volcanism.

This inference of uplift may shed light on the unit relationships reported by Stevens and Harms (1995) in the Dorsey terrane near the Seagull batholith. In the southeastern part of the area, a "middle phyllite-chert unit", corresponding the lower chert-argillite-siliciclastic unit near McNaughton Creek, lies between the "lower unit" - now assigned to the Dorsey assemblage - and the "upper volcanic-carbonate unit", which includes the Pennsylvanian limestone and overlying volcanics of the upper Klinkit assemblage. Along strike to the northwest, the "middle phyllite-chert" unit disappears, and Pennsylvanian limestone and volcanic rocks directly overlie the Dorsey assemblage. Perhaps this transgressive contact is a sub-Pennsylvanian unconformity. If so, it illustrates the complex stratigraphic relationships that must be unravelled in these pericratonic, multistage volcanic arc provinces.

The Klinkit Assemblage is cut, not only by large Early Jurassic plutons (Gabrielse, 1969), but also by hornblende (-plagioclase) phyric dykes, seen in the field this summer near McNaughton Creek. No age is yet available from these dykes. They post-date low-grade metamorphism of the Klinkit Assemblage and are not seen cutting Cretaceous granite bodies. An Early Mesozoic age is most likely. Texturally, these dykes are identical to one of the characteristic igneous types in central Quesnellia, which forms dykes and volcanoclastic units in the Takla arc of latest Triassic(?) to Early Jurassic age (Nelson and Bellefontaine, 1996). This textural/compositional type is characterised by very well-formed, commonly acicular but also bladed hornblende phenocrysts with less abundant and smaller plagioclase and augite. Most examples contain xenoliths of black hornblendite and amphibolite. Compositionally these rocks are diorites to monzodiorites: many contain significant matrix potassium feldspar and are mildly alkalic. The hornblende porphyries are very distinctive, even within Quesnellia. Stratigraphically they concentrate in the upper part of the Triassic (Takla Group) section and the lower part of the Lower Jurassic section. They generally post-date the augite porphyries, although clasts of acicular-hornblende porphyries are found even in the late Carnian-early Norian tuff unit that underlies the main augite porphyry volcanic pile.

If the Klinkit Assemblage does represent Quesnellia, then the underlying Dorsey Assemblage may be Quesnellia's roots. The Dorsey Terrane may thus provide a window into the ancient basement of one of the late Paleozoic to Mesozoic volcanic arc terranes of the Cordillera.

REFERENCES

- Ferri, F. (in press): Nina Creek Group and Lay Range Assemblage, North-Central British Columbia: Remnants of Late Paleozoic Oceanic and Arc Terranes; *Canadian Journal of Earth Sciences*; 1997.
- Gabrielse, H. (1969): Geology of Jennings River Map Area, British Columbia (104/O), scale 1:250,000; *Geological Survey of Canada*, Paper 68-55.
- Harms, T.A. and Stevens, R.A. (1996): A Working Hypothesis for the Tectonostratigraphic Affinity of the Stikine Ranges and a Portion of the Dorsey Terrane, *Lithoprobe and Cordilleran Tectonics Workshop* March 1-3 1996, Lithoprobe Report No. 50, pages 93-95.
- Nelson, J.L. and Bellefontaine, K.A. (1996): The Geology and Mineral Deposits of North-Central Quesnellia; Tezzeron Lake to Discovery Creek, Central British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 99.
- Poole, W.H. (1956): Geology of the Cassiar Mountains in the vicinity of the Yukon-British Columbia boundary; Ph.D. Thesis, Princeton University.
- Stevens, R.A. and Harms, T.A. (1995): Investigations in the Dorsey Terrane, Part 1: Stratigraphy, Structure and Metamorphism in the Dorsey Terrane, Southern Yukon Territory and Northern British Columbia; *Geological Survey of Canada*, Current Research 1995-A, pages 117-128.
- Wheeler, J.O., Brookfield, A.J., Gabrielse, H., Monger, J.W.H., Tipper, H.W. and Woodsworth, G.J. (1991): Terrane Map of the Canadian Cordillera; *Geological Survey of Canada* Map 1713A, Scale 1:2,000,000.

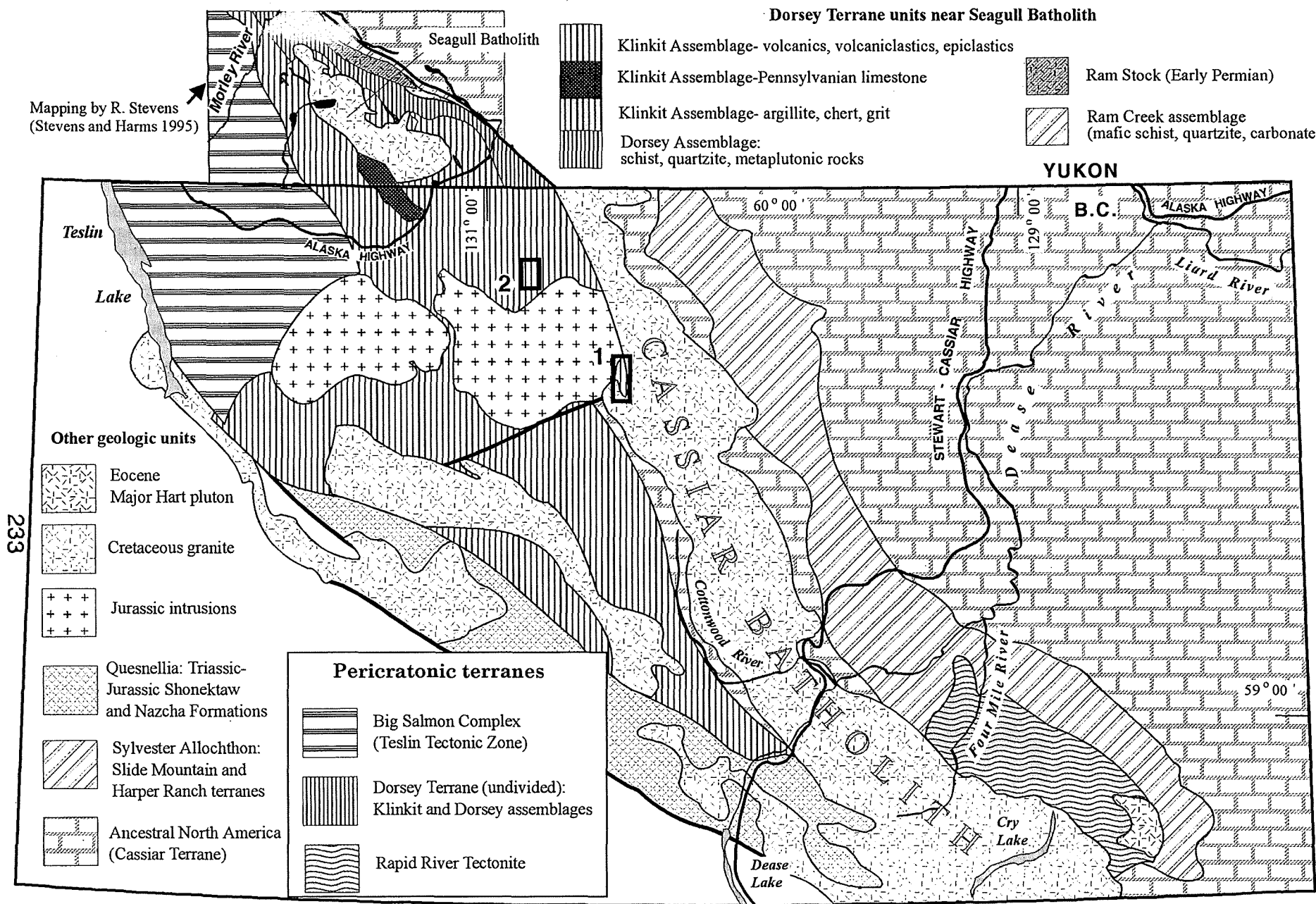


Figure 1. Regional setting of the Dorsey terrane in northern British Columbia - southernmost Yukon
1) and 2) are 1996 detailed map areas in Dorsey and Klinkit assemblages respectively.

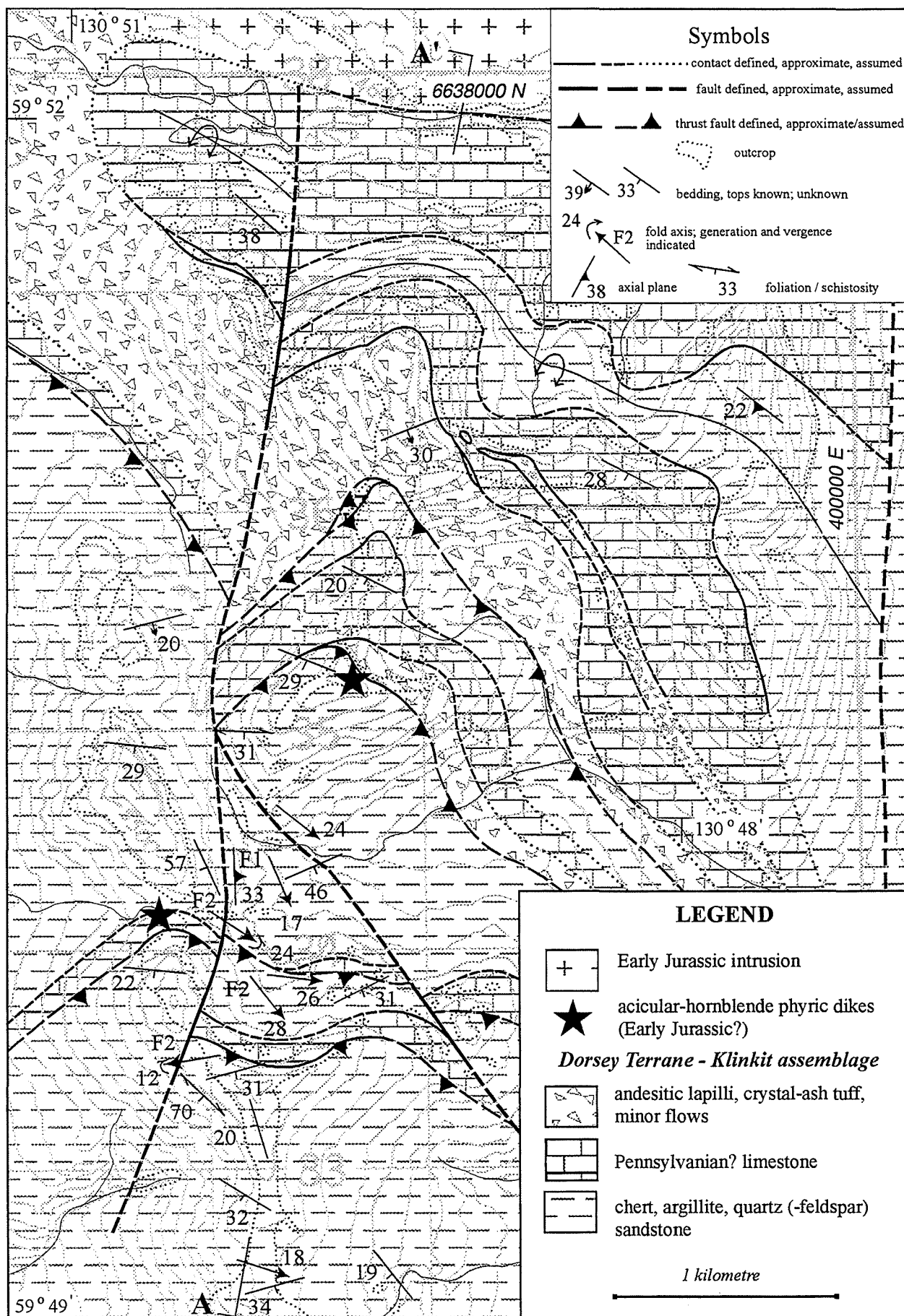


Figure 2a. 1:25,000 geologic map of Klinkit assemblage near McNaughton Creek
(location 2 on Figure 234)

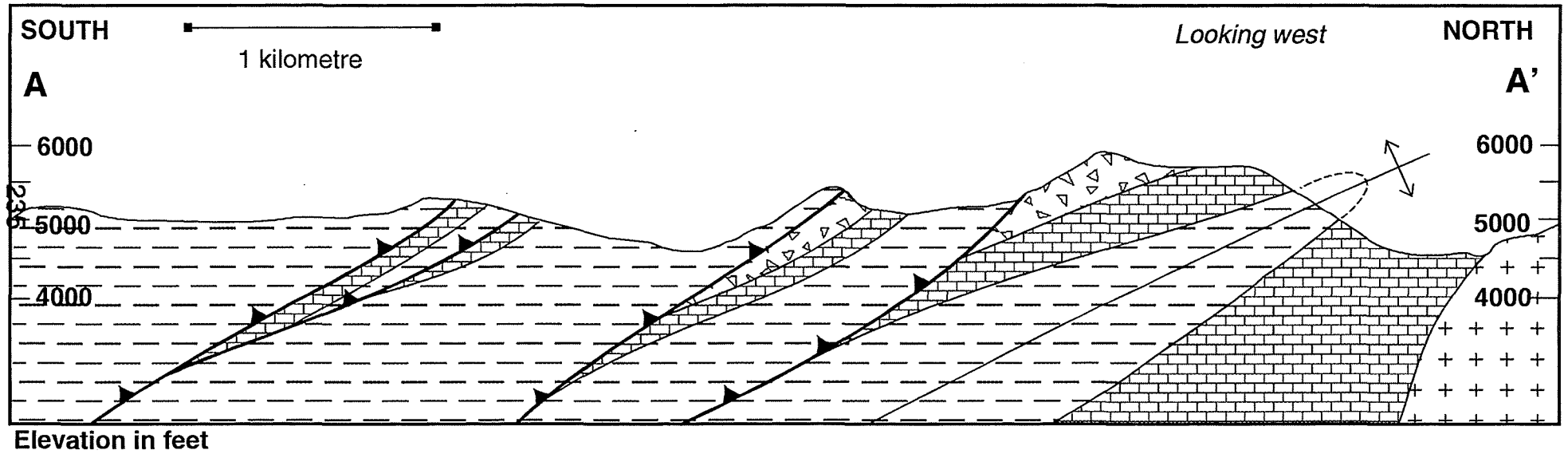


Figure 2b. Cross section of the Klinkit assemblage near McNaughton Creek; line A-A' on Figure 2a. Note patterns same as Figure 2a.

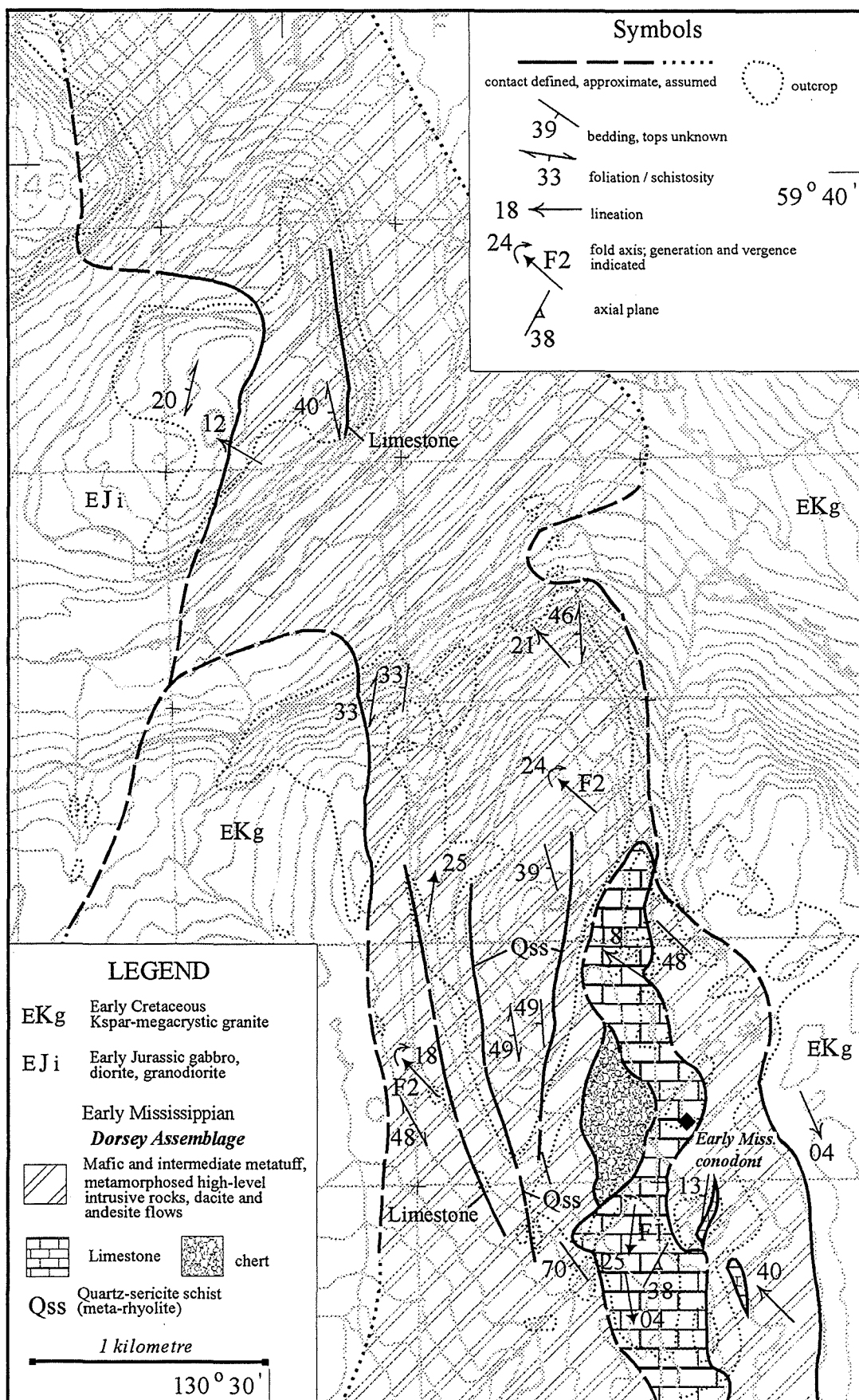


Figure 3. 1:25,000 map of the Dorsey assemblage near the Little Rancheria River

**Lay Range Assemblage in its type area in the Lay Range,
central British Columbia: stratigraphic column**

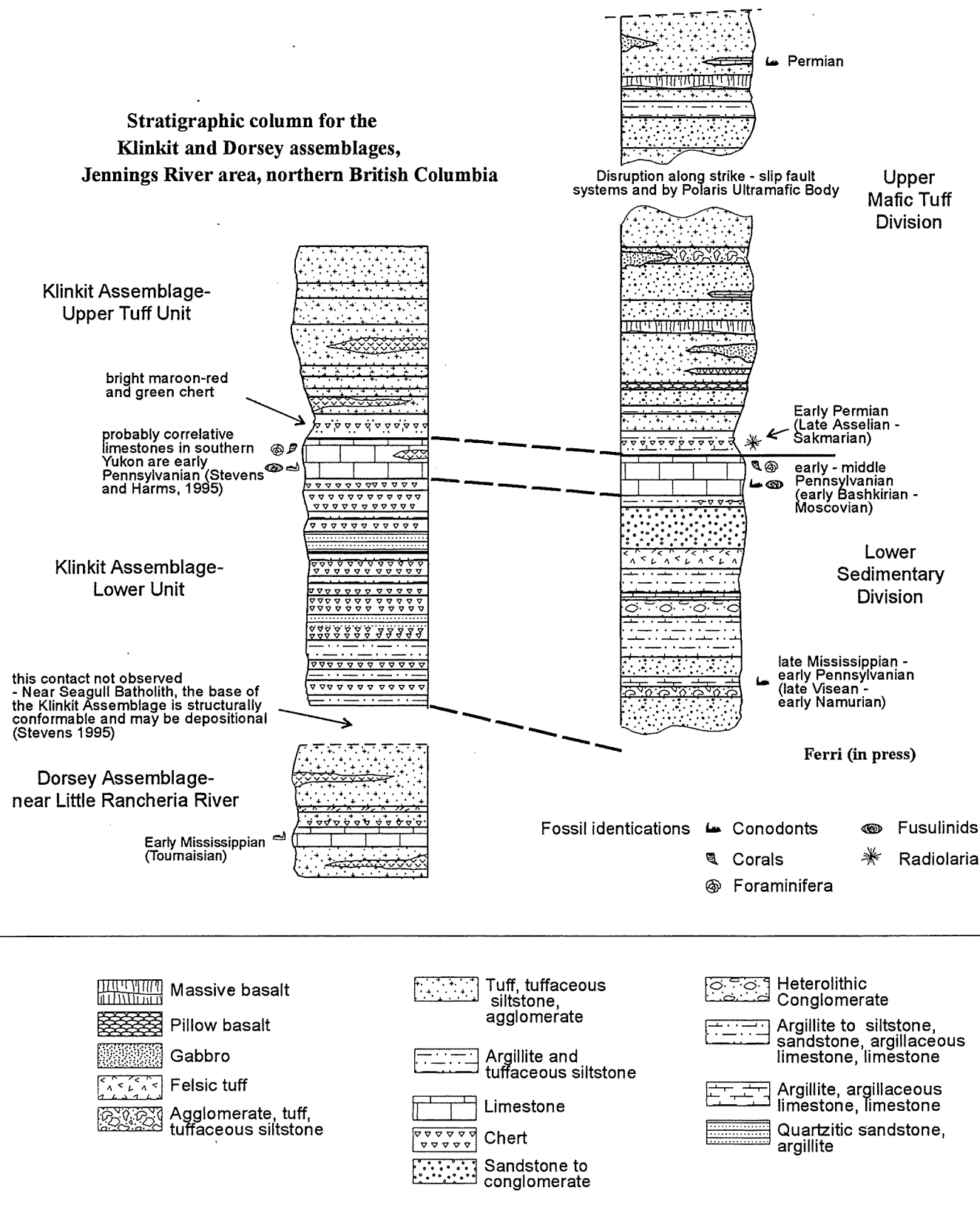


Figure 4. Comparative stratigraphic columns for the Klinkit assemblage and the Lay Range Assemblage in the Lay Range (Ferri, in press)

Pressures and Temperatures for Ultramafic Xenoliths, Atlin Lake Area, British Columbia

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Ultramafic xenoliths formed under mantle conditions of pressure and temperature. Compositions of the minerals in the xenoliths, olivine, clinopyroxene, orthopyroxene, and spinel, have been combined with mineral geothermometers to estimate temperatures of equilibration. The xenoliths from northern British Columbia, however, are chemically inhomogeneous. Consequently, temperatures derived from the mineral geothermometers are uncertain by unknown amounts. The pyroxenes have significant variations in FeO, CaO, and Al_2O_3 . These variations preclude accurate and reliable estimations of pressure and temperature in standard mineral geothermometers. The olivines and orthopyroxenes in any one xenolith, in contrast, are homogeneous to within a percentage point in any major oxide.

The textures of the xenoliths, on the other hand, often appear pristine with no evidence of reaction between minerals such as reaction rims. The unaltered appearance of the textures suggests that a geothermometer based on mineral proportions rather than mineral compositions would provide results that are more reliable. That such a geothermometer is possible is guaranteed by a little known theorem in thermodynamics, Duhem's theorem (Duhem, 1898a, 1898b). Duhem's theorem, states that for a system of known composition, there are only two independent thermodynamic variables. The proportions of the phases are among the variables in Duhem's theorem. Consequently, if the modes of the ultramafic xenoliths have remained unchanged during transport from the mantle to the surface, then we can use the proportions of two phases as independent variables in Duhem's theorem to calculate the remaining variables: *compositions of the phases, pressure, and temperature*. The composition of the rock is derived from the mode and compositions of the phases as they exist today.

The modes of the xenoliths are dominated by olivine (Table 1). The proportions of the phases vary from xenolith to xenolith, in part perhaps, because sections through the xenoliths are not large enough to provide representative samples. An advantage of a geothermometer-barometer based on mineral modes and rock compositions derived from the mode is insensitivity to uncertainties due to sampling.

A preliminary version of a thermometer based on Duhem's theorem is under development. The thermodynamic data compiled by Sack and Ghiorso (1989, 1991a, 1991b, 1994a, 1994b, 1994c) is being recast into a set of compositional variables that are computationally efficient.

Table 1. Modes of Ultramafic Xenoliths, Atlin Lake Area, British Columbia.				
Sample	Oliv	Opyx	Cpyx	Spinel
LL5-1	64.83	26.45	5.57	3.16
LL5-2	55.01	29.40	13.17	2.42
LL5-2	54.46	30.86	12.63	2.05
LL5-3	88.57	9.73	1.50	0.20
LL5-4	75.00	19.63	1.34	4.03
LL5-6(1)	96.31	3.29	0.16	0.24
LL5-6(2)	85.23	13.48	1.04	0.25
LL5-9(1)	62.67	25.77	8.58	2.99
LL5-9(2)	66.09	24.34	6.80	2.78
A1	70.60	15.90	5.30	8.19
A2	72.18	20.98	6.56	0.29

References Cited

- Duhem, P. 1898a. On the general problem of chemical statics. *The Journal of Physical Chemistry*, 2: 1-42.
- Duhem, P. 1898b. On the general problem of chemical statics. *The Journal of Physical Chemistry*, 2: 91-115.
- Sack, R. O., and Ghiorso, M. S. 1989. Importance of considerations of mixing properties in establishing an internally consistent thermodynamic data base: thermochemistry of minerals in the system $\text{Mg}_2\text{SiO}_4\text{-Fe}_2\text{SiO}_4\text{-SiO}_2$. *Contributions to Mineralogy and Petrology*, 102: 41-68.
- Sack, R. O., and Ghiorso, M. S. 1991a. Chromian spinels as petrogenetic indicators: Thermodynamics and petrological applications. *American Mineralogist*, 76: 827-847.
- Sack, R. O., and Ghiorso, M. S. 1991b. An internally consistent model for the thermodynamic properties of Fe-Mg-titanomagnetite-aluminate spinels. *Contributions to Mineralogy and Petrology*, 106: 474-505.
- Sack, R. O., and Ghiorso, M. S. 1994a. Thermodynamics of multicomponent pyroxenes: I. Formulation of a general model. *Contributions to Mineralogy and Petrology*, 116: 277-286.

- Sack, R. O., and Ghiorso, M. S. 1994b. Thermodynamics of multicomponent pyroxenes: III. Calibration of $\text{Fe}^{+2}(\text{Mg})_{-1}$, $\text{TiAl}_2(\text{MgSi}_2)_{-1}$, $\text{TiFe}^{+3}(\text{MgSi}_2)_{-1}$, $\text{AlFe}^{+3}(\text{MgSi})_{-1}$, $\text{NaAl}(\text{CaMg})_{-1}$, $\text{Al}_2(\text{MgSi})_{-1}$ and $\text{Ca}(\text{Mg})_{-1}$ exchange reactions between pyroxenes and silicate melts. *Contributions to Mineralogy and Petrology*, 118: 271-296.
- Sack, R. O., and Ghiorso, M. S. 1994c. Thermodynamics of multicomponent pyroxenes: II. Phase relations in the quadrilateral. *Contributions to Mineralogy and Petrology*, 116: 287-300.

Remagnetizations and overprints in the Foreland Belt of the Canadian Cordillera - indicators for orogenic and epeirogenic tectonics and processes

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Paleozoic carbonates in the southern Canadian Cordillera (latitude range 49 to 53 degrees N) are pervasively remagnetized (105 sites studied). All stably magnetized sites contain an orogenic, but locally predeformational, asynchronous and eastward migrating Cretaceous overprint acquired in front of the active crustal accretionary wedge. It affects the complete Paleozoic carbonate succession (3 km thick), without regard for lithology, diagenetic history or stratigraphic and geographic position. The remanence is consistent throughout a 100 km wide and 400 km long portion of the Foreland Belt, except that all Front Range sites have normal polarity magnetization, while all Foothills sites show reverse polarity magnetization. From the orogenic age of the remagnetization and its discrete polarity domains, we infer that the, as yet unspecified, process causing the remagnetization operates during distinct events (<1 m.y.?) yoked to the eastward migration of the crustal accretionary wedge. Organic maturation and fission-track thermochronological studies constrain peak temperatures in the remagnetized succession to be < 200 degrees C, such that this magnetite remanence must have a chemical origin. North of 51 degrees N, a post-deformational intermediate temperature component of reverse polarity occurs within the Front Range. This component increases in magnitude and peak unblocking temperature eastward until it dominates the total remanence of sites at the eastern margin of the Front Ranges. Pole position and polarity suggest this component is an ancient overprint, post-dating thrusting, acquired during epeirogenic uplift and erosion of the Foreland Belt.

Poster presentation - SNORCLE transect meeting, March 7-9, 1997.

Upper Crustal Structures in the Slave Craton - Preliminary Results from SNORCLE Line 1

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ABSTRACT

Seismic reflection data from corridor 1 of the SNORCLE transect (line 1) was acquired in October-November, 1996. The purpose of the profile is to investigate processes of tectonic accretion of progressively younger crustal blocks, beginning from the Archean Slave craton and working westward through Early Proterozoic (Great Bear and Hottah) and Middle Proterozoic (Fort Simpson and Nahanni) terranes. The data has been processed to 32 s two-way time at the Lithoprobe Seismic Processing Facility (LSPF), with a final section being produced for the Slave segment of the line (Yellowknife section) in mid January.

The seismic section displays strong, coherent reflectivity throughout the crust except for the top 3 sec in the Anton Terrane, where we observe very few reflections presumably due to the abundance of granitoid plutons (Figure 1). In the Yellowknife Domain we have complex reflectivity below 3 s and strong linear reflections which appear to clearly define the depth of the Yellowknife basin and can be extended very near to surface. Whether or not the linear reflections can be correlated with the metavolcanics of the Yellowknife Supergroup is unknown at this point. In order to better resolve some of the detailed features in the upper crust and perhaps provide better surface correlations, we have begun a parallel processing stream of the Yellowknife section at the GSC, starting from uncorrelated field records, using the ProMAX seismic processing package.

This poster will show the preliminary results of the GSC processing and present ideas on the interpretation of some of the structures in the upper crust which are observed with the seismic data.

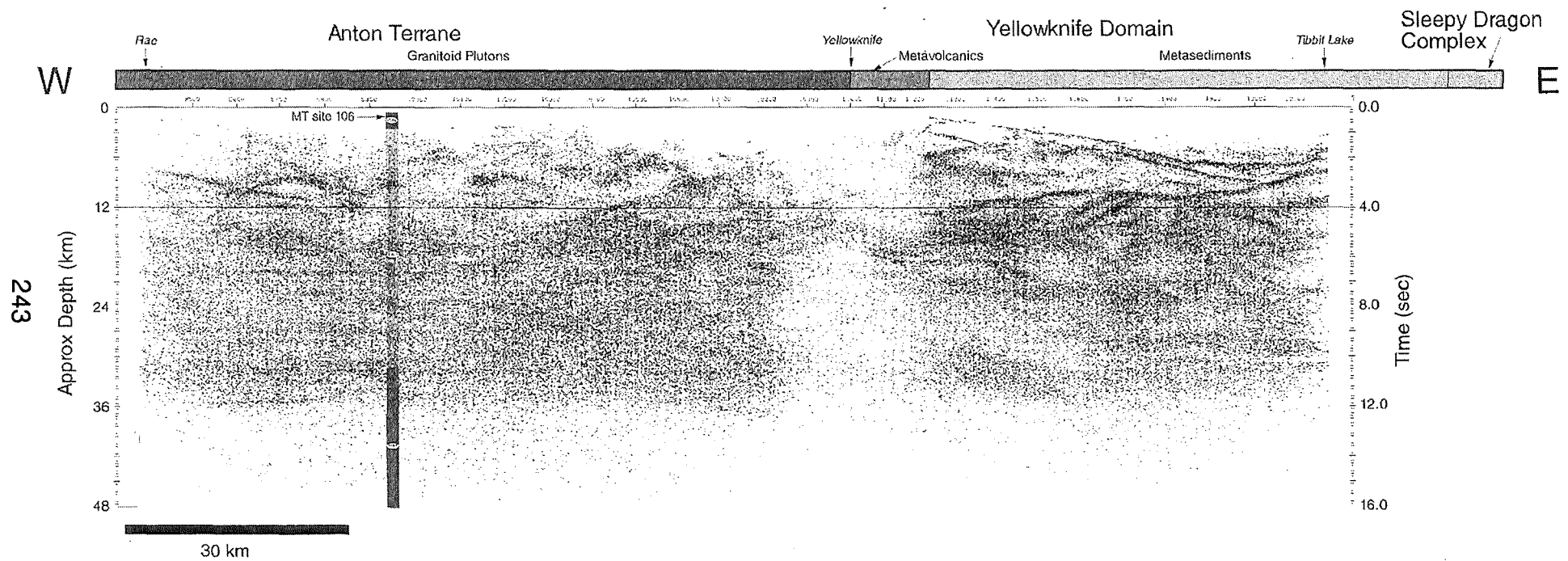


Figure 1. Slave portion of SNORCLE line 1 seismic data, migrated

Fault geometry in Lansing map area, central Yukon

Charlie Roots

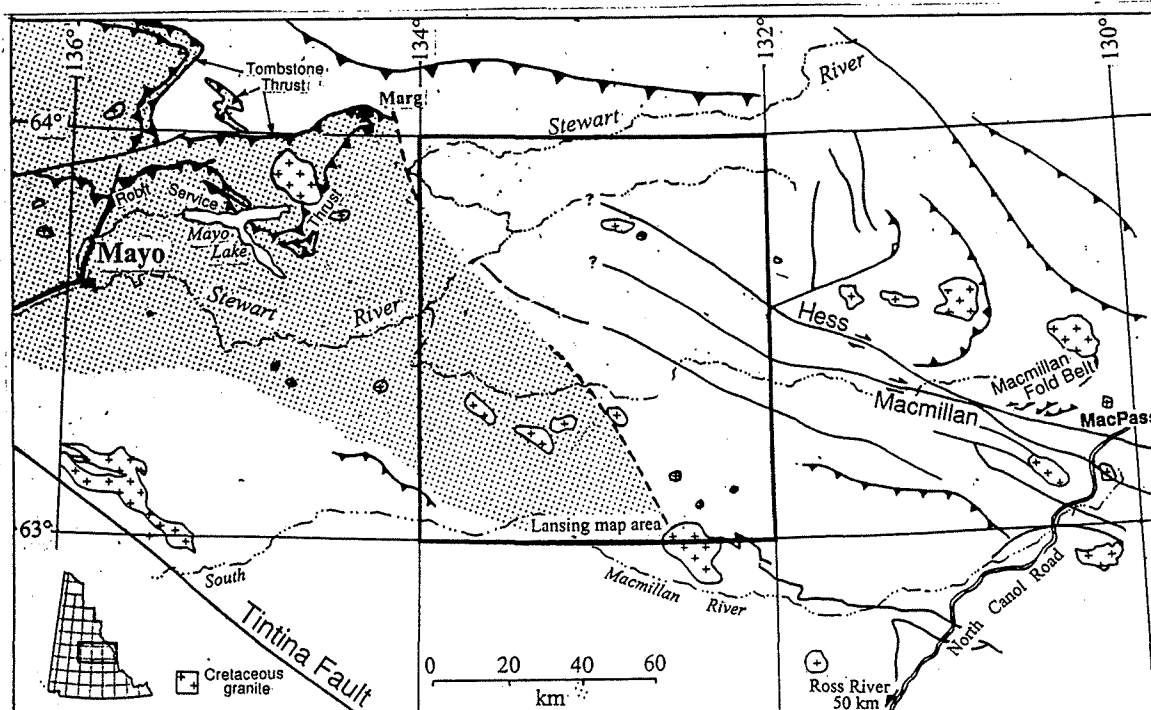
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Abstract

Regional mapping near Lansing, midway between Mayo and Macmillan Pass (northeast terminus of SNORCLE Yukon segment), outlines the distribution of Late Proterozoic to Devonian (Selwyn Basin) and Devonian to Triassic clastic units. The units are cut by regional-scale, northwest-trending faults which separate belts 3-10 km wide containing distinct stratigraphic successions and structural styles. These faults are the western extension of the dextral Hess (25 km) and Macmillan faults in the Macmillan Pass region (Abbott and Turner, 1990).

In addition, Lansing map area contains a linear transition (about 1 km wide; dashed on diagram) between highly strained Late Proterozoic grit and a less deformed upright Selwyn Basin succession. Although the linkage is unclear, this strain transition appears to be the northeastern margin of the Tombstone Strain Zone (patterned area on diagram; Murphy, in prep.), resulting from 90 km northwestward displacement on the Tombstone Thrust (Murphy and Abbott, pers. comm. 1994). This transition zone should truncate the older Robert Service Thrust southeast of the Marg property, but the nature of the relationship is obscure.

The large northward and northwestward displacement of the Robert Service and Tombstone thrusts farther west is transferred or dissipated along the northwest-trending dextral slip faults in Lansing map area. The precise details in how this change in structural style is accommodated is not yet clear.



- Abbott, J.G. and Turner, R.J., 1990. Character and paleotectonic setting of Devonian stratiform sediment-hosted Zn, Pb, Ba deposits, Macmillan Fold Belt, Yukon. In J.G. Abbott and R.J.W. Turner (ed.), Field trip Guidebook 14. 8th International Association on the Genesis of Ore Deposits symposium, 1990., Geological Survey of Canada, Open File 2169, p. 99-136.
- Murphy, D.C. in prep. Geology of the McQuesten River region, northern Mayo and McQuesten map areas (105 M/13, 14 and 115P/14, 15, 16) Yukon Territory. Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Bulletin 6. (includes coloured 1:50 000 maps of above areas).
- Murphy, D.C and Abbott, J.G., pers. comm., 1994. The Tombstone Thrust, a WNW-directed (dextral, orogen-parallel) Early Cretaceous fault in central Yukon Territory. In: 1994 Canadian Cordilleran Tectonics Workshop, Victoria, B.C. Program with Abstracts.

Geology of the Nulki Hills and surrounding area, central British Columbia^{1,2}

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Abstract: The Nulki Hills, south west of Vanderhoof, British Columbia (NTS 93 F/9 and F/16) are entirely underlain by the Cretaceous Frank Lake pluton. Miocene Chilcotin Group plateau basalts extend around and onto the Nulki Hills to an elevation rarely exceeding 1220 m. Stratigraphically below the Miocene basalts are Eocene Endako group and Ootsa Lake group volcanic rocks, the monzodiorite to diorite Brooks Diorite Complex and Jurassic Hazelton Group volcanic rocks.

A prominent shear zone (the Nulki Shear Zone) terminates the Frank Lake pluton and the Nulki Hills on their west side. The shear zone is a shallow dipping, NNE striking panel of mylonite and deformed plutonic rocks with top-to-the-northwest sense of motion.

From mapping in the 1995 field season east of the Nulki Hills (NTS 93 G/12 and G/13), a ductile shear zone similar to the Nulki Shear Zone was observed southeast of Sinkut Mountain. These ductile strain features are below a low angle detachment (the Sinkut Fault) which moves upper plate rocks down to the southeast. The Sinkut Fault is responsible for bringing non-metamorphosed Cache Creek ultramafic rocks into contact with the schists, orthogneisses and plutonic rocks of the Vanderhoof Metamorphic Complex, and is interpreted to be an extensional feature that facilitated the exhuming of these metamorphic rocks.

Extensional structures in the study area and are interpreted to be Eocene in age which were accompanied by syn-tectonic Eocene volcanism.

¹ Contribution to the Nechako NATMAP Project

² This is a joint mapping project of the Geological Survey of Canada and British Columbia Geological Survey Branch

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